

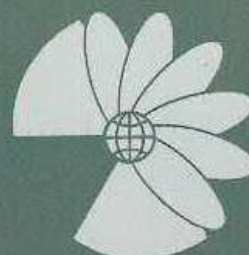
E.G. Batyrbekov, A.O. Aidarkhanov,
V.A. Vityuk, N.V. Larionova, M.A. Umarov

COMPREHENSIVE RADIOECOLOGICAL SURVEY OF THE SEMIPALATINSK TEST SITE

2021



*dedicated to 30th
anniversary of
Semipalatinsk
Test Site shut-down*



NATIONAL NUCLEAR CENTER
REPUBLIC OF KAZAKHSTAN
KURCHATOV T.

**COMPREHENSIVE
RADIOECOLOGICAL SURVEY OF
SEMIPALATINSK TEST SITE**

**E. Batyrbekov, A. Aidarkhanov, V. Vityuk,
N. Larionova, M. Umarov**

Kurchatov, 2021

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Monograph

‘Comprehensive Radioecological Survey of Semipalatinsk Test Site’

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This monograph provides outcomes of the comprehensive radioecological survey of the territory of the former Semipalatinsk Test Site. The survey was conducted by specialists of the National Nuclear Center of the Republic of Kazakhstan between 2008 and 2021. Outputs enabled to determine the current radiological situation in the territory, identify areas posing hazard to man and the environment and the ones to be potentially released to the economic turnover. The book is intended for specialists engaged in radioecology, radiation safety, environmental protection as well as for a wide audience interested in topical issues of the ecological state at the former Semipalatinsk Test Site.

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FOREWORD

The fact that 30 years ago, on August 29, 1991, according to the Decree issued by the First President of the Republic of Kazakhstan N. Nazarbayev, the Semipalatinsk Nuclear Test Site was shut down was the first step that laid the foundation of Kazakhstan's future mass destruction weapon non-proliferation policy.

This event is momentous not only to Kazakhstan but also to the entire global community – the world's largest nuclear test site ceased to operate.

After this landmark decision was made, Kazakhstan inherited a test site with the most complex huge infrastructure from the past age. What had to be done with that challenging legacy? Not every state could have coped with such large-scale problem. The country's leadership made a decision upon this issue in line with their peaceful initiatives. A straightforward course of actions – utilization of the capacity of the former Semipalatinsk Test Site for peaceful purposes, was taken.

Nowadays we are pleased to note that thanks to the large-scale activity on elimination of infrastructure and remediation after nuclear weapon tests, conversion of the former military and industrial STS facility to be utilized for peace, the territory of the former Semipalatinsk Nuclear Test Site has been completely remediated after the nuclear activity of the USSR's military and industrial facility and secured. Measures taken by Kazakhstan's leadership for nuclear non-proliferation virtually prevented the threat to be posed by uncontrolled breakup of the Soviet nuclear armament facility being powerful at one time to foreign affairs system.

9 years later after STS was shut down, all adits and boreholes designed for underground detonations of nuclear charges were secured not to allow utilization for their intended purpose. All the STS denuclearization work was performed as part of broad international cooperation between our country and the USA, Russia and other

countries. This unique experience of collaboration on the shut-down of the nuclear test site, its future research and rehabilitation has remained the only one and second to none worldwide.

Along with elimination of nuclear infrastructure and solution to non-proliferation issues, the problem of radioactive contamination of vast test site and adjacent areas has been broadly outlined. A decision was made to carry out large-scale ever activities in Kazakhstan on STS research, namely, to conduct a comprehensive ecological survey. The survey began in 2008 and was completed in 2021. Over that period, more than 18,000 square kilometers of the test site has been explored, dozens of thousands of laboratory analyses carried out, radiological state of STS soil cover, air, water, fauna and flora assessed. The main thing is that ways to ensure general safety of test site lands have been defined in order to utilize these in the country's economic turnover in the future.

This monograph presents some of outputs obtained in STS large-scale activities that will elucidate current problems at and prospects for STS, allow setting ourselves new tasks aimed at further enhancement of nuclear and radiation safety of the test site and adjacent areas.

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TABLE OF CONTENTS

INTRODUCTION	7
CHAPTER 1. GENERAL INFORMATION ON SEMIPALATINSK TEST SITE	9
1.1 General.....	9
1.2 Brief historical background.....	9
1.3 Chronology of studied nuclear consequences.....	14
1.4 Testing sites.....	19
CHAPTER 2. COMPREHENSIVE ECOLOGICAL SURVEY OF SEMIPALATINSK TEST SITE	38
2.1 Radionuclides contributing to the current radiological situation.....	38
2.2 Methodology of the comprehensive ecological survey of the test site.....	43
2.3 Radiological state of soil cover (topsoil).....	48
2.4 Vertical distribution of radionuclides in the profile.....	58
2.5 Research into species of artificial radionuclides in soils.....	75
2.6 Radiological state of aquatic medium.....	80
2.7 Radiological state of ambient air.....	95
2.8 Radiological state of plant cover.....	111
2.9 Radiological state of fauna.....	126
2.10 Assessment of the radiological state of farm products.....	137
2.11 Assessment of public radiation exposure.....	155
2.12 Follow-up research.....	167

CHAPTER 3. RADIOACTIVE CONTAMINATION OF TESTING SITES.....	174
3.1 Survey methodology.....	174
3.2 Description of findings.....	176
CHAPTER 4. PROSPECTS FOR TEST SITE DEVELOPMENT.....	194
4.1 Radiological situation in adjacent areas.....	194
4.2 Radiation monitoring.....	205
4.3 Predicted progression of the radiological situation in study areas.....	212
4.4 Land rehabilitation.....	228
4.5 Present-day land utilization.....	233
4.6 Scientific development prospects.....	238
CONCLUSION.....	251
ANNEX 1.....	254
ANNEX 2.....	269

INTRODUCTION

Nuclear tests that were conducted at the USSR military proving ground located 130 km away from Semipalatinsk city (the Republic of Kazakhstan) for 40 years have resulted in large-scale environmental contamination.

Not only the territory of Semipalatinsk Test Site itself with the area of 18,311.4 km² but also the territory beyond it have been exposed to contamination.

Despite the fact that 30 years have passed since the test site was shut down in 1991, disputes about real consequences of nuclear tests are still underway nowadays. There are two general opinions: the test site poses hazard to any living creature including man, and its land can be rationally used for residence and economic activity. In addition, the subject of Semipalatinsk Test Site becomes the object of unscrupulous speculations every now and then.

Obviously, this happens due to lack of reliable information on the current radiological situation at the test site. Oftentimes, serious conclusions are made based upon a limited amount of data. Results obtained for a certain area of the test site apply to the entire territory without taking into account all aspects affecting the distribution of radioactivity in environmental compartments.

For 14 years, 2008 through 2021, staff members of the National Nuclear Center of the Republic of Kazakhstan were giving a comprehensive assessment of radioecological consequences of nuclear tests at Semipalatinsk Test Site step-by-step.

As of today, this work is the only full-scale study of all environmental objects at the test site including soil cover, ambient air, surface and ground waters, flora and fauna. The paper is completely dedicated to the study of the current radiological state of the test site and assessment of residence and economic hazard rate. When conducting a comprehensive ecological survey, state-of-the-art radioecology techniques and

equipment were applied. All the equipment is included in the State Cadaster of Measurement Facilities and is metrologically calibrated. Reliability of findings was ensured by applicable quality and ecological management systems (ISO 9001:2015, ISO 14001:2015, ISO 19011-2011) as well as according to certificate No. KZ.T.07.2142. available in the accreditation system of the Republic of Kazakhstan against GOST/ISO/IEC 17025-2009 requirements ‘General requirements for competencies of testing and calibrating laboratories’.

Outputs were approved by specialists of the International Atomic Energy Agency (IAEA), who as part of project KAZ9016 ‘Supporting the Transfer of the Former Semipalatinsk Test Site Land for Economic Use’ (Scientific and technical support of work to release lands of the former Semipalatinsk Test Site to economic use), highly appraised the completeness degree of research, reliability of findings, relevance of inferences and recommendations as well as gave their respective opinion.

This monograph presents research findings on the radiological state of all environmental compartments at Semipalatinsk Test Site. The content of artificial radionuclides potentially contained in animal and crop products if produced at the test site has been evaluated (i.e. if inhabited by man). Exposure doses to be received by man while living at a particular point of Semipalatinsk Test Site have been estimated.

CHAPTER 1. GENERAL INFORMATION ON SEMIPALATINSK TEST SITE

1.1 General

Semipalatinsk Test Site (STS) is located at the junction of three regions of the Republic of Kazakhstan.

The test site area is 18,311.4 km², of which, the East Kazakhstan region occupies 54 % of the total test site area, Pavlodar region – 39 % and Karaganda region – 7 %.

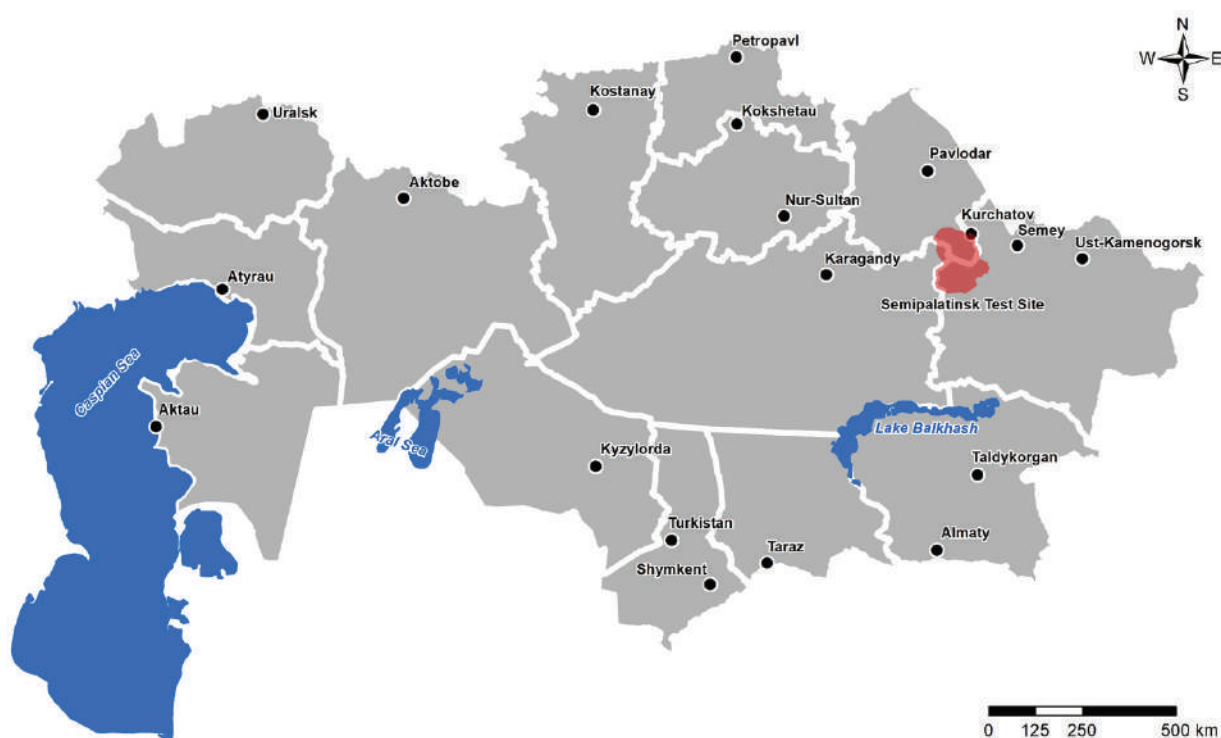


Figure 1.1. Location of Semipalatinsk Test Site on the map of Kazakhstan

Kurchatov town in the East Kazakhstan region (about 10 thous. residents) is the nearest large settlement, which is virtually on the STS border. Semey city (formerly Semipalatinsk, from which the test site name is conventionally derived) is located 130 km east of the test site.

1.2 Brief historical background

A lot of books have been written on STS history by Kazakhstani and Russian specialists. These present historical information, facts

and comments in sufficient detail. The most relevant and complete information on the current STS radioecological state, infrastructure and scientific research undertaken in its territory is currently provided in a three-volume monograph ‘A range of scientific and technical, engineering activities to secure the former Semipalatinsk Test Site’. The monograph has been written by a scientific team of the National Nuclear Center of the Republic of Kazakhstan under the guidance of the First President N. Nazarbayev and published in 2016 [1]. The initial history and activity of the test site are described in detail in the book ‘Semipalatinsk Test Site. Assurance of the general and radiation nuclear safety’ written by a group of specialists from the Healthcare Ministry of the Russian Federation, the Atomic Energy Ministry of the Russian Federation, the Ministry of Defense of the Russian Federation and Hydrometeorology and Environmental Monitoring Federal Agency supervised by professor V. Logachyov in 1997, in the book ‘Nuclear USSR tests’ prepared by a team of specialists supervised by professor V. Mikhailov in 1997, the book by a resigned colonel, Ph.D in Engineering Science I. Akchurin ‘Semipalatinsk Test Site. Construction, establishment, operation’ published in 2007 [2, 3, 4].

Therefore, this monograph only outlines the main STS milestones.

On August 20, 1945 according to the Decree by the State Defense Committee, the Special Committee and the First Chief Directorate were established. These were conferred extraordinary powers to supervise all atomic design operations. L. Beriya was appointed a Head of the Special Committee [5].

The first national atomic charge was being developed under the comprehensive program ‘Atomic USSR project’ that was supervised by a Soviet physicist, academician of the USSR AS I. Kurchatov (1949-1955).

On November 14, 1946 according to the Decree by the Council of the USSR’s Ministers, a decision was made to construct a dedicated

proving ground for testing the atomic bomb. The proving ground was named ‘Mining Station of the First Chief Directorate’. The first chief of the Mining Seismic Station – lieutenant general of the artillery P. Rozhanovich (1947-1948) [4].

A Deputy Director of the Institute of Chemical Physics of USSR AS, geophysicist M. Sadovsky was appointed the First Academic Supervisor of the proving ground (1947-1968) [4].

At the stage of alternative locations under consideration, the test site was named the Mining Station (‘Object-905’) [6]. This name was in use until August 21, 1947 when the test site was transferred to the administration of the Ministry of the USSR Defense according to the Decree issued by the Central Committee the Central Committee of the All-Union Communist Party (b) and came to be called ‘Training Site No. 2 of the Ministry of the USSR Armed Forces’ in 1948, conventionally named as military unit No. 52605 [7]. On May 12, 1970, the test site name was changed to the Central Scientific Research Test Site No. 2 (GosStNIIP-2) and preserved this state until its closure on August 29, 1991 [1, 8].

On June 1, 1948, the first subdivisions of the test site (military unit No. 52605) began to relocate to the assembly area, and in July 1949, test arrangements were completed.

A unique experimental and testing base that allowed large-scale nuclear testing involved the following main elements: an administrative and residential area (M site); Experimental Field site (P site) with an adjacent technological site, automatics command post of the Experimental Field site (N site) and a testers’ inhabited area (Sh site); base aerodrome in the suburbs of Semipalatinsk city, Zhana-Semey (A site).

Design and technological development of a nuclear charge was entrusted to specialists of the design bureau supervised by academician of USSR AS Yu. Khariton. On August 26, 1949, Yu. Khariton provided

I. Kurchatov with acts of readiness of all product assemblies for the experiment. I. Kurchatov, as personally ordered by L. Beriya, fixed a testing date – August 29, 1949, at the ‘Experimental Field’ testing site thereby launching a long-term process of nuclear weapon tests.

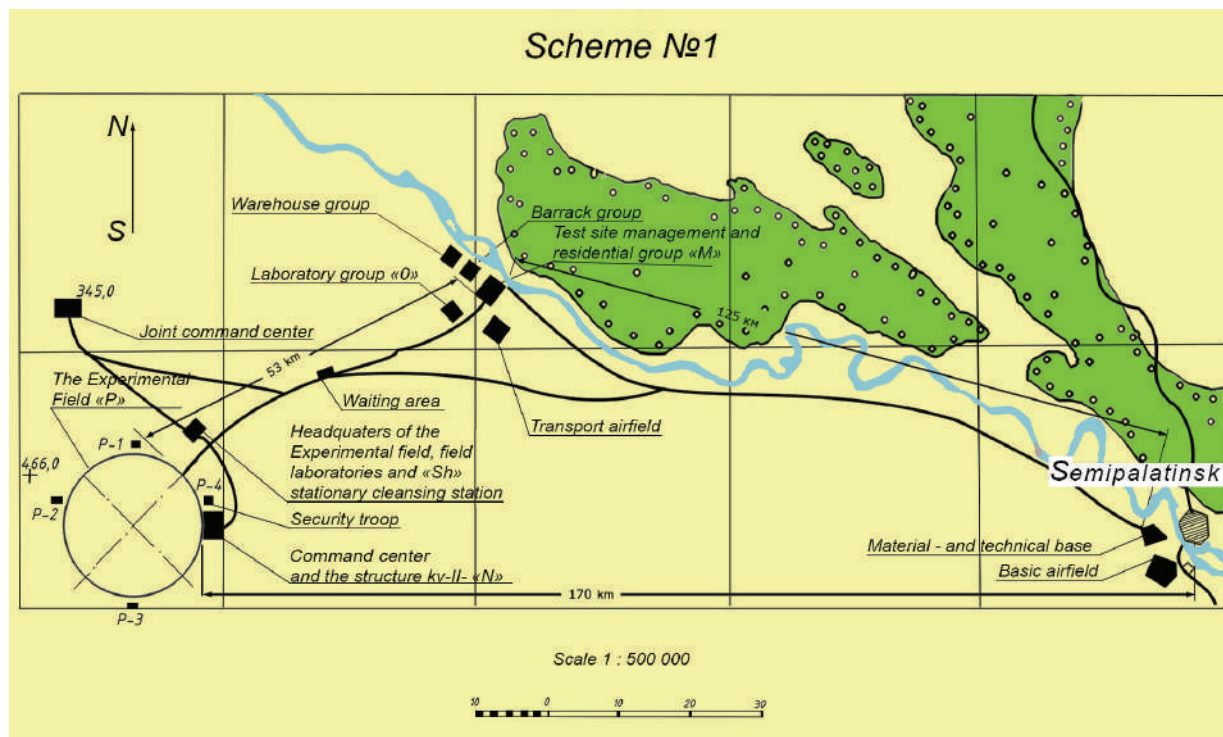


Figure 1.2. A construction site in the vicinity of the Irtysh river selected for the test site

Currently, another term of the test site is commonly used worldwide – STS.

Highly significant tests conducted at STS:

- August 29, 1949 – the first nuclear test;
- October 18, 1951 – the first test by dropping an atomic bomb from the airplane;
- August 12, 1953 – the first fusion charge test;
- November 22, 1955 – the most powerful test in the STS territory by dropping a hydrogen bomb from the airplane;
- January 15, 1965 – the first industrial explosion in the borehole to create an artificial reservoir at the junction of the Shagan and Aschysu rivers (a so-called ‘Atomic Lake’).

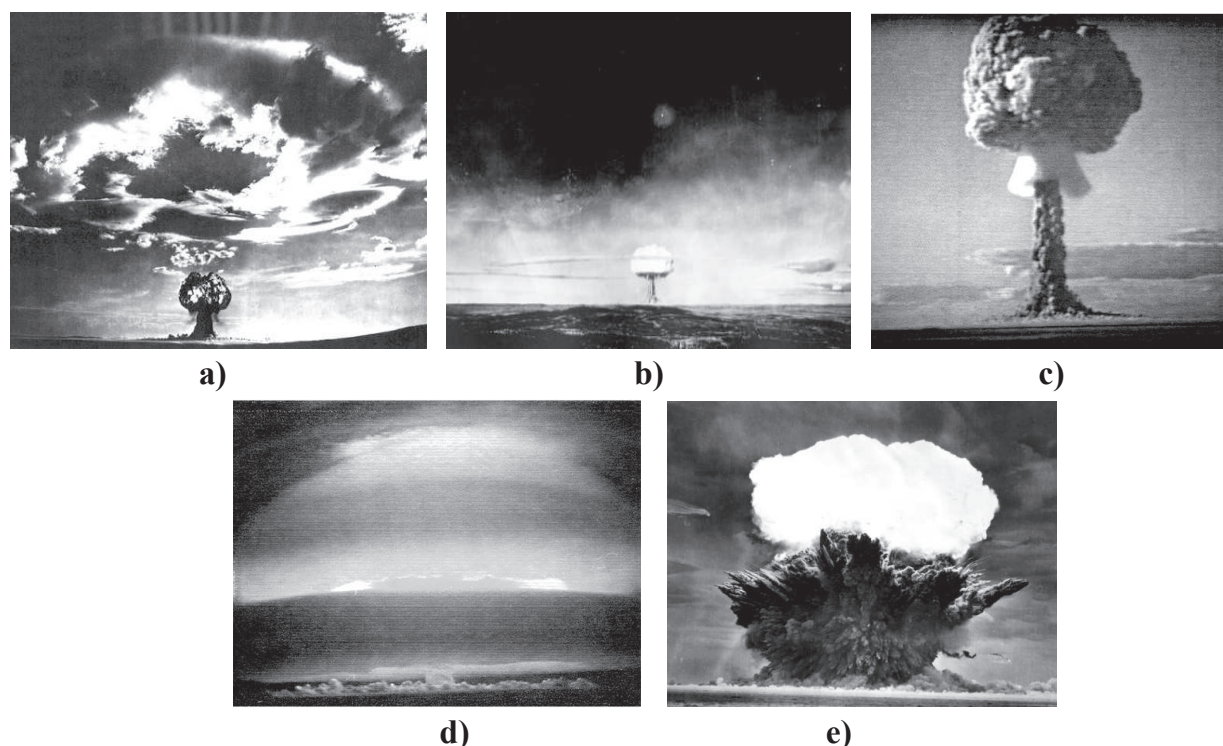


Figure 1.3. Nuclear tests at STS: a) Detonation of the first Soviet atomic bomb RDS-1; b) the first air explosion RDS-3; c) detonation of the first fusion charge RDS-6s; d) detonation of the first Soviet double-stage bomb RDS-37; e) the first industrial explosion in the borehole with soil ejected

Nuclear testing at STS can be divided into 2 stages [1]:

Stage 1 – nuclear explosions in the atmosphere between 1949 and 1962;

Stage 2 – underground nuclear explosions (in adits and boreholes) between 1961 and 1989.

Overall, 1949 through 1989, 456 nuclear tests were conducted at the test site. Of those – 116 atmospheric tests including aboveground (at the earth's surface) and air explosions; and 340 – underground nuclear explosions.

Between 1989 and 1991, no nuclear charge was detonated within the test site.

On August 29, 1991, President of the Kazakh SSR N. Nazarbayev signed a decree No. 409 'On the closure of Semipalatinsk Nuclear Test Site' [9], which gave rise to begin large-scale activities on elimination of infrastructure and remediation after nuclear testing. The test site

turned from the source of a military threat into the object of scientific research.

Kazakhstan is currently known all over the globe thanks to its antinuclear initiatives, the first of which was to renounce nuclear weapons that the young republic possessed following the USSR breakup. UN declared the date of the first Soviet nuclear test – August 29, as proposed by Kazakhstan, the Day of International Actions against Nuclear Tests [1].

1.3 Chronology of studied nuclear consequences

After the test site was shut down, the young state faced a number of issues which remained unanswered due to certain circumstances at that moment – what is a test site, what hazard does it pose to man, what is the extent of radioactive contamination and many other things.

Undoubtedly, such circumstances were attributed to the fact that all tests at the test site were marked as ‘top secret’. Accordingly, neither test data nor consequences were to be made public. Once the test site was shut down, virtually all the operation materials were taken out.

In October 1993, the Institute of Radiation Safety and Ecology of the National Nuclear Center RK was established on the premises of military unit No. 52605 – a unique biological center that was built in 1949 at STS.

Now some facts about the history of military unit No. 52605 that was set up to provide biomedical support of nuclear tests at STS.

Of scarce archival data that remained in the Institute of Radiation Safety and Ecology, it became clear that research undertaken by military unit 52605 aimed at studying and giving a hygienic assessment of the radiological situation that arose due to nuclear debris of tests conducted as from 1949. The following tasks had to be fulfilled here: to study natural, social-economic and health conditions for the rural population living in a radioactive plume area as well as define

features affecting radiation exposure; establish the main contributors to the dynamics of how radiation exposure of the local population is produced in the zone of spreading debris; to study conditions and evaluate usability of water reservoirs created at the Shagan river for economic needs; give a hygienic assessment of the radiological situation that emerged during the underground nuclear explosion and evaluate the degree of potential risk to health of local residents. The center was well-equipped. A two-storey vivarium held over 750 guinea pigs, 400 rabbits, 500 white mice, 1,500 white rats, 20 monkeys; open-air cages were intended to hold 114 dogs. Cows, horses and sheep were additionally taken from local state farms prior to explosions.

As research progressed, concepts of nuclear weapon effects on bioobjects were specified. Principles to arrange and take therapeutic measures were developed at evacuation stages of victims who suffered from the shockwave and other nuclear effects. Along with institutions of the USSR Ministry of Defense, the management of the Third Chief Directorate under the USSR Ministry of Healthcare, staff members of the Institute of Biophysics and other leading medical institutions were actively involved in drafting. Experimental data was obtained on radioactive and optical effects on animals afield, in open trenches, in closed engineering structures and in military vehicles. Based upon findings, including postmortem study data, the main features of radiation sickness progression were revealed. These served as the basis for classifying radiation sickness by severity degree. Cases like 'deaths under the beam' when demise takes place right while exposure is in progress or soon after it ends were noted as individual. The postmortem study of dead animals allowed confirmation of disease severity, death periods and exposure doses with a high reliability degree. This data was of great importance for the national radiobiology and radiation medicine to advance. Based upon experimental findings from animals, the efficiency of comprehensive therapy technique was demonstrated when treating acute radiation sickness and, in particular,

that of protective agents (radioprotectors) combined with therapeutic agents. The work done by this center made a fundamental contribution to the study of mechanisms of ionizing radiation and radiation sickness pathogenesis effects. Thanks to this, the information field in radiobiology and radiation medicine was created and developed as a scientific basis for solving problems in radiation safety assurance, preventive care, early diagnosis and treatment of radiation injuries, prevention or reduction of late-effect risk.

By the time the Institute of Radiation Safety and Ecology was established, the whole archive and all equipment of military unit No. 52605 were taken out, and staff scientists left back to Russia. There was no data on the radiological situation at the entire test site. No contaminated areas were mapped. In this regard, specialists of the National Nuclear Center RK had to begin all the work to study the radiological situation at the test site and the effect of radiation on man and biota from scratch. Obtainment of relevant data on the current radiological situation in the STS territory was the main line of research. All environmental components – soil, air, water, natural populations of plants and animals were concurrently studied including assessment of human radiation exposure.

The country's leadership supported large-scale radioecological research at STS after it was shut down. In practice, that was stated in the approved Republican target scientific and technical program 'Development of Atomic Energy in Kazakhstan' (RTSTP). The scope of work covered a wide range of issues because plants and animals could not be studied without data on areal contamination of soil cover with radionuclides. This data required quantitative analytical techniques to be developed.

Thus, as part of stages 'Biologist' (1994-1999) and 'Test Site' (1994-1997), the radiological situation in the STS territory and adjacent areas as well as the effect of nuclear consequences on flora

and fauna were assessed [10, 11]. Information on the development and implementation of environmental measures in radioactively contaminated areas and environmental rehabilitation was provided [12]. One line of research under stages of ‘Search for novel effective radioprotectors and agents modifying the effect of radiation’ (1994-1998) and ‘Protector’ (1996-1999) was selection of novel effective radioprotectors and agents modifying the effect of radiation [13, 14]. Much research under the stage ‘Biological effects of radioecological factors on natural populations of plants and animals’ was aimed at making a list of STS plants and animals as well as assessing biological effects of nuclear tests (including genetic effects induced by chronic exposure in low doses in certain animal species) [10, 15]. At the stage ‘Area of distribution’, contamination maps of a STS part were constructed on the 1:50000 scale, an improved procedure for ^{137}Cs determination in water was prepared, a procedure for experimental research into the content of plutonium in plant samples was developed, monitoring of water streams and radioactive contamination of entries at Degelen massif began, an attempt was taken to use a biotechnological technique for purifying soil and water of radionuclides [16, 17].

In the 90s, test site lands were already used in economic activities – both authorized (mining, geological prospecting etc.) and unauthorized (cable excavation work, agricultural production etc.). According to the Decree issued by the RK Government dated June 16, 1997 No. 976, only after all remediation measures and the comprehensive ecological survey were completed, ownership and land use of parts of the STS territory could be transferred. Therefore, between 1998 and 1999, as part of RTSTP, the work at the stage ‘Differentiation of the former STS territory from the perspective of its economic use’ was performed [18]. As a result, materials were collected and summarized on radiological research undertaken in the STS territory, the first electronic maps were created showing locations of the major sources of radioactive contamination and probable places of farmlands.

In 2000, a follow-up radiological survey of individual STS spots was carried out. It included radiometry and gamma-spectrometry, soil sampling. Findings on the distribution of radionuclides within sites explored and at profile depths (down to 20 cm.) were obtained. These were compared with 1994 research findings, which, as a whole, indicated a reduced contamination with radionuclides in the study area [19]. In 2001, research under RTSTP task 01.01.01.N ‘Assessment of radiological situation and monitoring of the STS territory and adjacent areas. Development of environmental measures’ was undertaken. In 2002, an areal survey of the central and eastern part of ‘Balapan’ site and a comprehensive radioecological survey in the vicinity of the ‘Atomic Lake’ and the Shagan river began, water of ‘Degelen’ was monitored and creek beds of Karabulak, Baitles and Toktakushuk were surveyed. The same year morpho-anatomic indicators and data on cytogenetic effects in dominating plant indicator species were also obtained; cytogenetic research into natural populations of chironomids was undertaken, a new species of previously unknown *Chironomus degilenicum* genus was described for the first time [20, 21].

Between 2004 and 2006, a small- and medium-scale areal radiological survey of a STS part was carried out (on the 1:1 000 000 and 1:200 000 scale). Laboratory and field experiments were conducted to study processes of secondary transfer of long-lived radionuclides by air. Techniques to restrict spreading radioactive contamination by air were studied. Processes of vertical and horizontal migration along the water stream bed as well as the major contributors to the spread of radionuclides in the aquatic system were studied. Laboratory and field experiments were conducted to study processes of secondary transfer of long-lived radionuclides by water. Under the system developed, water streams from adits at ‘Degelen’ site were monitored. Full-scale experiments to restrict the spread of radioactive contamination by water were conducted.

A practical technique was developed to purify water stream of ^{137}Cs and ^{90}Sr based upon sorption of radionuclides by topsoil as a soil dam at the bed of water stream of adit No. 176. Ecological and biological research into the territory of ‘Degelen’, ‘Balapan’ and ‘Sartay-Kora’ winter hut was undertaken [22].

Radiation safety assurance during authorized economic activities in the STS territory, development of a scientific and technical, methodological framework to regulate safety of economic activities and research in the STS territory as well as the arrangement of monitoring of economic activities on a regular basis began in 2004 as part of the state-funded program ‘Safety assurance at the former Semipalatinsk Test Site and making arrangements for economic activities given features of its territory’ [23].

However, by 2007, it became clear that the survey of individual STS parts, though the most contaminated, would not provide a complete picture of the radiological situation. Issues of the situation around areas in which no nuclear tests were officially conducted but became contaminated due to fallout, remain open: are test site lands usable for economic needs and what parts etc.?

To solve this problem, from 2008 onwards, a large-scale comprehensive ecological survey of the STS territory began under the state program [24].

This book presents results of the long-term comprehensive ecological survey of the former Semipalatinsk Test Site.

1.4. Testing sites

Before we begin to discuss and analyze results of the comprehensive ecological survey of STS, it should be noted that despite the fact that a large part of the test site had not been studied prior to the survey, yet, the bulk of radioactivity was expected to be concentrated in locations of nuclear tests. Besides, not only nuclear but also radioactive warfare agent, hydronuclear, and hydrodynamic tests were conducted at the

test site. STS has 8 such places, to be more precise, 8 sites at which tests were conducted – ‘Experimental Field’, ‘Degelen’, ‘Balapan’, ‘Sary-Uzen’, ‘4’, ‘4A’, ‘Telkem’, ‘Aktan-Berli’.

Therefore, these are going to be briefly discussed below.

‘Experimental Field’ site

The ‘Experimental Field’ site is the first and the most commonly known at STS [1, 3, 8]. The site was designed for atmospheric (air and aboveground) nuclear tests and simulated non-nuclear-explosive (hydronuclear and hydrodynamic) experiments. Tests were mostly conducted as part of the upgrade of nuclear weapons, research into its operation in abnormal conditions and damage effects. Non-nuclear-explosive experiments were also conducted at the site as part of scientific research into physical processes in the operation of nuclear explosive devices [3].

The ‘Experimental Field’ testing site represents a plain of about 20 km in diameter surrounded by small hills on three sides (bald peaks) [1, 3, 25]. Its area is approximately 270 km², and the perimeter is in the order of 60 km. The center of the site is at a distance of about 60 km from Kurchatov town.

The first Soviet nuclear test was conducted at the ‘Experimental Field’ site in the territory of the P-1 technical site in the center on August 29, 1949 at 7:00 a.m. of local time. Here, on August 12, 1953, the world’s first fusion product RDS-6s was tested, and on November 22, 1955, at an altitude of about 2 km, the first Soviet hydrogen bomb was detonated by being dropped from the airplane

At some point in time, several additional technical sites were built at the ‘Experimental Field’ site itself. These were necessary due to new models of nuclear weapons increasingly developed for various purposes (for aviation, artillery, navy, etc.) and rapidly increasing frequency of nuclear tests necessitating to conduct not only aboveground but also air tests of different yield (Figure 1.4) [3, 8].

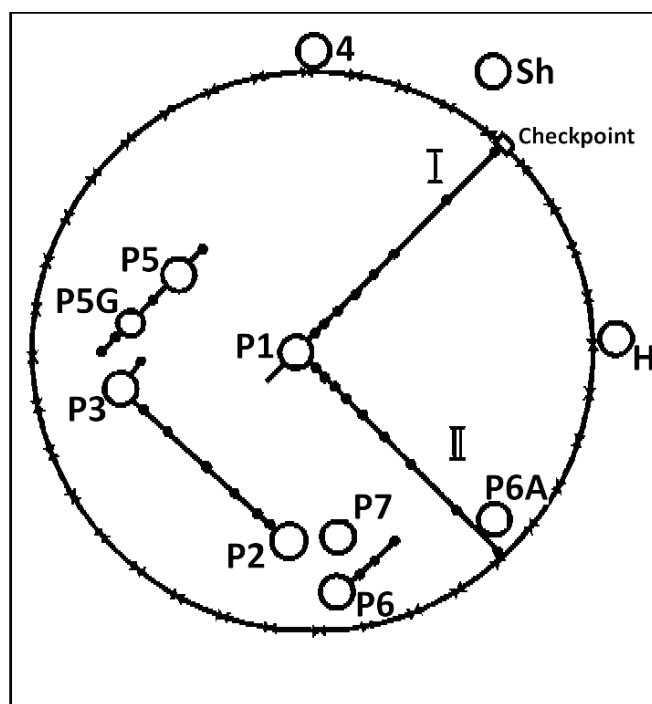


Figure 1.4. Historical scheme of the ‘Experimental Field’ testing site and technical sites on it

Between 1953 and 1961, new technical testing sites were built: P-2 (for aboveground tests), P-3 (for air tests of small- and medium-yield nuclear bombs), P-5 (for aboveground tests of low-yield bombs and air tests of medium- and high-yield nuclear bombs), P-7 (for testing low-yield nuclear charges, hydronuclear tests as well as experiments with chemical charges with a yield of up to 1 kt), P-6 and P-6A (for testing mock-ups of nuclear charges [3, 8]), P-2G (P-2M) (for hydronuclear testing). Each technical site created was an unfenced area of approximately 2 km radius. [3].

Between 1949 and 1963, 116 atmospheric nuclear tests were conducted at the ‘Experimental Field’, of which 86 were air tests, 30 were aboveground tests at low or zero altitude, while in 5 cases the nuclear device malfunctioned [26, 27, 28, 29, 30]. These tests have become the major source of surface radioactive contamination of the STS territory. The total energy release from atmospheric nuclear tests expressed as the equivalent of a conventional explosive (trinitrotoluene) was 6.6 megatons in trinitrotoluene-equivalent.

Between 1958 and 1965, a series of simulated non-nuclear explosive (hydronuclear) experiments were conducted in the territory of the ‘Experimental Field’ testing site. The results of hydronuclear experiments were of great importance to analyze issues of whether nuclear weapons were reliable and safe to store and operate [1, 8]. When conducted, hydronuclear experiments produced hardly any nuclear energy release, which caused few fission fragments of nuclear charge materials to be produced. Hence, the radiation effect on the environment occurred due to dispersion of nuclear materials incorporated in the nuclear charge. Plutonium was dispersed in simulated experiments [29].

The ‘Experimental Field’ site has been a unique memorial of the nuclear age to this day and is of great scientific interest as the natural proving ground to study nuclear consequences.

‘Degelen’ site

When a Partial Nuclear Test Ban Treaty (also known as the Moscow treaty, [31]) was signed in Moscow city on August 5, 1963 by Governments of the USSR, Great Britain and USA, nuclear tests came to be conducted underground.

The first site for underground testing was the ‘Degelen’ site, which was designed for medium- and low-yield nuclear tests [1, 3]. The site is located at the same-name mountain range, which is a dome-shaped elevation of about 17-18 km diameter. The total area is about 300 km². The ‘Degelen’ site is one of the main STS testing sites, at which underground nuclear explosions (UNE) of up to 150 kt were conducted in horizontal mine workings – adits (Figure 1.5).

The first 1 kt underground nuclear explosion was conducted in the granite massif of V-1 adit at STS on October 11, 1961. The main goals of this experiment were to determine whether it was possible to measure the major operating characteristics of nuclear charges under conditions of the underground explosion and to study physical phenomena in

terms of utilization for the development of physical measurement procedures and for long-range detection of nuclear explosions.

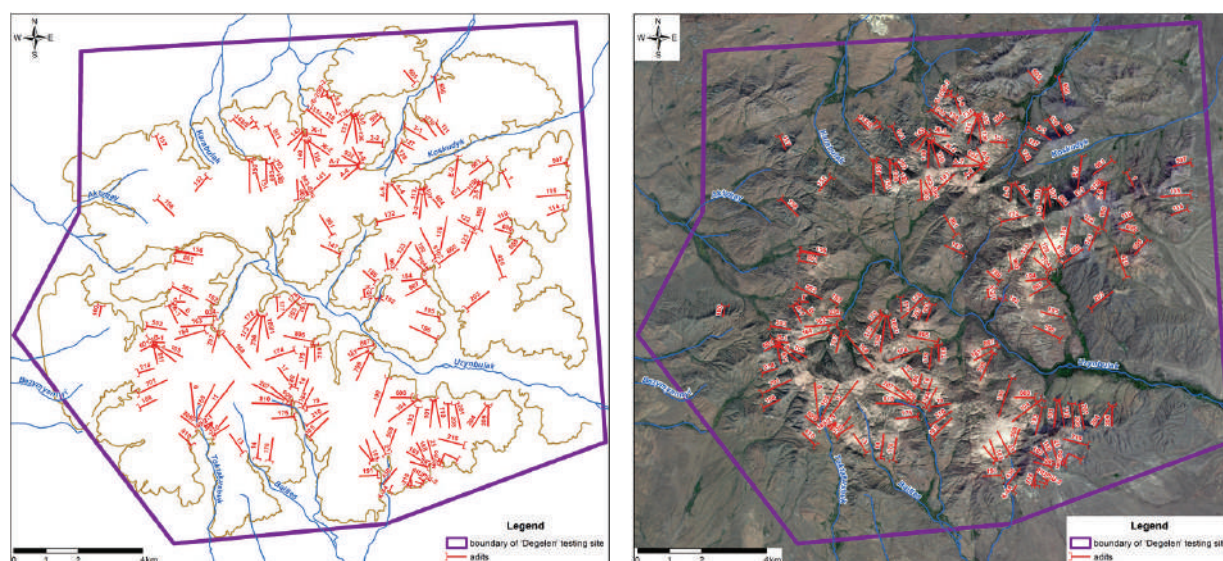


Figure 1.5. Location map of adits at the ‘Degelen’ site

In total, 209 nuclear tests were conducted in 181 adits between 1961 and 1989.

The last test was conducted on October 4, 1989 in adit 169/2.

At the site, multiple nuclear explosions were conducted both in separate workings (adits) and in more than one working when nuclear devices were simultaneously detonated. The first multiple explosion was conducted on December 3, 1966 in adit 14, during which two nuclear devices were simultaneously detonated. 2 nuclear devices were simultaneously tested 43 times, 3 devices – 16 times, 4 devices – 5 times and 5 devices at most – 2 times.

Cross-sections of horizontal mine workings (adits, strike entries) for conducting underground nuclear tests were 9-50 m² taken to be appropriate for conditions in which driving equipment was placed and for its normal operation, nuclear charges and assemblies of technological equipment were transported as well as technological equipment and cable communications were placed (Figure 1.6) . The adit length varying from 140 to 1,600 m was chosen depending on the depth that the end box with a nuclear charge was lowered to. Workings

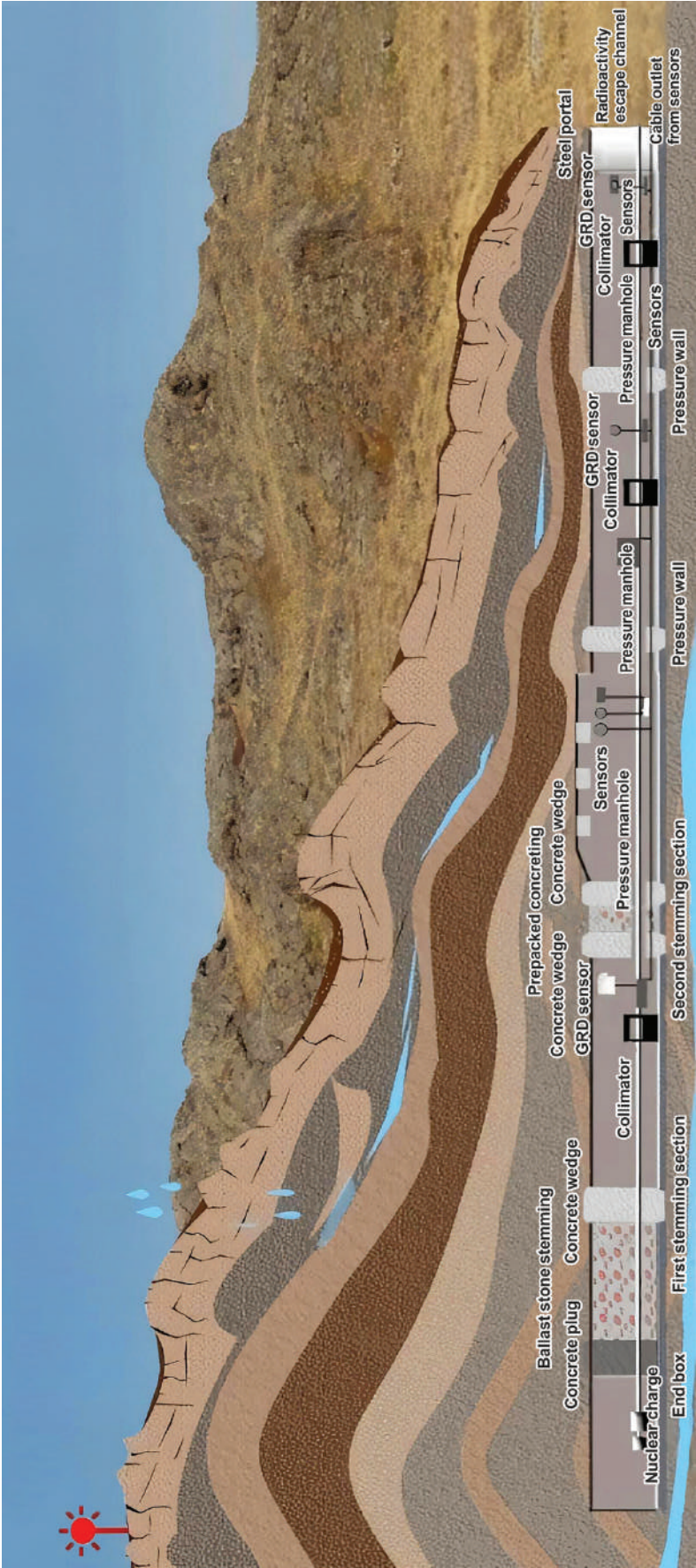


Figure 1.6. Adit cross-section prior to a test

were in dry drained rocks. When the precipitation event was hard, these could be water-logged due to infiltration through fractures. To drain water from the workings, adits and strike entries had a slope of 0.004 towards the mouth. Physical and mechanical properties of rocks enabled to drive adits and strike entries without erecting supports. Only mouth parts of adits, chamber workings and workings with large spans as well as sections of workings with tectonic disturbances had supports.

The near-entrance site of each adit has an industrial site erected, at which there were: an electric locomotive depot, compressor room, overpass for car dumps, transformer substation, material and machinery stockpile, aboveground rail tracks. At some distance, there was an active storage of explosive materials. Upon completion of mining and driving operations, the industrial site was transformed into a test equipment site. To this end, the following facilities were additionally built: a site for unloading and assembling nuclear charges, a site for storing materials and equipment, a site for installing measuring systems, a site for installing the system of detonation automatics, an overpass to unload stemming material, a lightning rod, a guard post. At 1-5 km from the adit mouth (depending on an explosion yield and landscape), there was a command post of detonation automatics and instrumentation control [33].

In addition to the necessary equipment, dumps of rocks removed in driving and remainders of technological equipment (radioactivity escape channels, technological metal structures, air ducts, rail tracks and others) after the test were placed at the near-entrance site (Figure 1.7).



Figure 1.7. View of near-entrance sites

A lot of adit bodies were opened up after nuclear tests both to study consequences and in order to use the same adits for other tests. At the same time, stemming material containing artificial radionuclides, was removed from the adit body and stored in the form of dumps at the near-entrance site. Currently, there are traces of man-made disturbance related to testing virtually at all near-entrance sites [33, 34].

‘Balapan’ site

The ‘Balapan’ testing site located in the eastern part of STS is another site, at which underground tests were conducted. The site area is about 780 km². The testing site was used for underground nuclear explosions in boreholes and simulated experiments using conventional explosives. A total of 105 nuclear explosions were conducted at this site between 1965 and 1989 including the first Soviet explosion with soil ejection as part of the experiment to make an artificial water reservoir on January 15, 1965. This experiment contributed to contamination of the testing site area with nuclear debris most of all [3].

As with ‘Degelen’ site, nuclear tests of low- and medium-yield were conducted at ‘Balapan’. The range of yields in TNT equivalent was divided into two parts: from 0.001 to 20 kt and from 20 to 150 kt. Borehole depths for experiments varied from 240 to 600 meters.

When comparing atmospheric nuclear tests with underground nuclear explosions in boreholes, in the latter case, the earth’s surface was hardly contaminated. The bulk of radioactive products remained ‘buried’ beneath the rock layer. During underground nuclear explosions in boreholes with a normal radiological situation, most of produced radioactivity remained in pit cavities in vitrified alloy. Only a small portion of it was released into the surface in the form of inert gases [35].

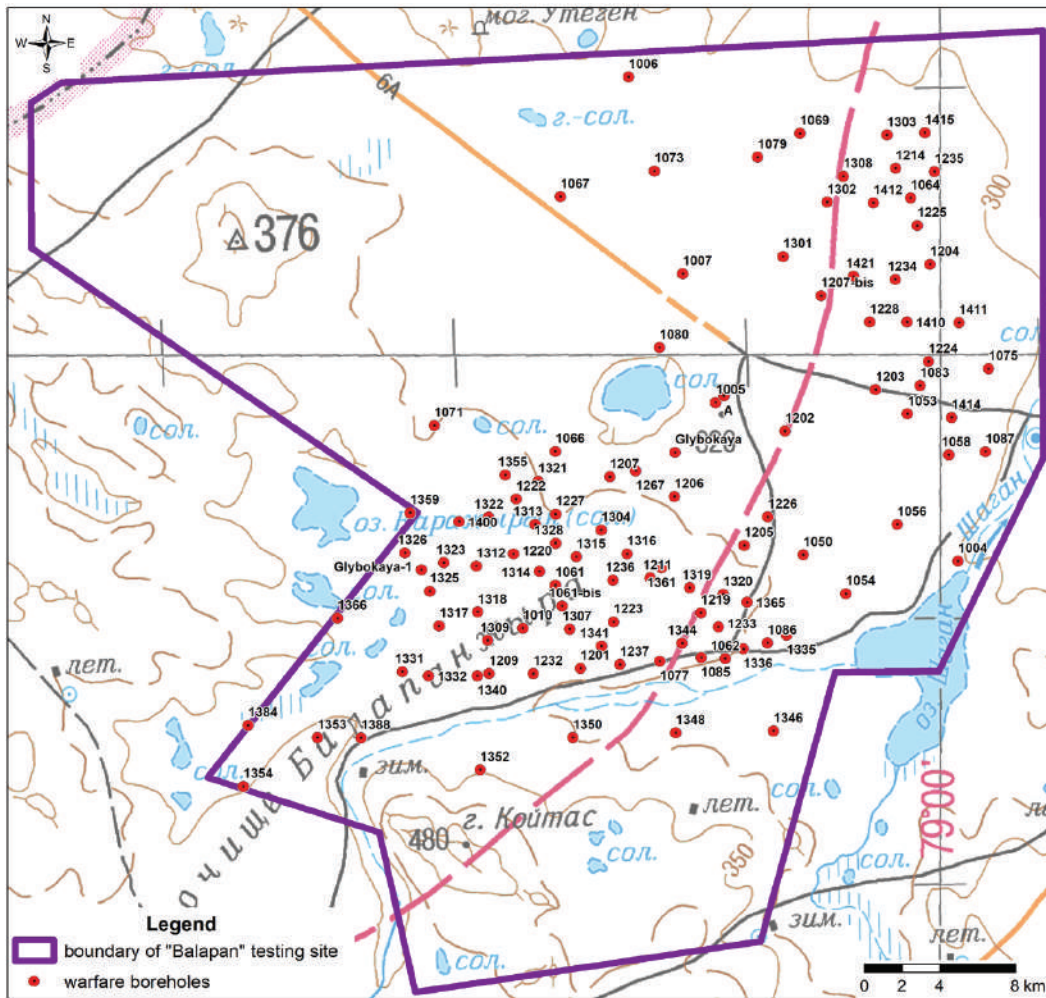


Figure 1.8. Location diagram of boreholes at the 'Balapan' site

To prevent the release of radioactive debris into the atmosphere through the borehole, a so-called stemming complex with extra strong thermal elements, dampening and gas-blocking devices etc. was built. (Figure 1.9). Boreholes were fully cemented or cement plugs were made there with gaps backfilled with crushed stone and sand in between. To keep space between cables securely cemented, special cable fittings were applied. Gas-blocking devices were mounted on cables within the soil block undisturbed by the explosion [3].

The first Soviet experiment to use fusion energy for peace was an underground explosion on the bank of the Chagan river (currently, the Shagan river) 80 km north-west of Semipalatinsk city (currently, Semey city) in order to make a large-capacity water reservoir. The project named as 'Chagan' was designed as the counterpart of the

American project ‘Sedan’ – a 104-kiloton fusion excavation explosion conducted on July 6, 1962 at the test site in Nevada (that was the world’s first industrial nuclear explosion). When the Soviet fusion charge was being designed, specialists of the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) managed to achieve a higher ‘purity’ – 94 % versus 70 % of ‘Sedan’ device. This meant that 94 % of the detonation energy was ensured by fusion reactions that produced no radioactive products. 170 kt explosive device looked like a metal container of 86 centimeters diameter and 3 meters long [2, 36].

The explosion was conducted in the vertical mining (borehole) No. 1004 by VNIIEF specialists at the confluence of the Shagan and Aschysu rivers. As a result, a crater 100 m deep was formed, and soil ejected resulted in a dump 20-25 m high formed along the contour of the crater thereby blocking beds of rivers. A temporary small village in the form of yurts and dugouts for testers was built at the site near the borehole. Power for the equipment employed in preparing and conducting the explosion was supplied by means of mobile power stations. The command post to detonate a nuclear charge and recording equipment were at a distance of 10 km from the borehole [37].

An experiment conducted at the ‘Balapan’ site on January 15, 1965 showed a possibility in principle to use nuclear explosions for making water reservoirs and creating a microclimate to ensure agricultural production in arid steppe regions. Technological principles of preparing a nuclear charge, lowering it to the borehole, controlling detonation were taken as a basis for designing future tests of nuclear charges in boreholes. As planned by the Soviet scientists, craters from nuclear excavation explosions could be used as appropriate water reservoirs: spring runoffs would be collected there, and a small evaporation surface with a fritted bottom would keep water for irrigation needs, cattle husbandry, prevent territories from being salinized etc. About 40 artificial water reservoirs with the total volume of 120-140 mln m³ were planned for Kazakhstan by conducting nuclear excavation explosions [38].

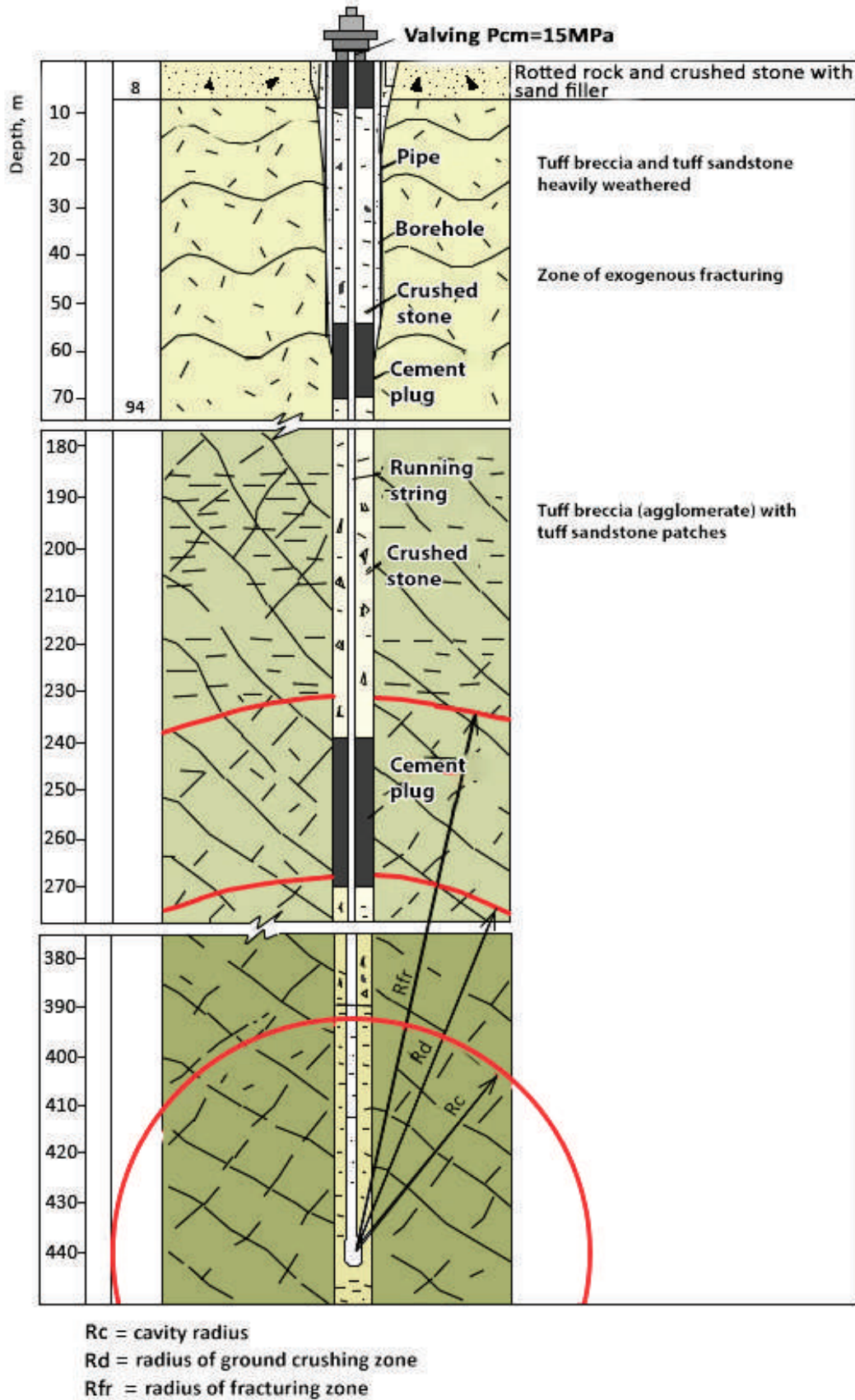


Figure 1.9. Borehole and stemming scheme with zones of explosive mechanical action

'Sary-Uzen' site

Simultaneously with tests at 'Balapan', underground nuclear explosions in boreholes were conducted at one more site. Between 1965 and 1980, 24 underground tests were conducted at the 'Sary-Uzen' site located in the southeastern STS part in 25 'warfare' boreholes [1]. One of these – 'Lasurite' was conducted in close proximity to the 'Sary-Uzen' site, at 'Murzhik' massif.

Reportedly, in most tests, the yield did not exceed 20 kt, testing depths varied from 50 to 430 m. The region of the heaviest man-made stress due to underground nuclear explosions is in the center and northwestern part of the site (Figure 1.10) [2].

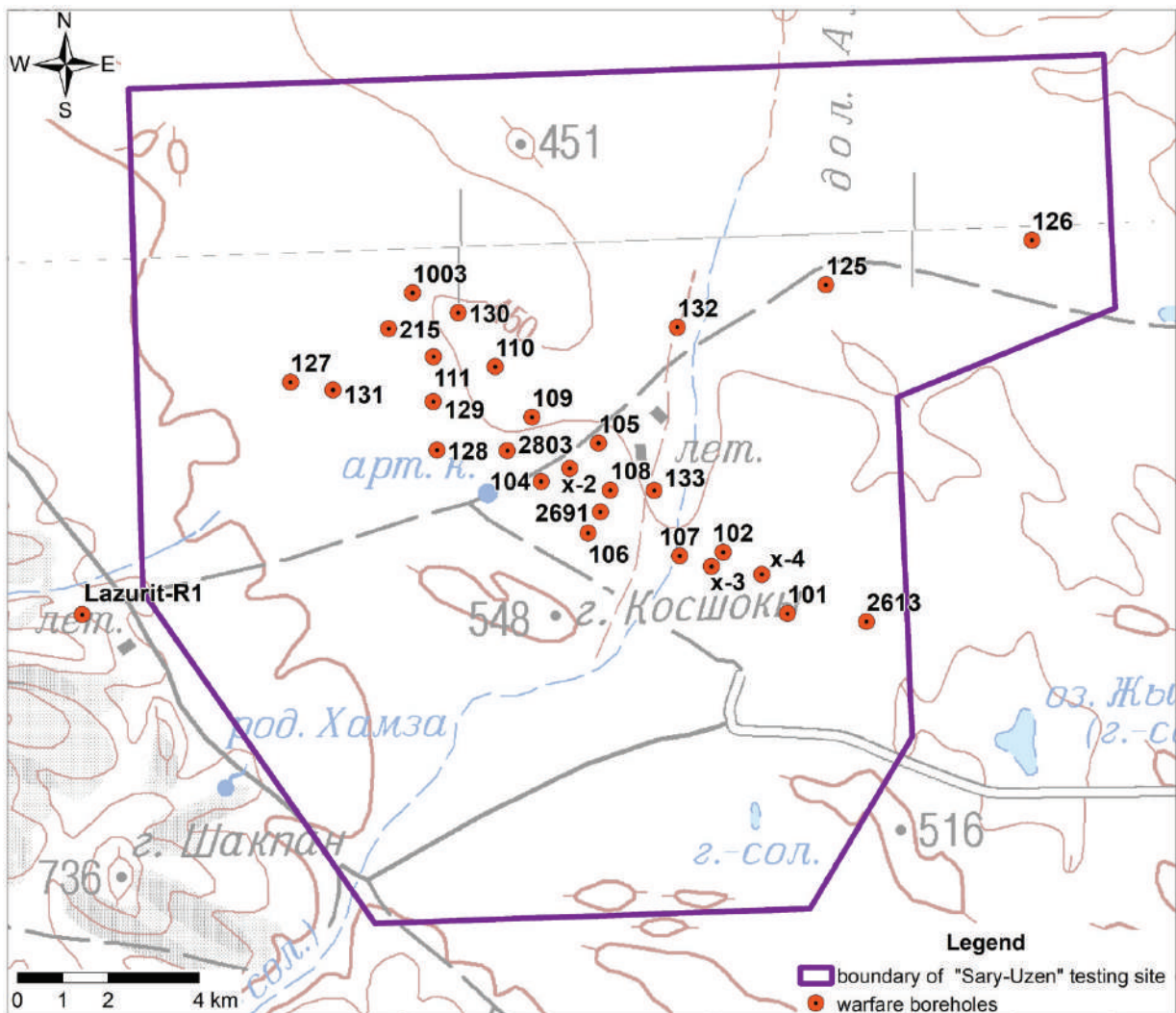


Figure 1.10. Location scheme of 'warfare' boreholes and special facilities at the 'Sary-Uzen' site

Excavation explosions – experimental nuclear explosions with soil ejection, deserve individual attention. Such test, in particular, was conducted in borehole No. 1003. A 1.1 kt special nuclear charge planted at a depth of 48 m was used in this explosion. Such experiment was mainly aimed at studying whether it was possible to make a channel through the dump of soil ejected from the crater without involving people or machinery in the follow-up work. To do so, prior to a nuclear explosion, a linear charge of conventional chemical explosives was planted in the place of the intended channel in the radial direction. The charge was planted to ensure that conventional chemical explosives should move beneath the soil dump after the nuclear explosion. Next, a charge of explosives was detonated resulting in a trench in the soil dump to be used as a water supply channel. Thus, the possibility to make a water supply channel in the radioactively contaminated area without involving people or excavation machinery was experimentally demonstrated.

In addition to boreholes, the ‘Sary-Uzen’ site area has special facilities with locally contaminated spots. Every facility may number up to 20 structural elements, both aboveground and underground. Fission products of nuclear fuel, unreacted fuel and neutron activation products were discovered at these objects [3].

‘4’ and ‘4A’ sites

Within the STS territory, besides radioactively contaminated spots produced due to nuclear testing, there are other places with significant levels of radioactive contamination that were formed as a result of radiological warfare agent (RWA) tests.

Between 1953 and 1957, the ‘4’ and ‘4A’ testing sites were a foothold to implement radiological warfare agent programs [1]. A radioactive substance in the form of powder-like and liquid formulations designed for mass human destruction, contamination of different types of

vehicles, armaments and environmental compartments was the main component in the test warhead. Abroad, this type of weapons was named as ‘radiological’ [4]. Both sites are in close proximity to the ‘Experimental Field’ testing site (Figure 1.11).

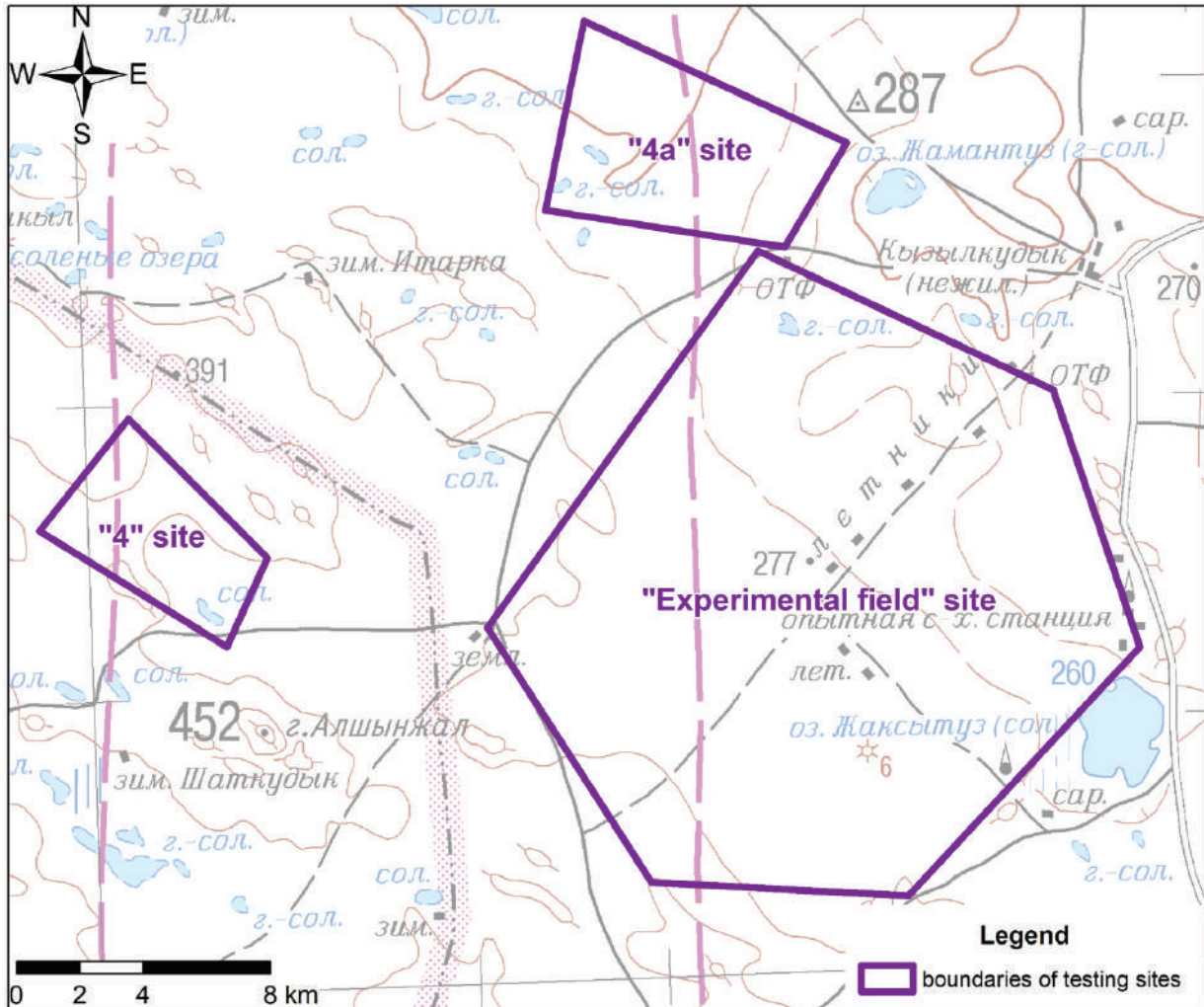


Figure 1.11. Locations of the ‘4’ and ‘4A’ sites for RWA tests

RWA were derived either from radiochemical waste or by irradiating specially selected components with neutrons of an operating nuclear reactor, that is by producing so-called prepared activity. A radioactive formulation (‘formulation 904’), the activity concentration of which varied between deciles and Curie units per liter was used at ‘4’ and ‘4A’ sites [1]. The ‘age’ of fission fragments at the time of tests was 3-4 months after extraction from the reactor. For RWA experiments,

‘formulation 904’ containing fission fragments with medium and long half-lives, was transported to the ‘4’ and ‘4A’ testing sites by car trailers in sphere-shaped lead containers. This formulation was used to fill up containers for experiments – cases of chemical air bombs, airborne spray tanks, artillery and mortar shells, land mines (Figure 1.12) [40].



Figure 1.12. Filling up the air shell with a radioactive formulation in progress

RWA tests were conducted by detonating individual warheads remotely, bombing from airplanes, with artillery and mortar guns or airborne spray tanks. For RWA tests, the ‘4’ and ‘4A’ sites were equipped with special targets. The contamination level and nature of ground, air and objects of the target layout were determined. Various test animals were also employed [3].

After a RWA shell was detonated leading to radioactive contamination of the ground, parameters defining RWA weapon combat efficiency were measured. Based upon such observations, radioactive plume schemes were constructed, sizes of areas with different contamination densities and exposure doses were identified. In addition, exposure doses of personnel who were staying under

different conditions of a contaminated area were determined, which did oftentimes define the combat efficiency of RWA.

To reduce the severity of radiation effect on testers, shielding screens, earth structures as well as one-of-a-kind devices to execute operations remotely were applied. Due to complicated decontamination, all the equipment employed in RWA tests (containers, conduits, pumps and others) was buried in a five-meter soil layer.

Various man-made objects exist in the site area – trenches, fortified structures, craters as well as a great many of metal fragments of test armament (remainders of mines, different air bombs etc.). In most cases, metal fragments discovered were heavily contaminated at the surface and, apparently, were test carriers of RWA [1].



Figure 1.13. View of one fortification and a metal ware fragment

At the same time, during RWA tests, combat efficiency to injure manpower of a potential enemy by these means compared to nuclear effects such as shockwave, optical radiation, penetrating radiation etc. was found to be low. Public sources provide no complete and trustworthy information on RWA tests including burial sites of all equipment, vehicles, overalls and so on.

‘Telkem’ site

In 1965, soon after two excavation explosions were conducted in borehole No. 1003 of the ‘Sary-Uzen’ site and borehole No. 1004 at

the ‘Balapan’ site, specialists’ attention was drawn to whether it was possible or not to construct a channel, which could help dewater arctic regions of the USSR. In order to develop such project, a decision was made to conduct two underground nuclear tests in the southeastern STS part with external action: a single explosion ‘Telkem-1’ and a multiple one – ‘Telkem-2’ [41].

The first test – a single underground nuclear explosion with soil ejection ‘Telkem-1’, 0.24 kt (the whole energy release occurred due to fission reactions of a nuclear charge material), conducted on October 21, 1968 at a depth of 31.4 m. This explosion was aimed at studying parameters of the mechanical and radiation factors to use findings in preparing and conducting a multiple explosion with external action [2, 42].

As a result of the explosion, a regularly shaped crater and a dump of ejected soil were formed in the epicentral area.



Figure 1.14. View of ‘Telkem-1’ object

The longest flyrock travel from the ground zero was 190 m. The crater is filled up with ground waters. The water surface from south to north is 80 m long, from west to east – 70 m long.

It has to be noted that due to a high gas capacity of rocks, the radius of resulted crater exceeded the estimated value by 25 %, and its depth increased by 40 %.

After ‘Telkem-1’ explosion, as the cloud was moving, radioactive contamination of the ground was produced in the form of a strip northward, on which the amount of radioactive debris did not exceed 0.2 % of the total amount produced during the explosion. This zone extending for several dozen kilometers is completely ‘located’ in the restricted test site area, i.e. remained within it. Four months after the explosion, radiation levels in soil dumps did not exceed 20 mR/h.

The main objective of the experimental explosion called ‘Telkem-2’ conducted on November 12, 1968, was to obtain data on the mechanical and radiation effect of the explosion that are necessary to design multiple underground explosions for industrial needs [43].

Characteristics of rocks during the ‘Telkem-2’ explosion were roughly the same as during ‘Telkem-1’ because a place of the second explosion was selected in close proximity to the ‘Telkem-1’ object (2.5 km). Three charges of 0.24 kt were planted in boreholes that were 31.4 m deep each with 40 m in between.

Once three linearly arranged charges were detonated, a trench-like ditch and a dump of ejected rock were formed. A crater produced in the multiple explosion was soon filled up with ground waters.

The crater is currently 150 m long and about 100 m wide. The dump height relative to the surface level of the surrounding area – 17 m.



Figure 1.15. View of ‘Telkem-2’ object

As these experiments progressed, technologies were tested to construct channels to be used to dewater country's arctic regions to basins of the Volga river and the Caspian Sea. Important data was obtained to plan the work on making Pechora-Kama river channels.

'Aktan-Berli' site

The 'Aktan-Berli' site is located in the southern part of the test site, west of the 'Degelen' site and southeast of the 'Sary-Uzen' site. The site area is flat, sometimes slightly hilly, at spurs of the Arshalyk mountains.

This site was used for hydronuclear experiments. In general, between 1958 and 1989, 89 hydronuclear experiments of different type were conducted [29]. 40 of 68 were conducted at the P-2G site [44], the other 28 – in other STS areas including at the 'Aktan-Berli' site [3, 45]. There is no information on locations of these 28 experiments (coordinates of spots or their layouts). Hydronuclear tests at the 'Aktan-Berli' site are known to have been conducted in boreholes at 5 to 30 meters deep [1].

CHAPTER 2. COMPREHENSIVE ECOLOGICAL SURVEY OF SEMIPALATINSK TEST SITE

The main goal of the comprehensive ecological survey of the test site is to assess the level of hazard currently posed to man and the environment, that is to say, it is the answer to the question – is it safe to live in its territory?

Hence, in this book, a comprehensive ecological survey means research into the state of vital environmental components: soil cover, ambient air, aquatic medium including surface and ground waters as well as flora and fauna to subsequently evaluate human radiation exposure.

At the same time, as part of the comprehensive ecological survey, only a radiation factor affecting the above environmental compartments was addressed and studied. Generally, the ecological survey implies research into all adverse factors affecting nature. Nevertheless, given STS specific nature, only the radiation constituent underlain by artificial radionuclides produced due to nuclear testing was studied. The content of natural radionuclides in environmental compartments was not studied.

2.1 Radionuclides contributing to the current radiological situation

During the explosion of a nuclear charge, the original mixture of nuclear debris contains more than 200 alpha-, beta- and gamma-emitting radionuclides with a wide range of half-lives and radiation energies. The major radiation hazard is posed by the nuclides which due to decay produce relatively long-lived isotopes.

By the way radionuclides contributing to the radiological situation at STS are produced, one can note the following three main groups:

– radionuclides – fission products (fission fragments) of nuclear materials;

- radionuclides produced in construction materials of a nuclear charge or in the equipment system used to detonate it as well as in soil in the place of a nuclear explosion and in other environmental compartments affected by a neutron radiation flux (induced activity);
- unreacted portion of a nuclear charge (fissile materials).

The influence by each on the nature of radioactive contamination of the test site territory depended on different parameters such as the type of an explosion (air, aboveground or underground), design features of a shell, soil type in the vicinity of an explosion and its elemental composition [46].

Fission products (fission fragments)

Radionuclides produced during a nuclear explosion – fission products, emit beta-gamma-activity that decrease with time relatively soon. The composition of fission products depends on a number of factors like the type of fissile material in a nuclear charge; the time that has passed since the explosion.

Relying on literature sources [47], activities of plutonium (^{239}Pu) charge fission products and their contribution to the total activity have been assessed by now. This type of a nuclear charge is considered because it is the most commonly used in nuclear weapons that were tested at STS.

Table 2.1. Activities of ^{239}Pu fission products

Radionuclide	Half-life $T_{1/2}$, years	A*(59 years), Bq/kg	Contribution to the total activity, %
^{79}Se	$6,5 \times 10^4$	$1,17 \times 10^7$	0
^{85}Kr	10,8	$4,4 \times 10^{10}$	1,3
^{90}Sr	27,7	$5,57 \times 10^{11}$	23,58
^{93}Zr	$1,5 \times 10^6$	$8,14 \times 10^7$	0
$^{93\text{m}}\text{Nb}$	13,6	$2,14 \times 10^5$	0

Radionuclide	Half-life $T_{1/2}$, years	A*(59 years), Bq/kg	Contribution to the total activity, %
^{107}Pd	$7,0 \times 10^6$	$2,12 \times 10^7$	0
^{115}In	$6,0 \times 10^4$	$4,25 \times 10^7$	0
$^{121\text{m}}\text{Sn}$	76,0	$8,43 \times 10^8$	0,04
^{125}Sb	2,71	$5,86 \times 10^5$	0
^{129}I	$1,7 \times 10^7$	$3,74 \times 10^6$	0
^{135}Cs	$3,0 \times 10^6$	$6,47 \times 10^7$	0
^{137}Cs	30,0	$1,64 \times 10^{12}$	68,24
^{144}Nd	$2,4 \times 10^5$	$2,82 \times 10^8$	0,01
^{151}Sm	87,0	$1,61 \times 10^{11}$	6,70
^{154}Eu	8,6	$1,05 \times 10^6$	0
Total activity, Bq/kg		$2,40 \times 10^{12}$	100
* – activity of radionuclides given the decay period (59 years) that passed since moratorium was imposed on air nuclear tests (1962-2021)			

The table illustrates that at this point in time, such radionuclides as ^{90}Sr , ^{137}Cs and ^{151}Sm being 23 %, 68 % and 7 % of the total activity of all radionuclides – fission products, respectively, contribute to STS radioactive contamination and, consequently, to radiation exposure most. Taking into account that ^{151}Sm dose factor through ingestion is two orders of magnitude lower than that of ^{90}Sr and ^{137}Cs , and through inhalation – one order of magnitude lower than ^{90}Sr , this radionuclide can be ignored from the perspective of radioactive contamination of the ground and contribution to internal and external human exposure [48].

In this regard, as part of the comprehensive ecological survey of STS, only ^{90}Sr and ^{137}Cs were studied from among radionuclides – fission products.

Neutron activation products

Induced activity is attributed to the effect of neutrons on isotopes of elements incorporated in substances of construction materials in a nuclear charge and in environmental compartments. The quantity of induced activity is directly proportional to neutrons yield in the explosion of a nuclear charge and rapidly decreases in time due to radioactive decay.

As a result of the radioactive capture reaction (n, γ), the ground zero produces both radioactive and stable isotopes. Most of these are short-lived, but the most significant – ^{54}Mn , ^{55}Fe , ^{60}Co and ^{152}Eu , ^{154}Eu should be noted.

Table 2.2. The most significant neutron activation products

Radionuclide	Half-life $T_{1/2}$, years
^{54}Mn	0,85
^{55}Fe	2,7
^{60}Co	5,3
^{152}Eu	13,5
^{154}Eu	8,6
^{14}C	5730
^3H	12,3

Air and steam activation producing radioactive ^3H and ^{14}C is also important. Atoms of these substances are able to substitute stable hydrogen and carbon in tissues of living organisms and are a source of long-term internal exposure and genetic mutations.

In addition, most (99 %) of ^{14}C , resulted from a nuclear test, in the form of gas passes into the stratosphere subsequently producing global fallout [49].

High concentrations of ^3H in the STS territory were discovered in ground and surface waters in the vicinity of underground nuclear tests.

Thus, radionuclides being neutron activation products are currently concentrated only at ground zeroes. Therefore, these radionuclides, because there were none or the ones with extremely low residual activity, were not addressed in the comprehensive ecological STS survey aimed at studying the radiological situation beyond places of nuclear tests. The exception is tritium the concentration of which in some water bodies of the test site is hundreds of thousands Bq per liter.

Residues of fissile material

If we compare the total activity of the unreacted portion of a nuclear charge at the time of the explosion with that of fission products, it will be relatively low. However, it is the one that is able to cause significant problems owing to high radiotoxicity of alpha-emitting radioactive substances and their long half-lives.

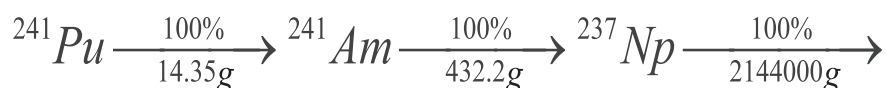
^{239}Pu , ^{235}U and ^{238}U are mostly used as materials forming the basis of a nuclear charge. Let us address the composition of a plutonium charge that is most commonly used in nuclear weapons in more detail.

Table 2.3. Isotopic composition of a plutonium-based nuclear charge [50]

Isotope	Mass fraction, %	Half-life $T_{1/2}$, years	Activity per unit mass of a nuclear charge, Bq/g
^{238}Pu	0,05	87,7	$3,2 \times 10^8$
^{239}Pu	93,1	$2,4 \times 10^4$	$2,1 \times 10^9$
^{240}Pu	6	$6,5 \times 10^3$	$5,0 \times 10^8$
^{241}Pu	0,8	14,4	$3,0 \times 10^{10}$
^{242}Pu	0,05	$3,7 \times 10^5$	$7,3 \times 10^4$

The bulk is represented by isotopes ^{239}Pu , ^{240}Pu – long-lived radionuclides and in the short term, no changes in their activities due to radioactive decay are expected.

^{241}Pu deserves individual attention. It is a beta-emitting isotope with a half-life of 14.4 years. Below is its decay scheme (three first isotopes):



^{241}Pu radioactive decay will result in gradually accumulated progeny of ^{241}Am . The accumulation of ^{241}Am progeny – ^{237}Np , will be extremely slow owing to a long half-life of ^{241}Am (432 years). 90 % of ^{241}Am activity will require about 4,300 years to decay.

Thus, in the short term (500 years), from among transuranic elements, ^{239}Pu , ^{240}Pu and ^{241}Am will be making the most significant contribution to radioactive contamination. Hence, only these were measured as part of the comprehensive ecological STS survey.

Thus, ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$, ^{241}Am as well as ^3H in water should currently (2021) be considered as the most significant radionuclides (nuclear debris) from the perspective of radioactive contamination and contribution to internal and external exposure.

2.2 Methodology of the comprehensive ecological survey of the test site

Obviously, a great many of nuclear tests, 456 conducted between 1949 and 1989, have had an adverse effect on the environment. Research undertaken prior to the comprehensive ecological STS survey in 2008, was supposed to solve high-priority tasks that the country was facing after the test site was shut down. Such tasks included ‘auditing and management of the former STS borders’, ‘safety assurance at nuclear and radiation-hazardous facilities and objects and taking measures for maintaining the non-proliferation regime’, ‘taking a range of measures to remediate and conserve wastes of nuclear weapons activity, radioactive and toxic wastes and to remediate (rehabilitate) radioactively contaminated areas’ etc. In

most cases, early research was conducted at STS technical sites, at which nuclear tests were conducted. There are 8 such sites at STS. The ‘Experimental Field’ site – a place of aboveground nuclear tests; ‘Balapan’ and ‘Sary-Uzen’ sites – places of underground nuclear explosions in boreholes at depths from one hundred to several hundred meters; the ‘Degelen’ site – a place of underground nuclear explosions in horizontal mine workings – ‘adits’; ‘4’ and ‘4A’ sites – places of aboveground tests of radiological warfare agents (dispersion of radioactive substances afield); the ‘Aktan-Berli’ site – a place of special experiments both on the earth’s surface and underground (special experiments mean tests of nuclear materials without conducting nuclear explosions); and the ‘Telkem’ site – a place of two nuclear excavation explosions (a charge was planted at a certain depth and soil was ejected during the explosion forming a crater) for so-called ‘peaceful’ purposes (making water reservoir pits, channels and so on).

Areas between STS testing sites mostly remained out of researchers’ sight. Naturally, several questions can be asked – has the entire STS territory been exposed to radioactive contamination, what radionuclides contributed to contamination, what maximum levels of radioactivity are there at the test site, where are those areas, and, eventually, how dangerous is it for man to stay in a particular part of the test site?

To answer these questions, it is necessary to investigate the test site completely, virtually every corner. But how can this be done in practice? There is an experience in surveying military nuclear proving grounds in the global practice but no detailed information is available to the public on techniques and the scope of research. The only analogue (by the scale of radioactive contamination and the level of knowledge), so to speak, is the territory exposed to contamination as a result of the Chernobyl NPP accident in 1986. However, it is impossible to apply the same research experience of

Chernobyl accident consequences to STS due to the difference in problems to be solved and both natural (different climatic zones, various production of carrying particles of radionuclides, various species of produced radionuclides caused radionuclides to behave different in the environment) and social and political (measures were taken in the Chernobyl exclusion zone to resettle the population, and in the case of STS, the task is to release a portion of lands to the economic turnover, i.e. to populate the STS territory) conditions. Nevertheless, public radiation safety has underlain research into both the Chernobyl and STS territories.

Therefore, the general approach (methodology) in the comprehensive ecological STS survey has to be based upon the assessment of the level of radiological hazard to man.

When assessing the radiological hazard of the test site, the most reasonable thing is to obtain data on exposure doses to be received by man while living at the test site. The fact is that data on the content of radionuclides (produced during nuclear tests) in soil, water, air can only point to the contamination level of the environment. This causes difficulties when interpreting data in the context of radiological hazard of the test site to man. Besides, one has to understand that all radionuclides in particular environmental compartments are sources of ionizing radiation that in fact may contribute to human exposure dose.

Proceeding from this, human exposure doses are a key factor when identifying a radiological hazard of the test site.

When it comes to the methodology of the comprehensive ecological STS survey in general, it can be depicted in the form of a sequential order of actions (operating procedure).

At stage 1 of the survey, a survey area is generally described, i.e. STS. The general description of the area involves its physical and geographical location, geomorphological and climatic characteristics, information on the natural environment – ambient air, water and land

resources, geological medium and subsoil, flora and fauna. Man-made objects that can be a part of the former STS infrastructure designed for nuclear weapon testing and are currently able to pose radiological hazard, are also revealed. Man-made objects are identified using a field satellite image interpretation technique, i.e. a field visit is made, radiation parameters of an object are identified and measured.

At stage 2 of the survey, the radiological situation around the survey area is studied. To this end, the content of man-made radionuclides is determined in environmental compartments including in soil cover, surface and ground waters, ambient air, objects of flora and fauna. In addition, at this stage, the content of man-made radionuclides in farm products that could be produced in the survey area is estimated. Values obtained and estimated for the content of man-made radionuclides in environmental compartments, are compared with the ones listed in respective regulatory documents.

At stage 3 – based upon results of the assessment of radiological environmental state, i.e. based upon results of the previous stage, exposure doses to be received by the public when living and/or carrying out economic activities at the survey land plot are calculated. Public exposure doses are calculated in order to evaluate the level of human radiation safety if a person is living at the land plot under survey. The main criterion for assessing human radiation safety level if a person is living at the land plot under survey, is the annual average effective dose to the public from man-made radionuclides.

At stage 4 of the survey, based upon data of estimated annual average effective public dose, land plots at which the effective exposure dose will not exceed 0.3 mSv/year are identified. These land plots pose no radiological hazard to the public. Accordingly, other land plots at which the value of the annual average effective dose exceeds 0.3 mSv/year are also identified. Such plots have to be remediated after nuclear weapon tests before being released to the economic turnover.

The value of 0.3 mSv/year is a so-called intervention level, i.e. such level of radiation effect which, if exceeded, requires protective measures to be taken in order to restrict public exposure. This level is regulated by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48].

At stage 5 of the survey, recommendations are given to remediate after nuclear weapon tests or to restrict access to radioactively contaminated land plots that pose radiological hazard to the public.

At stage 6 (final), a predictive estimate is given to the state of the radiological situation in 10, 50 and 100 years. In case the radiological situation changes for the worse during the given period, measures to prevent these changes are defined.

Technically, it is a challenge to conduct a comprehensive ecological survey of the entire STS territory taking into account its size. Therefore, the test site area was surveyed portionwise (Figure 2.1). To do so, the entire territory was divided into a few (to be more precise, thirteen) parts and each part was surveyed as per the same procedure (as described above) for two years – on the first year, a preliminary survey was conducted, on the second year – a follow-up one. Once all parts were investigated, a summarized report was drawn up.

Thus, if we formulate the methodology of the comprehensive ecological STS survey, figuratively speaking, in a nutshell, the following things work out:

- 1) determination of the content of radionuclides in environmental compartments (in soil, air, water etc.);
- 2) calculations of exposure doses (based upon results of paragraph 1) to man staying/living at a particular point of the test site;
- 3) territorial zoning into ‘radiation-hazardous’ and ‘safe’ zones (based upon results of paragraph 2). The word ‘safe’ is quoted because the point at issue is only about radiation. Other hazards at the test site were not studied under the comprehensive ecological survey.

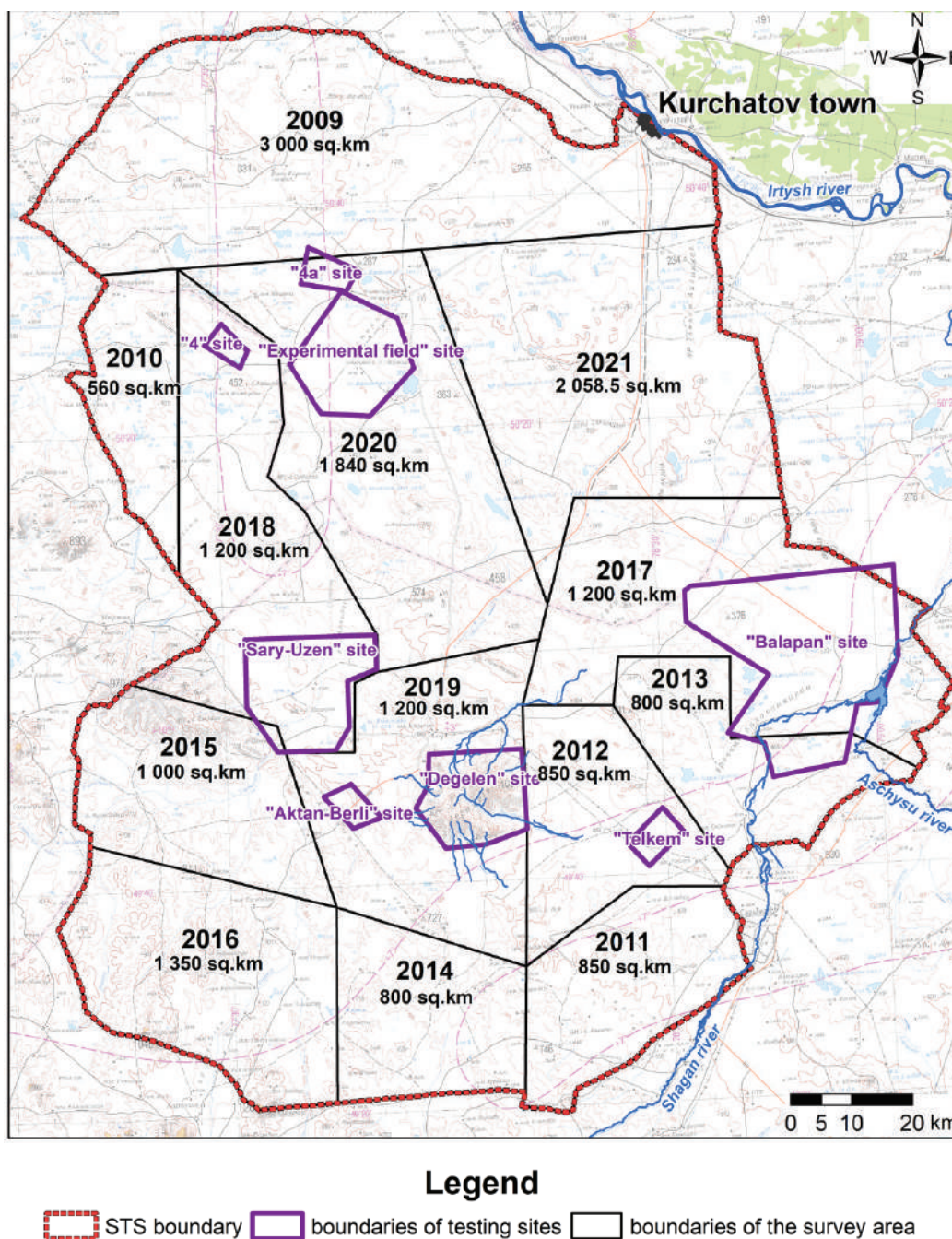


Figure 2.1. Plan of the comprehensive ecological STS survey by years

2.3 Radiological state of soil cover (topsoil)

Soil cover has been the major natural ecosystem exposed to radioactive contamination due to nuclear testing at the test site. Strictly speaking, the bulk of radioactivity is yet concentrated in deep geological formations rather than in soil cover because most nuclear tests (340) were conducted underground, and only 116 – at the earth’s

surface (30 aboveground tests and 86 air tests). However, as a result of underground testing, radioactive elements remained in test locations, i.e. underground, and did not result in a massive escape of radioactivity into the daylight surface except for abnormal situations that occurred during some tests that, nevertheless, also contributed to radioactive contamination of the ground to some extent. At the same time, of 116 atmospheric nuclear tests, the environment, mainly, soil cover, has been most affected by aboveground tests (30 tests).

Thus, soil cover, from the perspective of the assessment of impact on man and human activity, was addressed as the major source contributing to human exposure dose. In addition, soil cover contributed both to external exposure dose (directly) and to internal exposure dose (indirectly), i.e. through inhalation of microscopic soil particles (simply speaking, dust) as well as through the gastrointestinal tract in the food chain ‘soil-plant-animal-foodstuffs-man’.

When surveying soil cover, two main goals were pursued – firstly, get an insight into spatial distribution of artificial radionuclides (nuclear debris), i.e. identify areas of elevated concentrations of radionuclides, define quantities, configuration, space orientation; and, secondly, determine levels of concentrations of these radionuclides in soil cover, i.e. obtain figures expressed in units of areal (kBq/m^2) and/or specific activity (Bq/kg).

Now a few words about the survey technology of STS soil cover, techniques applied and assumptions that were accepted during the survey, the STS territory outside technical sites, i.e. areas themselves in which nuclear tests were not conducted.

Radioactive contamination of soil cover was evaluated through the analysis of soil samples collected from the test site. Of course, other techniques that allowed determination of levels of radioactive contamination of soil cover without sampling were also applied, for example, a pedestrian gamma-spectrometric survey, a radiometric survey in the ‘search’ mode and others, but all of these were, so to

speak, applied little-by-little to explore small-size areas. The large-scale survey of a 16,708.5 km² soil cover area was conducted, as mentioned above, by a laboratory technique of soil sample analysis.

There were three main assumptions when collecting soil samples to characterize radioactive contamination of soil cover.

The first, a so-called ‘injection’ technique was applied when sampling soil – pointwise sampling afield. In this case, the assumption was accepted that each sample collected from the same spot defined a certain area. For example, if samples were collected at junction points of a 1×1 km grid, each sample described a 1 square kilometer area at the spot under study irrespective of whether there was any difference, for example, between soil types at the spot under study or whether those were identical soil types. In fact, such differences can have a great effect on the distribution of radionuclides in soil cover. Nevertheless, this approach was taken.

The second, soil was sampled to a depth of 5 cm. The assumption was taken here that the whole amount of artificial radionuclides in soil cover was in its top five-centimeter layer. The issue of radionuclide penetration rate at the test site is addressed in more detail in the next section.

The third, the most important was that soil samples were collected at junction points of a uniform grid. The entire STS territory was conventionally split into squares with 1 km side, and a soil sample was collected at each corner of such square. This rather known technique is mainly applied for areas with unknown spatial contamination structure. The size of square sides as per the technique depends on the size of a spot under study. Results obtained by means of this technique, are regarded as source/basic to form the basis of further supplementary, follow-up research. In this case, it was assumed that radioactive contamination within squares varied uniformly/linearly. That is to say, radioactive contamination between two measured points could not be higher or lower than at these two points.

Before familiarizing yourselves with results of assessed radiological state of STS soil cover, it has to be clarified that radiological state means the areal activities (kBq/m^2) of four radionuclides – ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$, i.e. the amount of enumerated radionuclides contained in soil cover of the test site. Why exactly these radionuclides? Radionuclides listed are long-lived nuclear products having half-lives from 30 to a dozen of thousands years. Other radionuclides produced during nuclear tests have either fully decayed or values of their residual activities in soil are so negligible that these can be ignored in calculating exposure doses (this information is provided in more detail in Section 2.1 Radionuclides contributing to the current radiological situation). Lastly, why $^{239+240}\text{Pu}$ rather than ^{239}Pu and ^{240}Pu separately? This is due to the fact that the radiochemical measurement technique, applied to analyze plutonium, provides no opportunity to segregate these two isotopes, therefore their total activity was taken into account, all the more so as there is hardly any difference (we mean for practical tasks in radiation safety) in their radiological and chemical properties.

Besides, this section describes the radiological state of soil cover outside testing sites, i.e. areas themselves in which no nuclear tests were conducted. As a matter of fact, this presents research findings on consequences of nuclear tests for the STS territory.

So, let's us start assessing the radiological state of STS soil cover with the distribution of ^{137}Cs areal activity.

For construction of distribution maps of radionuclide areal activities, results of the gamma-spectrometric and radiochemical analyses of over 18 thousand soil samples were used.

Aboveground nuclear tests conducted on September 24, 1951 (38 kt), August 12, 1953 (400 kt) produced fallout plumes that extend from the 'Experimental Field' site southeastward and southward as far as the STS boundary and go beyond it. ^{137}Cs areal activity in 'plumes' ranged from 7.5 to 104 kBq/m^2 . In the other territory – less than 7.5 kBq/m^2 .

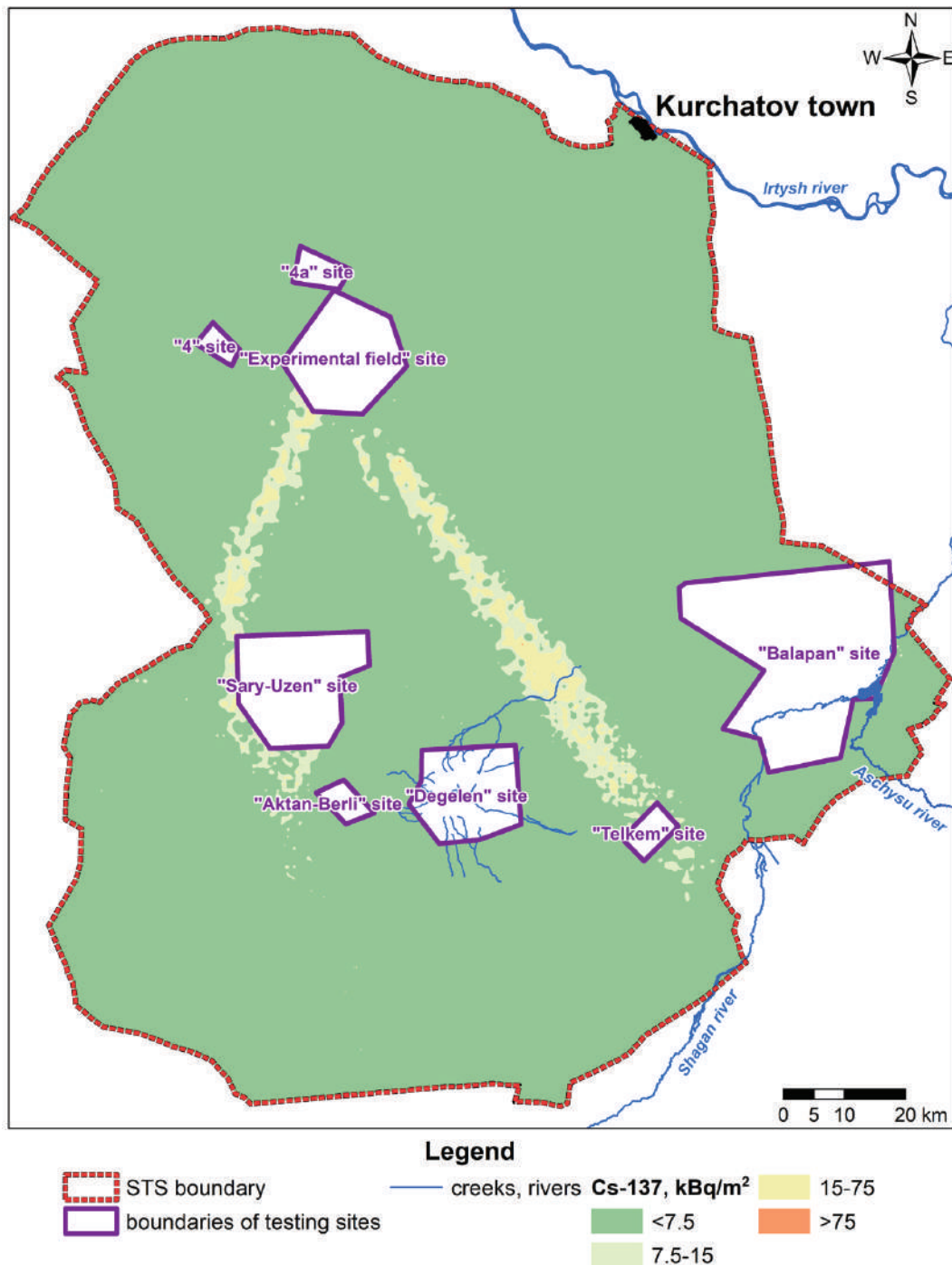


Figure 2.2. Distribution map of ¹³⁷Cs areal activity in STS soil cover

Background information. According to ‘Criteria for the assessment of the environmental situation around areas’, areas in which ¹³⁷Cs areal activity ranges from 0 to 75 kBq/m², refer to territories with ‘relatively satisfactory situations’, the one from 75 to 400 kBq/m² – to areas with ‘environmental emergency’, the one above 400 kBq/m² – to areas of ‘ecological disaster’ [51].

The length of each of such fallout plumes was 80-100 km within the test site. At the same time, it should be noted that at the test site (outside testing sites), even these fallout plumes have no areas in which the content of ^{137}Cs in soil, according to the classification 'Criteria for the assessment of environmental situation', exceeds levels when such areas can be classified as 'ecological disaster' areas, and the total area of lands to be referred to as areas with 'environmental emergency', is approximately 3 km² [51].

The distribution nature of ^{90}Sr is similar.

Both radionuclides, ^{137}Cs and ^{90}Sr , are products of plutonium nuclear fission (or uranium depending on the nuclear charge composition). Inert gases, ^{137}Xe with a half-life of 3.9 min and ^{90}Kr with a half-life of about 3 min, respectively, precede both radionuclides. Similarity in nuclear physical characteristics of how these radionuclides are produced, determines the similarity in their distribution at the earth's surface after a nuclear explosion. Undoubtedly, the way they subsequently behave in the environment will vary but as a whole, they can be regarded as accompanying elements using their activity ratios for practical purposes.

Radioactive contamination of soil cover with ^{90}Sr appears as the same two fallout plumes extending from the 'Experimental Field' site southeastward and southward. ^{90}Sr areal activity in these plumes ranged from 12 to 344 kBq/m². In the other territory – less than 12 kBq/m².

In the case of ^{90}Sr as with ^{137}Cs , at the test site (outside testing sites), even fallout plumes have no areas in which the content of ^{90}Sr in soil according to classification 'Criteria for the assessment of environmental situation', exceeds levels when such areas can be referred to as 'ecological disaster' areas, and the total area of lands to be referred to as areas with 'environmental emergency', is approximately 18 km².

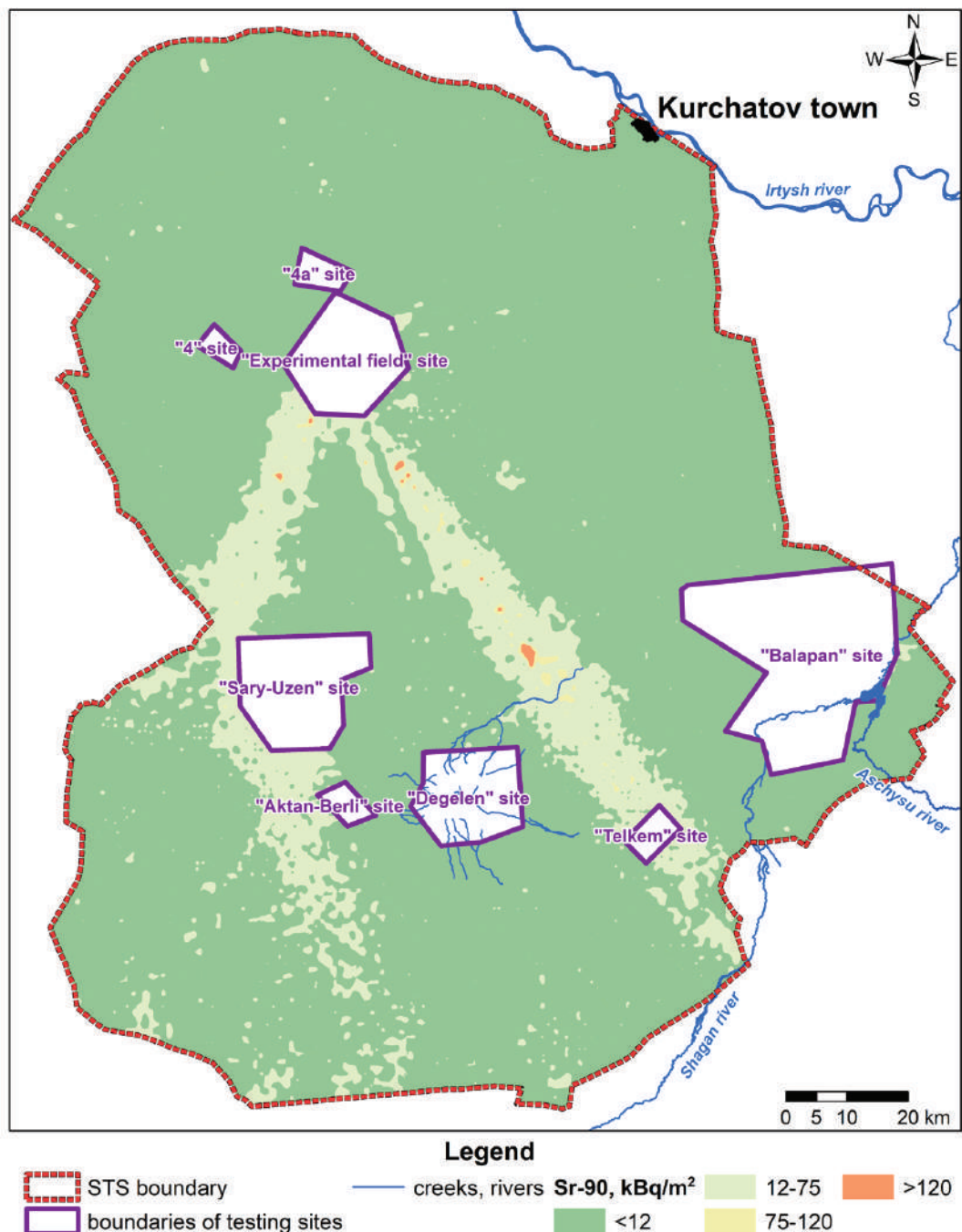


Figure 2.3. Distribution map of ⁹⁰Sr areal activity in STS soil cover

Background information. According to 'Criteria for the assessment of the environmental situation around territories', areas in which ⁹⁰Sr areal activity ranges from 0 to 120 kBq/m², refer to areas with 'relatively satisfactory situation', the one from 120 to 630 kBq/m² – to areas with 'environmental emergency', the one above 630 kBq/m² – to 'ecological disaster' areas [51].

Another group of radionuclides of interest are ^{241}Am and $^{239+240}\text{Pu}$. Radioactive contamination at STS with plutonium isotopes was produced after nuclear testing. The major plutonium isotope in the nuclear bomb charge is ^{239}Pu that is produced during a long irradiation with neutrons of natural or enriched uranium. The origin of other plutonium isotopes can be broadly presented as follows: during capture of ^{239}Pu neutrons, heavier plutonium isotopes are produced in the charge with mass numbers 240-242. The content of ^{239}Pu in the material of a nuclear charge is usually 90-95 %, that of ^{240}Pu – 1-7 %, the content of other isotopes does not exceed deciles of a percent. That is plutonium isotopes – (240-242) are an admixture [52].

^{241}Am is produced in the β -decay of ^{241}Pu . In addition, ^{241}Pu is incorporated in the nuclear charge (as an admixture) in a definite ratio to $^{239+240}\text{Pu}$, hence, after the explosion its behavior as well as the behavior of other plutonium isotopes that are incorporated in the material of a nuclear charge, will be identical to that of $^{239+240}\text{Pu}$ in environmental compartments because it is the same chemical element – plutonium.

As a matter of fact, such commonly known mechanism of ^{241}Am production in the nuclear charge enables to use figures on its content in environmental compartments to assess contamination with plutonium. Evidently, the ratio will also vary for different nuclear charges. Actually, this gives grounds for assessing radioactive contamination of the ground with plutonium by measuring ^{241}Am concentrations. At the same time, ^{241}Am and $^{239+240}\text{Pu}$ in soil cover of the study area is not taken to behave significantly different.

That is to say, ^{241}Am and $^{239+240}\text{Pu}$ distribution at the earth's surface after the nuclear explosion will be similar but significantly differ from that of nuclear fission products such as ^{137}Cs and ^{90}Sr .

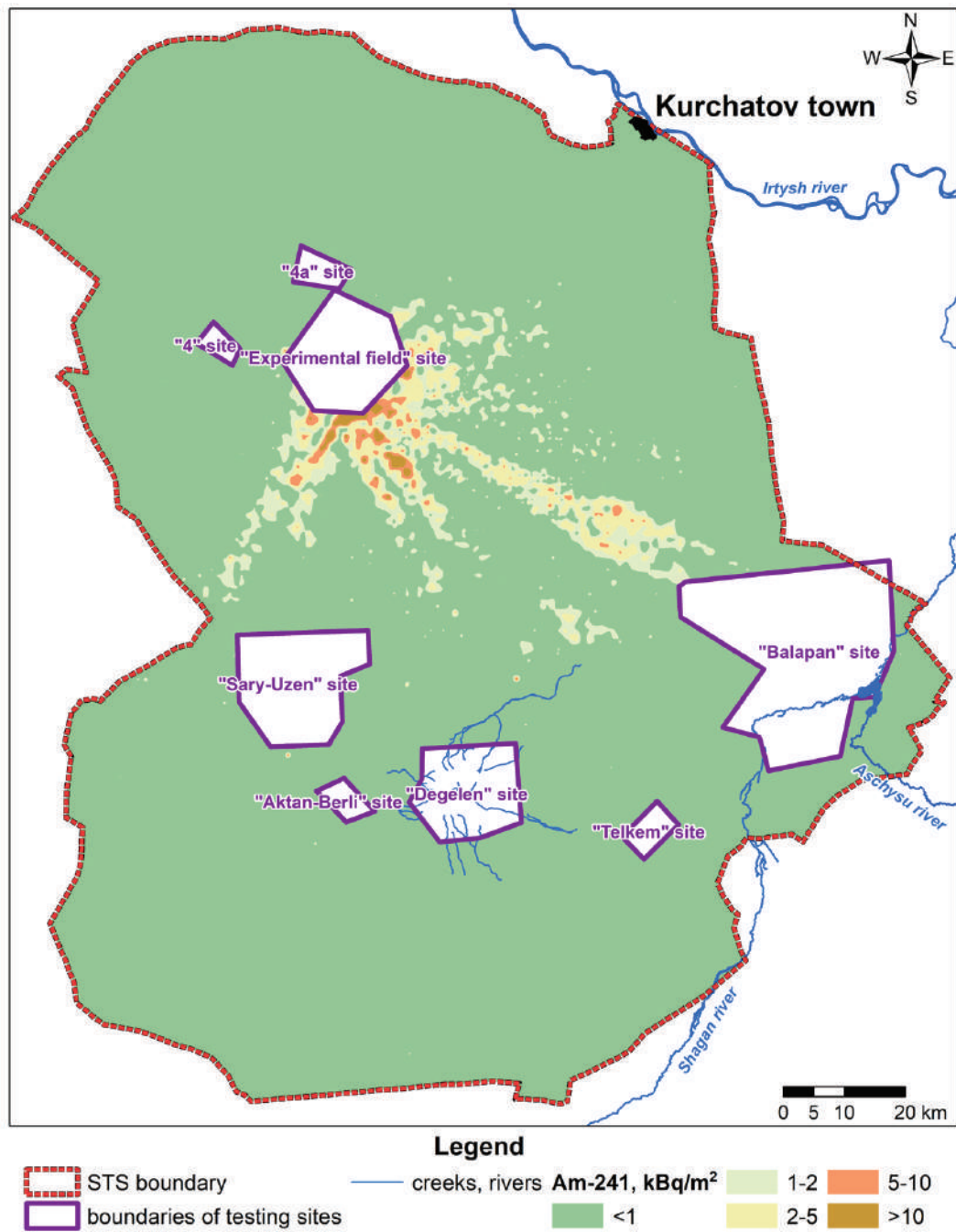


Figure 2.4. Distribution map of ²⁴¹Am areal activity in STS soil cover

Radioactive contamination of soil cover with ²⁴¹Am as opposed to the one with cesium and strontium is represented by a lot of areas as beams radially diverging from the ‘Experimental Field’ site. Such spatial distribution of ²⁴¹Am and, along with it, distributions of plutonium isotopes, were actually expected because aboveground nuclear tests that were largely conducted at the ‘Experimental Field’

site, were the major source of entry of these radionuclides into the earth's surface.

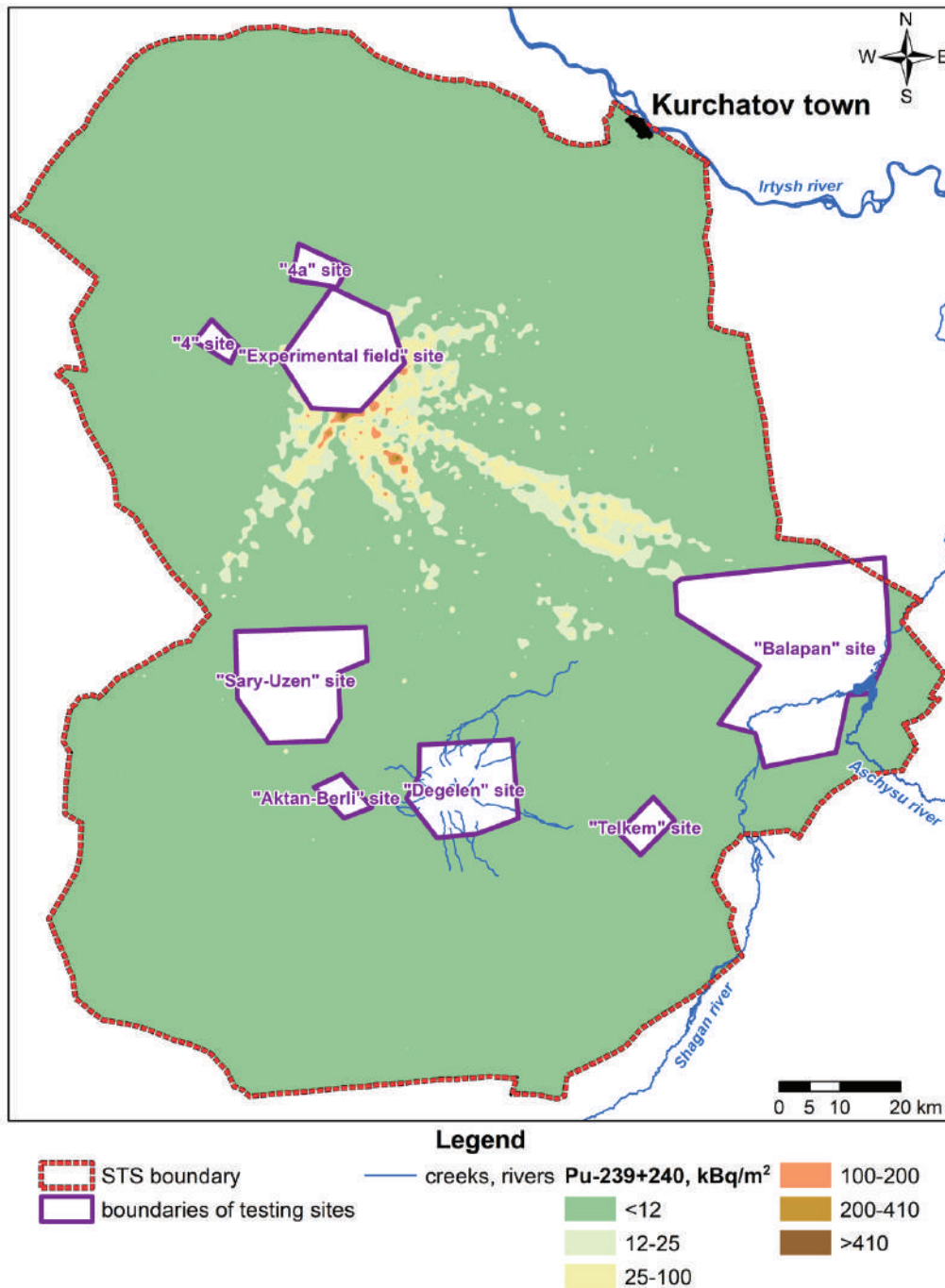


Figure 2.5. Distribution map of $^{239+240}\text{Pu}$ areal activity in STS soil cover

^{241}Am areal activity in plumes ranged from 1.0 to 78 kBq/m^2 . In the other territory – less than 1.0 kBq/m^2 .

$^{239+240}\text{Pu}$ areal activity in plumes ranged from 12 to 774.54 kBq/m^2 . In the other territory – less than 12 kBq/m^2 .

Background information. According to ‘Criteria for the assessment of environmental situation around territories’, areas in which ^{241}Am areal activity ranges from 0 to 490 kBq/m², refer to areas with ‘relatively satisfactory situation’, the one from 490 to 2,500 kBq/m² – to areas with ‘environmental emergency’, the one above 2,500 kBq/m² – to ‘ecological disaster’ areas. Areas in which $^{239+240}\text{Pu}$ areal activity ranges from 0 to 410 kBq/m², refer to areas with ‘relatively satisfactory situation’, the one from 410 to 2,080 kBq/m² – to areas with ‘environmental emergency’, the one above 2,080 kBq/m² – to ‘ecological disaster’ areas [51].

Measurements of ^{241}Am and $^{239+240}\text{Pu}$ showed that the test site (outside testing sites) has no areas in which the content of these radionuclides in soil according to classification ‘Criteria for the assessment of the environmental situation around territories’, exceeds levels when such areas can be referred to as ‘ecological disaster’ areas, and the total area of lands to be referred to as ‘environmental emergency’ areas is about 2 km² [51].

Conclusions

Thus, speaking of the radiological state of STS soil cover, one can state that outside of testing sites, there are areas of higher-than-normal surface radioactive contamination. These areas appeared due to fallout after aboveground nuclear tests.

2.4 Vertical distribution of radionuclides in the profile

Research into the vertical distribution of radionuclides in the profile provides an insight into their mobility in soil, which in turn defines the degree of biological availability of radionuclides to plants and further on through the food chain – to man.

Obviously, the penetration depth of artificial radionuclides resulted from nuclear explosions in soil cover depends on two main factors:

species, in this case in soils, and on soil type. Undoubtedly, there are other factors such as climatic conditions of the region, processes of radionuclide redistribution by plants and microorganisms, level of ground waters etc., but they all to a varying degree are really involved in forming soil cover making soil types diverse.

Therefore, it is necessary to say a few words about STS soil cover.

General information on soil cover of the test site

In soil-geographical terms, the STS territory covers two subzones of the steppe zone, namely, the subzone of dry steppes with the zonal subtype of chestnut soils and the subzone of desert steppes on light chestnut soils. Light chestnut soils are common in the central and southern parts of STS. These from the north, west and south are rimmed by a more humid subzone of chestnut soils [53].

Amidst zonal soils, the most common in the STS territory are underdeveloped soil geni. These are formed in flattened tops and slopes of bald peaks on thin illuvial-proluvial coarse skeletal deposits. Automorphic zonal normal and solonetzic soils, oftentimes along with automorphic sodic soils are formed in wide dry plains between bald peaks. In valleys of small rivers and creeks that split the hummocks, a genetic series of soil from hydromorphic excessively moistened to automorphic zonal can be observed. Here lower parts of the valley can be occupied by meadow and even swampy meadow soils. With distance from the bed, they are changed to semi-hydromorphic soils which to a variable degree can exhibit the process of salt accumulation. This series typically ends in zonal crushed stony soils in zones of friable deposits at bald peaks.

On denudation plains, zonal slightly loamy crushed stony soils largely prevail. These often exhibit signs of solonetzicity and salinification. Enclosed drainless depressions on plains and in hummocks are occupied by saline soils. Bottoms of such depressions

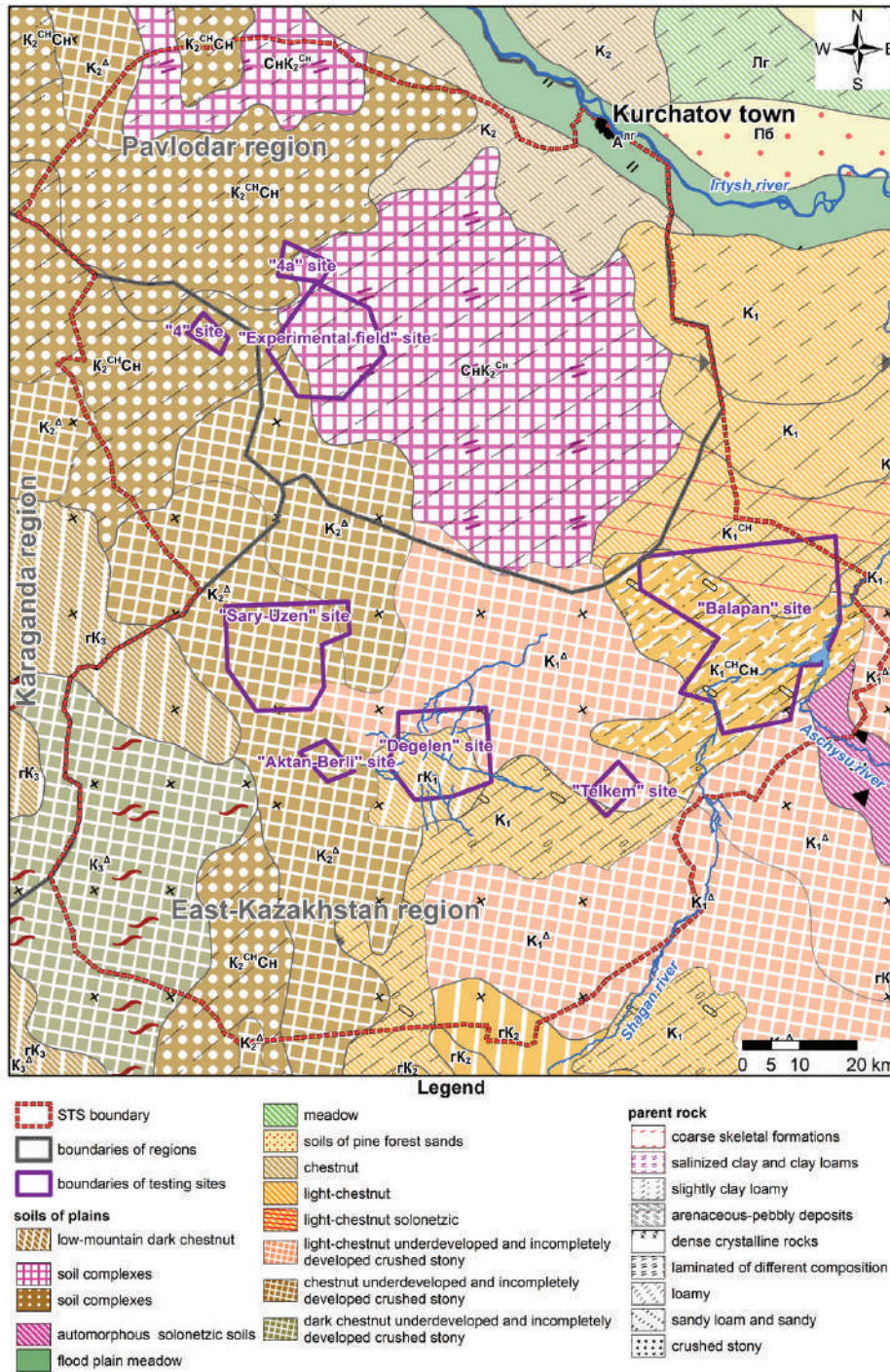
are rimmed by the zone of hydromorphic sodic soils combined with semi-hydromorphic zonal solonetzic-saline soils [54].

In the territory passing from the Kazakh Hummocks to the Near-Irtysh plain, complexes of zonal solonetzic soils with steppe sodic soils, which oftentimes dominate, have been common. The morphological profile of normal chestnut soils looks most like soils of chestnut type. The profile is clearly differentiated into genetic horizons. The thickness of humus horizon 'A+B' ranges from 35 to 45 cm. Calcareous horizon is just beneath humus horizon. Carbonates occur in the form of whitish blurry spots. Gypsum aggregations can be found in parent rock.

The content of organic matter in chestnut soils can reach 2.5-3.5 %. The upper profile of normal chestnut soils is carbonate-free. These soils all over the profile contain no marked quantities of readily soluble salts.

The central and eastern part of STS are occupied by light-chestnut soils, which are a more southern zonal subtype of the steppe zone. These have a steady developed profile characterized by thin humus horizon ('A+B' in loamy variants does not exceed 35 cm thick) and by a clear-cut division into brownish-grey with a stratified consistency and a crumbly weak structure of horizon 'A' and brownish-light-brown fragipan 'B'. Calcareous-illuvial duripan passing into parent rock occurs deeper. Effervescence by hydrochloric acid is noted within humus horizon. Upper horizons of light-chestnut soils contain about 2-2.5 % of humus. Test site soils being described largely have a light loamy mechanical composition and are notable for the elevated content of skeletal particles across the profile [55].

Amidst subtypes of chestnut and light-chestnut soils, carbonate, solonetzic and underdeveloped soil geni also occur in the test site area besides normal soils. Carbonate soils are predominantly common amidst soils of the chestnut subzone.



Soils and soil complexes: 1 - mountain - chestnut (Mc); 2 - chestnut solonchek along with steppe sodic soils ($Ch_2^{sl} \cdot Ss$); 3 - steppe sodic soils along with chestnut solonchek soils ($Ss \cdot Ch_2^{sl}$); 4 - meadow saline sodic soils along with meadow saline soils ($Sdm^{ss} \cdot Ssm$); 5 - chestnut underdeveloped (Ch_2^{\wedge}); 6 - saline sodic soils along with meadow - chestnut solonchek soils ($Sd^{ss} \cdot Chm^{sl}$); 7 - chestnut normal (Ch_2^n); 8 - meadow - chestnut solonchek along with steppe sodic soils ($Chm \cdot Sd$); 9 - light - chestnut solonchek soils along with steppe sodic soils ($Ch_1^{sl} \cdot Sd$); 10 - floodplain - meadow (Fm); 11 - steppe saline sodic soils combined with chestnut incompletely developed soils ($Sds^{ss} + Ch_2^{\wedge}$); 12 - chestnut soils along with steppe saline sodic soils combined with chestnut underdeveloped soils ($Ch_2 \cdot Sds^{ss} + Ch_2^{\wedge}$); 13 - chestnut underdeveloped soils combined with chestnut incompletely developed soils ($Ch_2 + Ch_2^{\wedge}$); 14 - chestnut underdeveloped crushed stony soils (Ch_2^{\wedge}); 15 - chestnut soils along with steppe saline sodic soils combined with meadow - chestnut soils ($Ch_2 \cdot Sds^{ss} + Chm$).

Figure 2.6. Schematic soil map of STS

The main diagnostic sign of chestnut and light-chestnut solonetzic soils is illuvial solonetzic horizon existing in their morphological profile. It sharply stands out by colour, density and structure having darker, brown tints, significantly compacted and with a crumbly-nuciform or nuciform-prism-like structure. Of physical and chemical indicators, first of all, the composition of absorbed bases in the solonetzic horizon should be noted. Its absorbed complex contains exchangeable sodium up to 15 % of the total amount. In addition, alkalinity in this horizon is strengthened, and the content of fine mechanical elements increases.

Underdeveloped chestnut and light-chestnut soils are formed along sloping tops and bald peak slopes, in places dense bedding rocks occur close to the surface, and the depth of the skeletonless layer does not exceed 40 cm. These soils' morphological profiles are shortened, with high content of crushed stone in soil mass and incomplete set of genetic horizons.

Meadow-chestnut soils are soils of semi-hydromorphic series. They are formed beneath meadow-steppe vegetation in depressed landforms, consequently, they are additionally moistened due to the occasional impact by shallow ground waters or the runoff. Developing themselves in more favourable conditions, they are different from zonal soils in somewhat thicker hummus horizon, in higher content of organic matter, hence, in a darker colour. These soils quite often exhibit signs of salinification and solonetzicity.

Meadow soils in the test site area are found in lower parts of valleys of small rivers and creeks. In particular, these are very common in floodplains of creeks at Degelen massif [56]. Ground waters occurring at a depth of 1-3 m are actively involved in their formation. In addition, they can undergo surface moistening by being water-logged in snowmelt and rainwater. Peculiar composition of meadow soils is defined by moistening conditions, mineralization level of ground waters, features

of parent rocks. However, the formation of thick humus horizon with high content of mold is characteristic of all meadow soils.

Sodic soils in the test site area are found in the form of complexes along with other soils. Of them, automorphic, semi-hydromorphic and hydromorphic types are distinguished. Sodic soil profiles are clearly differentiated into genetic horizons. Peculiarity of the morphological structure of the genetic sodic soil profile consists, first of all, in two upper horizons – eluvial and illuvial.

Eluvial or above-solonetzic horizon is usually coloured in lighter grey tints. It is weakly compacted, depleted with mineral and organic colloids and has a relatively light mechanical composition. Illuvial, solonetzic horizon is sharply separated from the upper one. Its colour is significantly darker. It is very strongly compacted, split by vertical cracks and has a prism-like, column or nuciform structure. Calcareous horizon is beneath solonetzic one with bright recently formed carbonates in the form of ‘loess with lime nodules’. Parent rock stands out deeper with clusters of readily soluble salts and gypsum.

Of physical and chemical features of sodic soils, higher exchange capacity in solonetzic horizon, up to 20 and more percent of the total absorbed bases should be noted. Reaction of soil solutions in this horizon rises to alkaline. The distribution of particle-size fractions in the vertical profile shows regularity that is inherent to sodic soils – the upper profile is depleted with silt particles, and their amount sharply increases in illuvial horizon. Solonetzic profiles commonly contain elevated amount of readily soluble salts.

Saline soils in the test site area are common in enclosed drainless depressions on the denudation plain and in the hummocks. They are formed by mineralized waters occurring at a shallow depth and due to salt input from surrounding areas by the runoff. The general distinctive feature of all saline soils are readily soluble salts in topsoil exceeding 1 % [57].

Research findings on the vertical distribution of radionuclides in the soil profile

To develop a methodology of studying the vertical distribution of radionuclides in the soil profile of the STS territory, research into the nature of vertical distribution of radionuclides in soils given their types, subtypes and geni were previously undertaken. As part of research mentioned, 47 research sites were prepared with soil sampled layerwise to be analyzed for radionuclides at intervals of 0-3, 3-6, 6-9, 9-12, 12-15, 15-18, 18-21, 21-24, 21-27, 27-30, 30-35, 35-40, 45-50 cm. In certain cases, on underdeveloped soils, intervals were 0-2, 2-5, 5-10, 10-15 cm. The sampling area of each layer within a research site was 200 cm². Sites were prepared given the distribution of soil contours and covered all the main types, subtypes and geni of soils in the STS territory (Figure 2.7).

Sites that were prepared covered the main types, subtypes and geni of chestnut soils as it is the type of chestnut soils that represents virtually the entire test site area (Table 2.4). In turn, two subtypes of chestnut soils that are the most common in the STS territory were noted. Each type is divided into three geni: underdeveloped, normal and solonetzic. These are subtypes of light-chestnut and chestnut soils. Less common mountain-chestnut and meadow-chestnut soils with geni were noted – nonsaline and saline. Saline soils were noted as an individual soil type.

Table 2.4. Systematics of soils of interest

Soil type	Soil subtype	Soil genus
Chestnut	Chestnut	Underdeveloped
		Normal
		Solonetzic
	Light-chestnut	Underdeveloped
		Normal
		Solonetzic
	Meadow-chestnut	Nonsaline
		Saline
	Mountain-chestnut	-
Saline soils	-	-

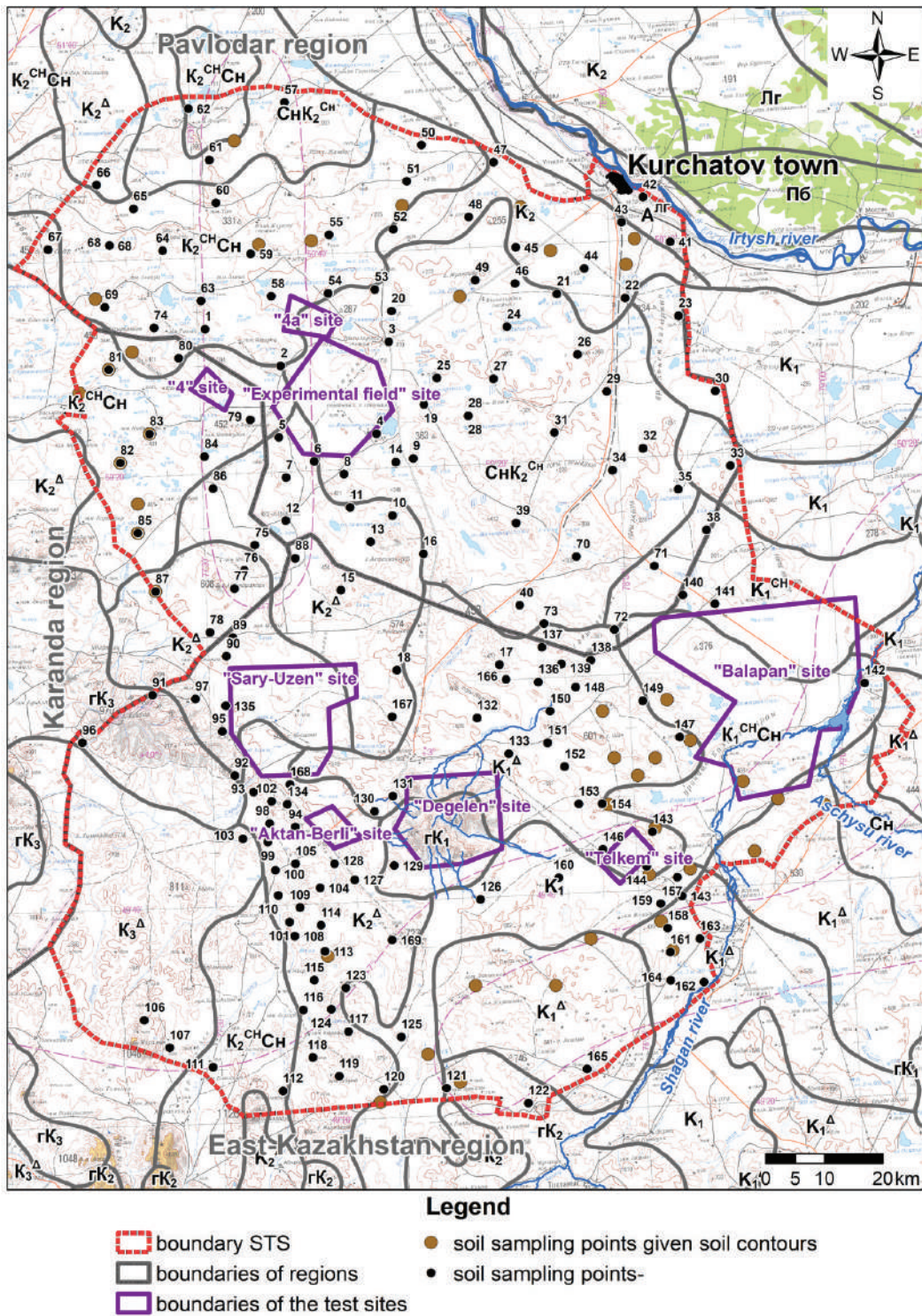


Figure 2.7. Schematic layout of sites with soil sampled layerwise in the STS territory

Findings describing the distribution of radionuclides in presented subtypes and variants of chestnut soils, illustrated that in areas themselves in which nuclear tests were not conducted, under conditions of nonpercolative water regime, artificial radionuclides and decay

products are mainly accumulated in epipedons and weakly migrate deep down the soil profile (Figure 2.8) [58].

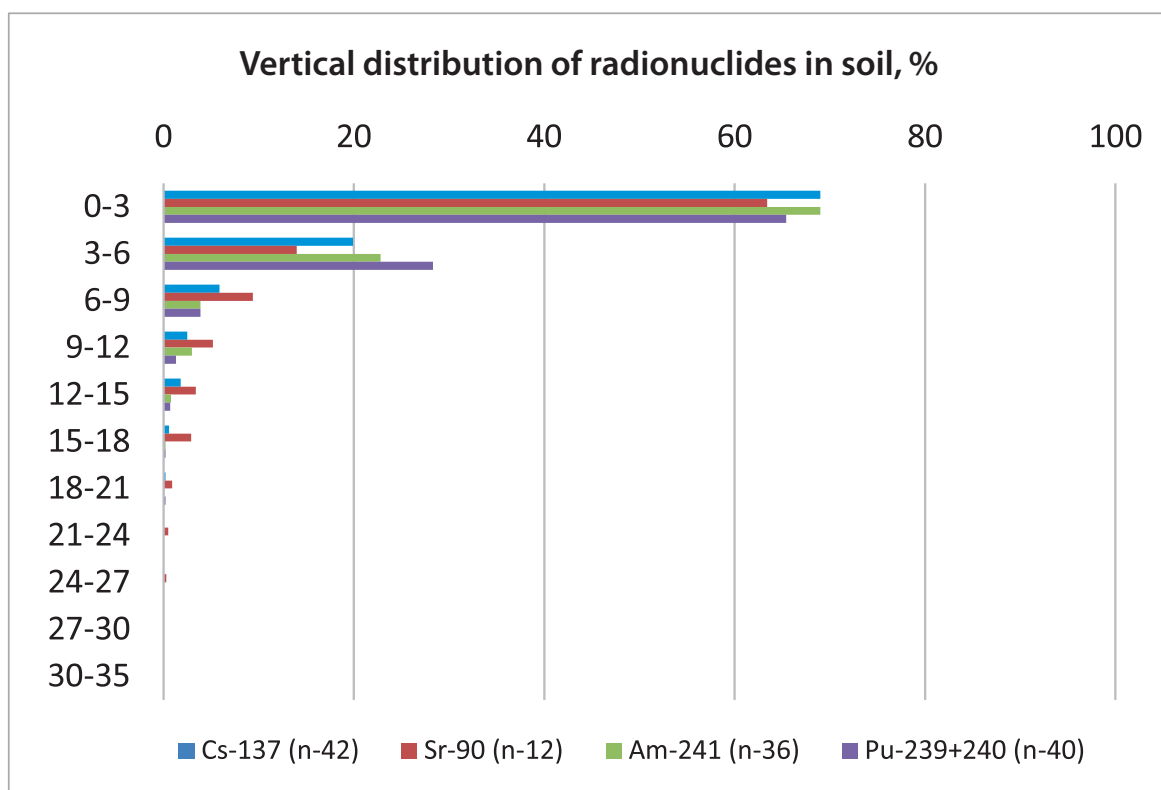


Figure 2.8. Nature of radionuclide distribution in soil down to 35 cm deep

Being formed under conditions of intense hydrothermal regime and high shortage of moisture only received due to precipitation, zonal chestnut and light-chestnut soils largely differ in shallow wetting from the surface. In this regard, the nature of radionuclide distribution in different soil subtypes is poorly differentiated. If we address functions describing the nature of radionuclides distribution in different soil subtypes, it is clear that they are sufficiently affined (Table 2.5). Thus, one can use functions derived from generalized data on the type of chestnut soils irrespective of the subtype for most of STS. Exceptions are meadow-chestnut soils found immediately around Degelen massif. If we compare functions derived from generalized data on the type of chestnut soils with the ones derived for saline soils, it is clear that they are similar for ^{137}Cs and $^{239+240}\text{Pu}$, whereas for ^{90}Sr these functions differ greatly.

Table 2.5. Curve functions of the vertical distribution of radionuclides in the type of chestnut soils

Radio-nuclide	Soil subtypes			Chestunt type	Saline soil
	light-chestunt	chestunt	meadow-chestunt		
¹³⁷ Cs	$y=(102\pm 11)e^{-(0,3\pm 0,03)x}$	$y=(85\pm 22)e^{-(0,4\pm 0,08)x}$	$y=(85\pm 12)e^{-(0,3\pm 0,03)x}$	$y=(125\pm 13)e^{-(0,4\pm 0,04)x}$	$y=(107\pm 19)e^{-(0,4\pm 0,05)x}$
⁹⁰ Sr	$y=(47\pm 10)e^{-(0,2\pm 0,05)x}$	$y=(51\pm 16)e^{-(0,2\pm 0,08)x}$	$y=(49\pm 11)e^{-(0,2\pm 0,09)x}$	$y=(79\pm 7)e^{-(0,3\pm 0,04)x}$	$y=(24\pm 5)e^{-(0,07\pm 0,06)x}$
²⁴¹ Am	$y=(76\pm 16)e^{-(0,3\pm 0,04)x}$	$y=(106\pm 14)e^{-(0,4\pm 0,04)x}$	$y=108e^{-0,3x}$	$y=(85\pm 12)e^{-(0,3\pm 0,03)x}$	-*
²³⁹⁺²⁴⁰ Pu	$y=(90\pm 16)e^{-(0,4\pm 0,05)x}$	$y=(128\pm 28)e^{-(0,4\pm 0,07)x}$	$y=34,1e^{-0,2x}$	$y=(126\pm 17)e^{-(0,4\pm 0,04)x}$	$y=(87\pm 16)e^{-(0,4\pm 0,008)x}$
*- no figures reported					

Thus, taking into account poor differentiation of the nature of radionuclide distribution, which can be due to measurement uncertainty, methodological uncertainties in field work and ignored factors that are impossible to identify at the time of sampling (long-term mixing of layers due to burrowers or farm animals etc.), arguably, it is sufficient to classify soil cover up to the soil type for assessing the distribution of radionuclides in the vertical soil profile. In particular, the STS territory is represented by the chestnut soil type. Saline soils found in the study area, are not typically used in agriculture, and the main soils on which cattle is grazing at STS, by virtue of abundance, are chestnut and light-chestnut soil subtypes. Besides, it was found that in soils of areas that do not refer to testing sites, radionuclides are concentrated in topsoil and are mostly detectable as deep as 15-20 cm. This fact allows the survey of STS areas to be optimized by limiting soil cover research depth to 30 cm and due to no need for dividing the territory into soil subtypes. The research depth chosen allows the nature of radionuclide distribution to be reliably identified in the vertical profile of soils in

study areas and exclude sampling from disturbed soil lots. Activity concentration for the 0-20 cm layer is converted at a depth of 0-5 cm (soil sampling depth during the areal survey). Therefore, the interval advised for layerwise sampling was 5 cm.

Taking into account the above findings, 169 research sites were prepared with samples collected layerwise to be analyzed for radionuclides at intervals of 0-5, 5-10, 10-15, 15-20, 22-25, 25-30 cm for identifying the nature of vertical distribution of radionuclides in the STS territory. Thus, to study features of the vertical distribution of radionuclides in soils, 1,014 stratified soil samples were collected. Sites were prepared based on one site per 100 square kilometers. The sampling area of each soil layer was 200 cm². Initially, soil in STS areas located in Pavlodar and Karaganda regions, was sampled relative to the uniform grid. In such approach, quantitative values of the activity concentration of radionuclides in soil samples were not always successfully registered. Therefore, subsequently, sites of stratified soil samples in the East Kazakhstan region were mainly prepared in fallout plumes from nuclear tests to obtain a large amount of figures. Based upon results of studied distribution of the areal activity of radionuclides in soil cover, spots in areas of conventionally elevated values (fallout plumes from nuclear tests) and in the conventionally 'background' territory (the study area except testing sites and fallout plumes) were noted.

To determine activity concentrations of ²⁴¹Am, ¹³⁷Cs, ²³⁹⁺²⁴⁰Pu, ⁹⁰Sr in soil samples, γ -spectrometry and radiochemical analyses were carried out as per standardized guidelines with calibrated equipment [59, 60].

Mean values and ranges of activity concentrations of radionuclides in soil layers down to 30 cm derived at stratified soil sampling points in regions of conventionally elevated values and in the conventionally 'background' territory, are listed in the table (Table 2.6).

Table 2.6. Activity concentrations of radionuclides in the study area in soil layers as deep as 30 cm

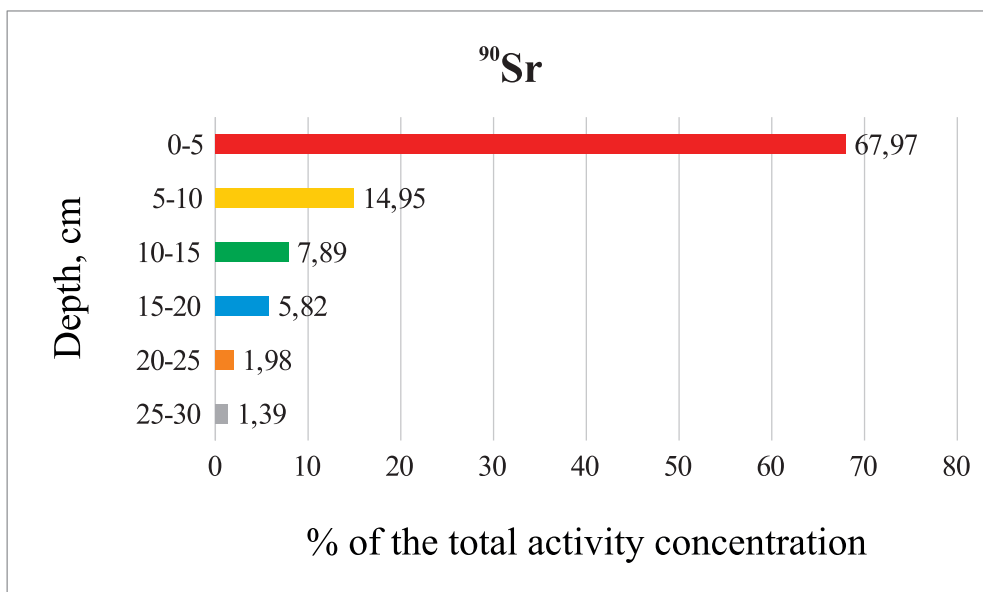
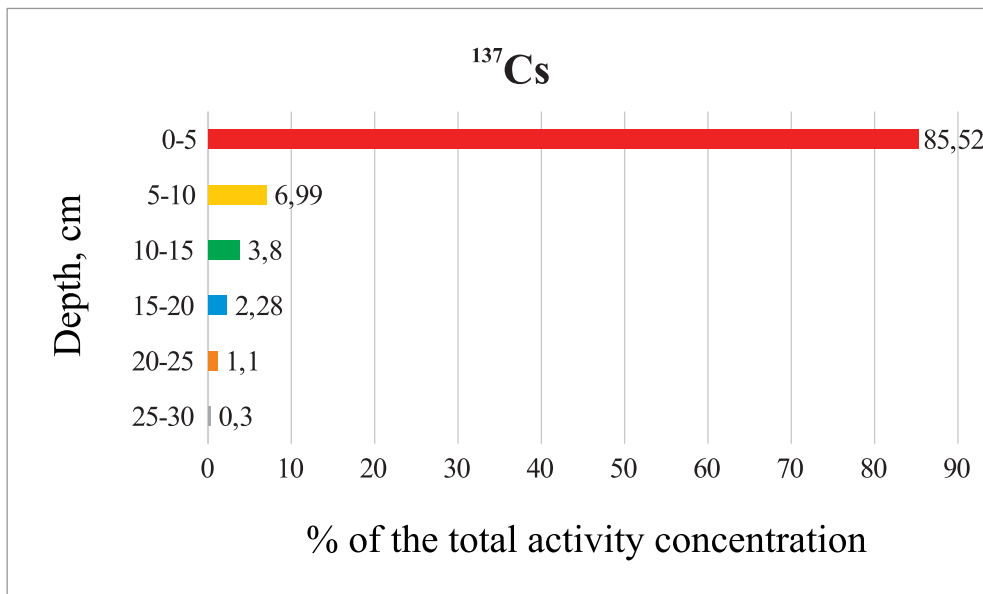
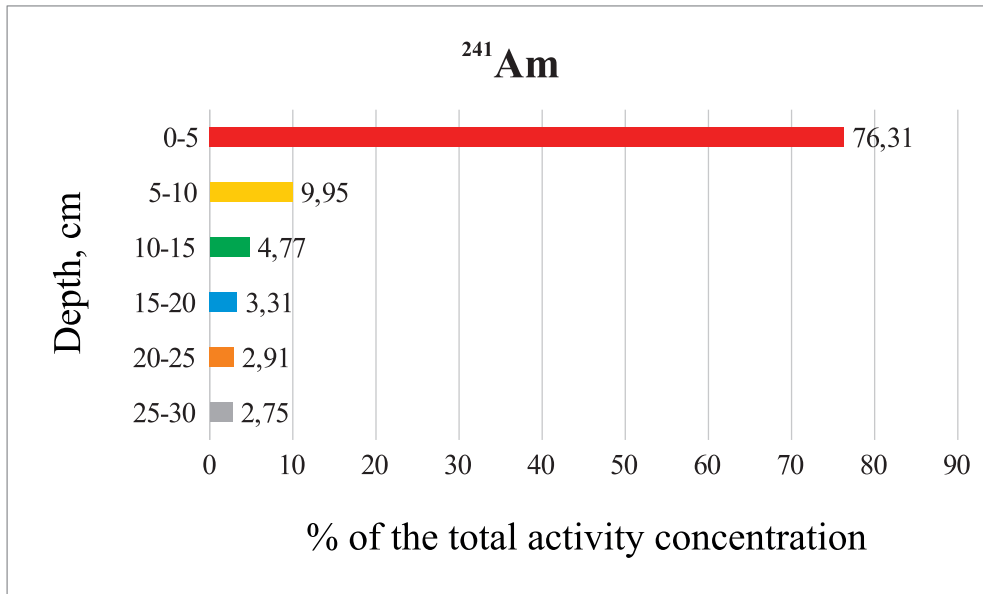
Depth, cm	Activity concentration, Bq/kg			
	²⁴¹ Am	¹³⁷ Cs	²³⁹⁺²⁴⁰ Pu	⁹⁰ Sr
Regions of elevated values (n=79)				
0-5	$\frac{32 \pm 7}{2 - 81}$	$\frac{124 \pm 33}{5 - 610}$	$\frac{549 \pm 196}{12 - 3600}$	$\frac{46 \pm 14}{3 - 230}$
5-10	$\frac{2 \pm 0,5}{0,3 - 8}$	$\frac{10 \pm 3}{0,7 - 63}$	$\frac{25 \pm 9}{0,4 - 160}$	$\frac{18 \pm 8}{1 - 147}$
10-15	$\frac{1 \pm 0,4}{0,1 - 8}$	$\frac{2 \pm 0,8}{0,2 - 32}$	$\frac{11 \pm 6}{0,2 - 110}$	$\frac{8 \pm 4}{1 - 72}$
15-20	$\frac{0,7 \pm 0,1}{0,1 - 3}$	$\frac{1 \pm 0,3}{0,1 - 8}$	$\frac{3 \pm 2}{0,1 - 40}$	$\frac{10 \pm 4}{0,8 - 64}$
20-25	$\frac{0,7 \pm 0,08}{0,1 - 2}$	$\frac{0,9 \pm 0,3}{0,1 - 11}$	$\frac{2 \pm 1,7}{0,1 - 25}$	$\frac{13 \pm 8}{1 - 148}$
25-30	$\frac{0,75 \pm 0,1}{0,1 - 2}$	$\frac{0,51 \pm 0,1}{0,1 - 2}$	$\frac{7 \pm 5}{0,1 - 69}$	$\frac{8 \pm 4}{1 - 64}$
Conventionally 'background' areas (n=90)				
0-5	$\frac{4 \pm 1}{0,3 - 48}$	$\frac{20 \pm 4}{3 - 210}$	$\frac{108 \pm 54}{0,2 - 750}$	$\frac{9 \pm 3}{0,7 - 90}$
5-10	$\frac{1 \pm 0,2}{0,1 - 6}$	$\frac{4 \pm 1}{0,3 - 35}$	$\frac{15 \pm 5}{0,2 - 64}$	$\frac{5 \pm 2}{0,1 - 29}$
10-15	$\frac{0,9 \pm 0,1}{0,1 - 3}$	$\frac{1 \pm 0,3}{0,2 - 5}$	$\frac{8 \pm 3}{0,1 - 49}$	$\frac{4 \pm 0,9}{0,2 - 11}$
15-20	$\frac{0,4 \pm 0,05}{0,1 - 0,9}$	$\frac{0,6 \pm 0,2}{0,1 - 2}$	$\frac{3 \pm 1}{0,1 - 21}$	$\frac{3 \pm 1}{0,1 - 22}$
20-25	$\frac{0,4 \pm 0,05}{0,1 - 0,7}$	$\frac{0,7 \pm 0,2}{0,1 - 3}$	$\frac{0,9 \pm 0,3}{0,1 - 6}$	$\frac{4 \pm 1}{0,1 - 18}$
25-30	$\frac{0,4 \pm 0,07}{0,1 - 1}$	$\frac{0,4 \pm 0,05}{0,1 - 1}$	$\frac{3 \pm 2}{0,1 - 47}$	$\frac{2 \pm 0,5}{0,8 - 7}$
In the numerator – arithmetic mean, error of arithmetic mean. In the denominator – minimum and maximum activity concentration				

Based upon findings value ranges of activity concentrations in soil of the study area for $^{239+240}\text{Pu}$ and ^{90}Sr were found to average two orders of magnitude, for ^{241}Am – one order of magnitude. Ranges of ^{137}Cs activity concentrations in regions of elevated values are two orders of magnitude, in the conventionally ‘background’ area – one order. The highest activity concentration in soil of regions of elevated values and in the conventionally ‘background’ area is noted for $^{239+240}\text{Pu}$ (3,600 and 750 Bq/kg) and ^{137}Cs (610 and 210 Bq/kg), lower concentrations are characteristic of ^{90}Sr (230 and 90 Bq/kg), the content of ^{241}Am is minimum and does not exceed 81 and 48 Bq/kg, respectively. At the same time, maxima of activity concentrations of radionuclides are characteristic of nuclear fallout plume areas and are noted in the soil layer down to 5 cm deep.

To determine the percentage of radionuclides in each soil layer, the total activity concentration across the soil profile depth was calculated. The average total activity concentrations across the soil profile depth for $^{239+240}\text{Pu}$, ^{137}Cs , ^{90}Sr and ^{241}Am were: in the territory of conventionally elevated values – 627 Bq/kg, 145 Bq/kg, 109 Bq/kg and 39 Bq/kg; in the conventionally ‘background’ territory – 121 Bq/kg, 34 Bq/kg, 33 Bq/kg, 9 Bq/kg, respectively.

According to findings, histograms of ^{241}Am , ^{137}Cs , $^{239+240}\text{Pu}$, ^{90}Sr vertical distribution in the soil profile of the study area were built (Figure 2.9).

As you can see from histograms, maxima of activity concentrations in the entire study area are noted for the 0-5 cm layer being for ^{241}Am – 76 %, ^{137}Cs – 86 %, $^{239+240}\text{Pu}$ – 84 % and ^{90}Sr – 68 %. The content of radionuclides in the 0-20 cm tilth topsoil, which has most of cultivated plant roots, is for ^{241}Am – 94 %, ^{137}Cs – 99 %, $^{239+240}\text{Pu}$ and ^{90}Sr – 97 %. Minimum concentration of radionuclides is observed at a depth of 20-30 cm and is for ^{241}Am – 6 %, for ^{137}Cs – 1 %, for $^{239+240}\text{Pu}$ and ^{90}Sr – 3 %.



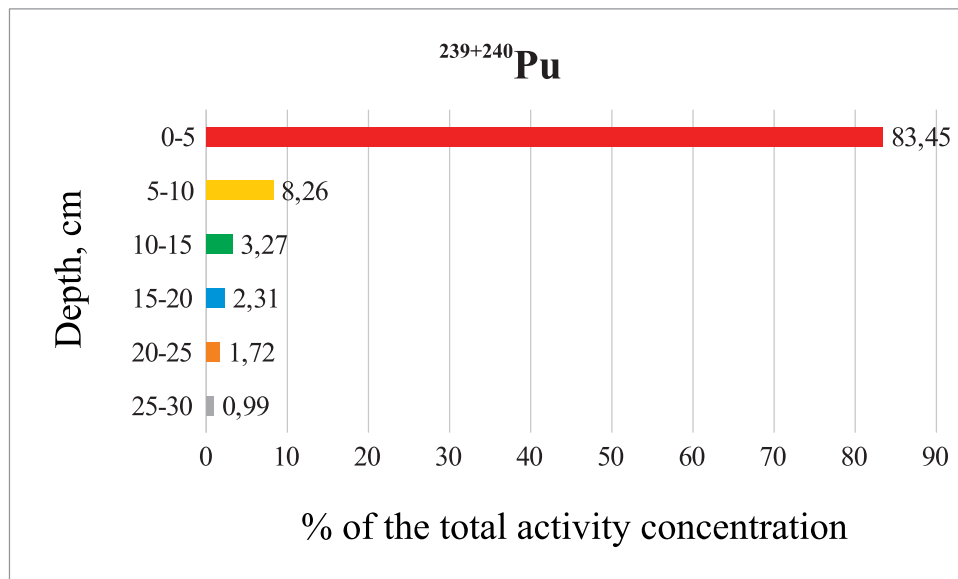


Figure 2.9. Vertical distribution of radionuclides in the soil profile

Follow-up research into the vertical distribution of radionuclides in the soil profile

In addition to the concept of the penetration rate of radionuclides in STS soils, findings can be used to calculate the entry of radionuclides into crop products.

If the test site, naturally its safe part, is populated, one has to make sure that it poses no hazard to man, and the human exposure dose when living there does not exceed regulatory values. At the same time, one component contributing to the exposure dose are foodstuffs including crop products cultivated at the test site.

However, since no crop products are currently produced in the STS territory, because nobody is living there, the content of radionuclides in crop products to be cultivated at the test site, was assessed by calculation. This technique is based upon the use of factors of the accumulation (transfer) of radionuclides by plants. Since transfer factors used in the global practice for assessing radioactive contamination of plants are calculated for the 0-20 cm soil layer [60], data on the content of radionuclides in the soil layer as deep as at least 20 cm was used.

Values, obtained for activity concentrations of radionuclides in soil layers as deep as 20 cm at 169 points of stratified soil sampling, allow derivation of a sufficiently reliable coefficient for each radionuclide. This coefficient defines the ratio of the activity of a radionuclide in the 0-20 cm soil cover layer to the activity concentration of a radionuclide in the 0-5 cm topsoil. In turn, this coefficient makes it possible to calculate activity concentrations of radionuclides at 0-5 cm deep when obtained in determining the areal distribution of radionuclides to a depth of 0-20 cm. These activity concentrations are necessary for further assessment of potential concentrations of radionuclides in crop products.

Values of coefficient $K_{n,0-20}$ were calculated as per the formula:

$$K_{n,0-20} = \frac{A_{m,i,0-20}}{A_{m,i,0-5}},$$

where:

$K_{n,0-20}$ – a coefficient defining the ratio of the activity concentration of a radionuclide in the 0-20 cm soil cover layer to the one in the 0-5 cm topsoil;

$A_{m,i,0-20}$ – the activity concentration of a radionuclide in the 0-5 cm soil cover layer, Bq/kg;

$A_{m,i,0-5}$ – the activity concentration of a radionuclide in the 0-20 cm soil cover layer, Bq/kg.

Mean values and ranges of $K_{n,0-20}$ at 169 points of stratified soil sampling are listed in the table (Table 2.7).

Table 2.7. Values of the coefficient defining the ratio of the activity of a radionuclide in the soil cover layer as deep as 20 cm to the one in the topsoil

	$K_{n,0-20}$			
	^{241}Am	^{137}Cs	$^{239+240}\text{Pu}$	^{90}Sr
Maximum	2,8	1,8	1,7	1,4
Minimum	0,1	0,2	0,2	0,2
Arithmetic mean	0,3	0,3	0,3	0,4

Activity concentrations of radionuclides in the 0-20 cm soil cover layer were determined from the areal sampling data (Section 2.2.1) and from mean values of $K_{n,0-20}$, which were for ^{241}Am – 0.6, for ^{137}Cs – 0.9, for $^{239+240}\text{Pu}$ – 0.7, for ^{90}Sr – 0.9, as per the formula:

$$A_{m,i,0-20} = K_{n,0-20} \times A_{m,i,0-5}$$

where:

$A_{m,i,0-20}$ – the activity concentration of a radionuclide in the soil cover layer as deep as 20 cm, Bq/kg;

$K_{n,0-20}$ – a coefficient defining the ratio of the activity of a radionuclide in the 0-20 cm soil cover layer to the one in the 0-5 cm soil cover layer;

$A_{m,i,0-5}$ – the activity concentration of a radionuclide in the 0-5 cm topsoil, Bq/kg.

Maxima, minima and means of activity concentrations of radionuclides in the 0-20 cm soil layer for each survey point of areal distribution of radionuclides are provided in the table (Table 2.8).

Table 2.8. Activity concentrations of radionuclides in the 0-20 cm soil layer, Bq/kg (based upon the data on each point of the areal survey grid – over 20,000 points)

	Activity concentrations of radionuclides in the 0-20 cm soil layer, Bq/kg			
	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}$
Maximum	$5,0 \times 10^4$	$4,0 \times 10^4$	$3,1 \times 10^4$	$4,3 \times 10^5$
Minimum	0,01	0,01	0,01	0,08
Arithmetic mean	25	74	342	$1,1 \times 10^3$

Conclusions

Thus, research undertaken into the vertical distribution of radionuclides in the soil cover of STS areas allowed definition

of the distribution nature of radionuclides in soil of these areas and calculation of coefficients that define the ratio of the activity concentration of a radionuclide in the 0-20 cm soil cover layer to the one in the 0-5 cm topsoil. Coefficients derived made it possible to calculate activity concentrations of radionuclides in the soil cover layer down to 20 cm deep at each survey point of the areal distribution of radionuclides. This data was subsequently applied in calculating the content of radionuclides in crop products, if raised at the test site. Calculation results were used in assessing public internal exposure doses at intake of radionuclides with foodstuffs produced in the study area.

2.5 Research into species of artificial radionuclides in soils

As part of research into the nature of radioactive contamination of STS soil cover, research into species of artificial radionuclides in soils were additionally undertaken. Element species are understood to be the distribution of an element amidst its chemical forms in the system. Findings on ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$, ^{241}Am species in STS soils allow assessment of their mobility and bioavailability.

Research into species of these radionuclides in soils was undertaken using a modified procedure for sequential extraction proposed by F. Pavlotskaya. This procedure provided for determination of the exchangeable and non-exchangeable (acid-soluble and tightly bound) forms of radionuclides in soil [62, 63]. The procedure was modified by adding an intermediate stage to determine organically bound radionuclides with a 0.1 NaOH solution based upon the procedure developed by I. Tyurin. [64].

As per the soil sampling methodology, areas of elevated concentrations of radionuclides under study in soil (fallout plumes of aboveground tests) and zones of background levels of concentrations were researched.

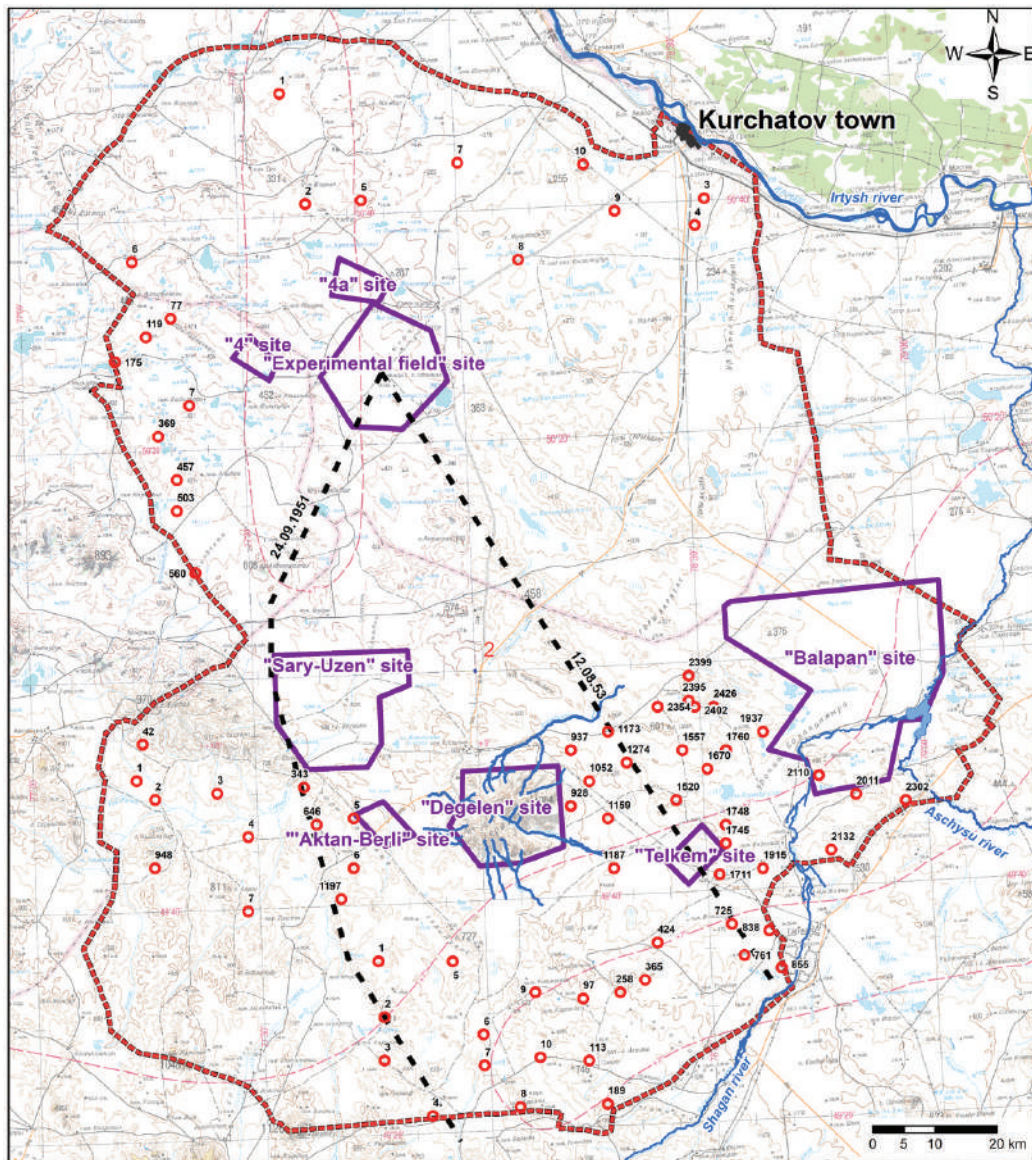
Table 2.9. Sequential extraction procedure

Form	Extractant	Group of compounds
Water-soluble + Exchangeable form (readily available form)	1M CH ₃ COONH ₄ (pH=6,8)	Water-soluble salts of inorganic acids and organic compounds (salts, complexes), unbound element fulvates, compounds sorbed by soil through the ion-exchange mechanism, partly carbonates in carbonate soils
Organic form (potential reserve)	0.1M NaOH	Bound with the organic constituent (fractions of humic and fulvic acids), free or loosely bound with the mineral soil constituent
Acid-soluble form (potential reserve)	1M HCl	Carbonates, compounds of an element loosely sorbed by ferrum and aluminum oxides, clay minerals, fulvates, hardly exchangeable ions, recently sedimented hydroxides
Tightly bound form (residual, unavailable form)	-	Incorporated in ferrum and aluminum sesquioxides, ions tightly bound (non-exchangeably) by soil organic matter, adsorbed by the type of isomorphic replacement in crystalline lattices

In STS soils, both beyond and within testing sites, ¹³⁷Cs is characterized by a low mobility. Beyond sites, in areas of elevated concentrations of radionuclides in soils (fallout plumes of aboveground tests) and in zones of background levels of concentrations of radionuclides, the content of ¹³⁷Cs in the tightly bound form averages 96 %.

²³⁹⁺²⁴⁰Pu, similarly to ¹³⁷Cs, is also characterized by a low mobility. The bulk of ²³⁹⁺²⁴⁰Pu in soils of all STS objects investigated was determined to be in the tightly bound form. Both in areas of

elevated concentrations of radionuclides in soils (fallout plumes of aboveground tests) and in zones of background levels of concentrations of radionuclides, the fate of the tightly bound form of $^{239+240}\text{Pu}$ averages 99 %. Obtainment of data on species of transuranic radionuclide ^{241}Am in soils beyond testing sites failed due to its low activity concentration.



Legend

- STS boundary
- boundaries of testing sites
- axis of a passing plume
- sampling points

Figure 2.10. Schematic arrangement of soil sampling points to research into species of radionuclides in soils

^{90}Sr is the most mobile of all radionuclides under discussion. According to the data on ^{90}Sr distribution, a difference in the nature of contamination of STS soil cover with radionuclides was found beyond testing sites. For example, in areas unaffected by fallout of aboveground tests (the northern and western STS part), its mobility is the highest. The fate of the exchangeable form accounts for at least 60 % (the northern area) and 40% (the western area) of the total content of all ^{90}Sr forms, the fate of the tightly bound form is 23 % and 33 % at most, respectively. The passing fallout plume of aboveground tests had a certain impact on the southeastern, southern and, least of all, southwestern STS part. In the southeastern area, the average content of the exchangeable form of ^{90}Sr is reduced to 31 %. The tightly bound form is less than 46 %. In the southern area, the influence of the plume is more pronounced: the fate of the exchangeable form here is minimum – 15 %, and the fate of the tightly bound form is maximum for zones under discussion averaging 74 % of the total content of all forms. The data on the content of species of radionuclides is noted to vary to the maximum extent, which is attributed to the nonuniform nature of soil contamination with radionuclides.

Directly in the zone of fallout plumes, ^{90}Sr behavior differs essentially [65]. The tightly bound form, the content of which reaches 98 % in the southeastern and 89 % in the southern area, begins to dominate. The average value of the fate of ^{90}Sr exchangeable form in the plume zone of the southeastern area decreases by an order of magnitude relative to the area beyond the plume zone, and in the southern STS part – by more than 3 times. The distribution nature of species of radionuclides in zones of fallout plumes of aboveground tests is similar to the one at the ‘Experimental Field’ site.

A variation was revealed in ^{90}Sr species in the fallout plume of the fusion test on August 12, 1953 with distance from the ground zero when studying the distribution nature of radionuclides along fallout plumes (Figure 2.11).

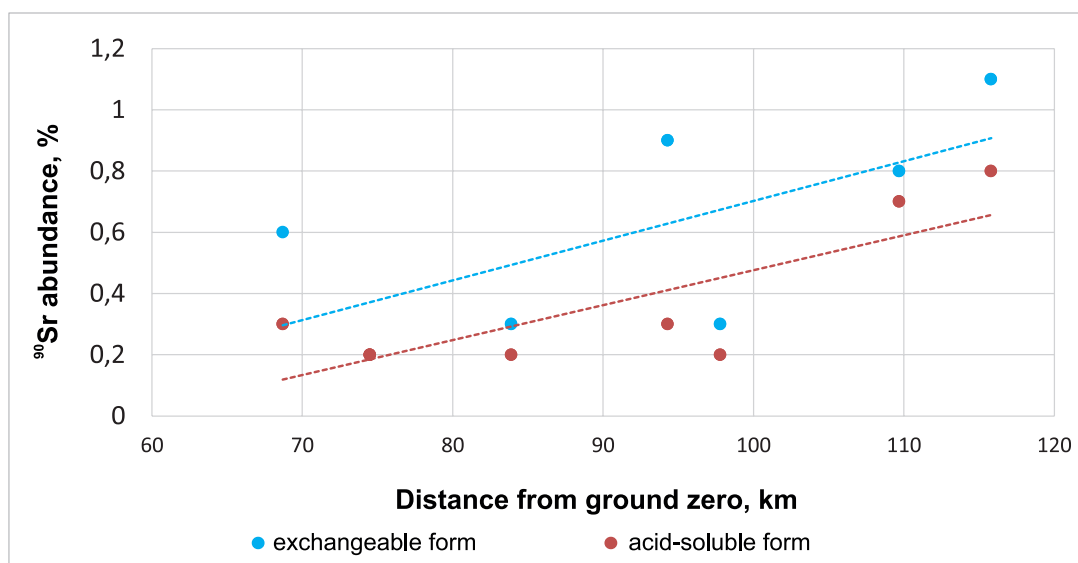


Figure 2.11. Variation in ^{90}Sr species in soil along the axis of the fallout plume of the aboveground test on August 12, 1953 in the southeastern STS territory

In the plume area (70-120 km from ground zero) of the fusion explosion, with increasing distance, the fate of the exchangeable and acid-soluble ^{90}Sr form in soil was found to rise. This regularity is attributed to fractionation processes of radionuclides and formation mechanisms of radioactive particles in atmospheric explosions [66, 67]. The regularity that was revealed is consistent with findings on increased parameters of the accumulation of radionuclides by zonal plants along the axis of this plume as the distance from ground zero increases [68].

Conclusions

Thus, in the STS territory (beyond testing sites) ^{137}Cs and $^{239+240}\text{Pu}$ are mainly contained in the tightly bound form. The distribution of ^{90}Sr species in areas unaffected by fallout of aboveground explosions is classical, i.e. the bulk of the radionuclide is incorporated in the exchangeable and acid-soluble forms. In areas affected by fallout of aboveground explosions and directly in plume zones, the distribution nature corresponds to the one characteristic of the ‘Experimental Field’ site, i.e. ^{90}Sr is mostly concentrated in the tightly bound form. Regularities revealed in the distribution of

species of radionuclides in soils of the investigated STS background part, are very likely to be common to the rest of the unsurveyed STS background territory irrespective of a soil type, since the origin of radioactive contamination has the major impact on the distribution of species of radionuclides.

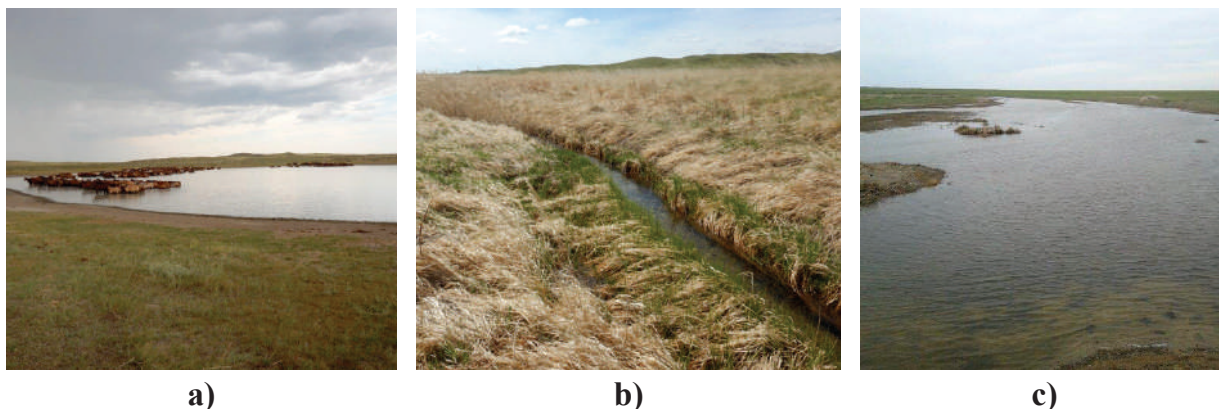
2.6 Radiological state of aquatic medium

To perceive the materials presented conveniently, information on the radiological state of aquatic medium at the test site is divided into two parts: surface and ground waters of STS.

Obviously, if a portion of test site lands is released to the economic use, surface water sources will be in demand first of all. However, because such sources are limited, special attention should be paid to ground waters that will be collected from wells or boreholes as indicated by numerous remainders of such structures that operated prior to the nuclear test site construction.

Surface waters

The test site territory refers to the insufficiently moistened zone with a relatively low precipitation and absolutely poor in surface waters. The hydrographic network of surface waters is represented by few rivers, lakes and shallow unnamed creeks having temporary streams related to spring floods and periods of abundant rainfall.



**Figure 2.12. Types of surface waters in the STS territory:
a) Unnamed lake b) Creek c) the Shagan river**

Creeks of the study area have surface water streams only during the spring flood. Their beds extend as far as 18-20 km. The runoff is produced and replenished by winter precipitation during the snowmelt. Summer rainfall hardly contributes to this because most of it is evaporated. The spring flood accounts for up to 95 % of the annual runoff, the summer-spring low-water – for about 5 %. In the period of the summer low-water, significant losses of surface waters to recharge aquifers are observed in lower reaches of creeks. The activity of surface waters stops, and even the runoff completely ceases [69, 70, 71, 72, 73, 74].

Lakes are shallow saucer-like hollows with shallow pits of low banks and refer to small lakes as large as 10 km². Their depths do not normally exceed 0.7 m. Recharging occurs by precipitation and snowmelt runoffs from small local basins. The fate of ground water runoff in the recharge is typically low and, sometimes, there is none at all. In the arid period, most lakes dry up forming sodic or grassy depressions, and in larger ones, water persists all the year. However, they sometimes dry up after several years of lack of water [69, 70, 71, 72, 73, 74].

The STS territory has a few rivers: the Shagan river with Aschysu tributary as well as shallower rivers like Karasu and Saryozen. These rivers within the test site extend for 11-64 km. The continuous runoff in river beds only persists in spring and only on years of heavy snowfall. In other seasons, water only persists in certain broads. No underground or only a minor recharge of rivers in the summer-autumn period [69, 70, 71, 72, 73, 74].

Lakes, creeks and rivers both distant and close to boundaries of testing sites were selected as objects of research into surface waters. The survey included sections of the Shagan river beyond the ‘Balapan’ site and creeks originating from and flowing beyond the ‘Degelen’ testing site: Uzynbulak, Karabulak, Baitles, Toktakushyk and Aktybai.

Water bodies were located by interpreting high-resolution satellite images as well as using hydrologic terrain maps. Next, field visits were made to sample water.

In the course of the long-term survey of surface waters, water was sampled from 130 water bodies.

The main difficulty in researching into surface waters is that most of selected objects are seasonal intermittent saline lakes and temporary water streams of intermittent rivers.

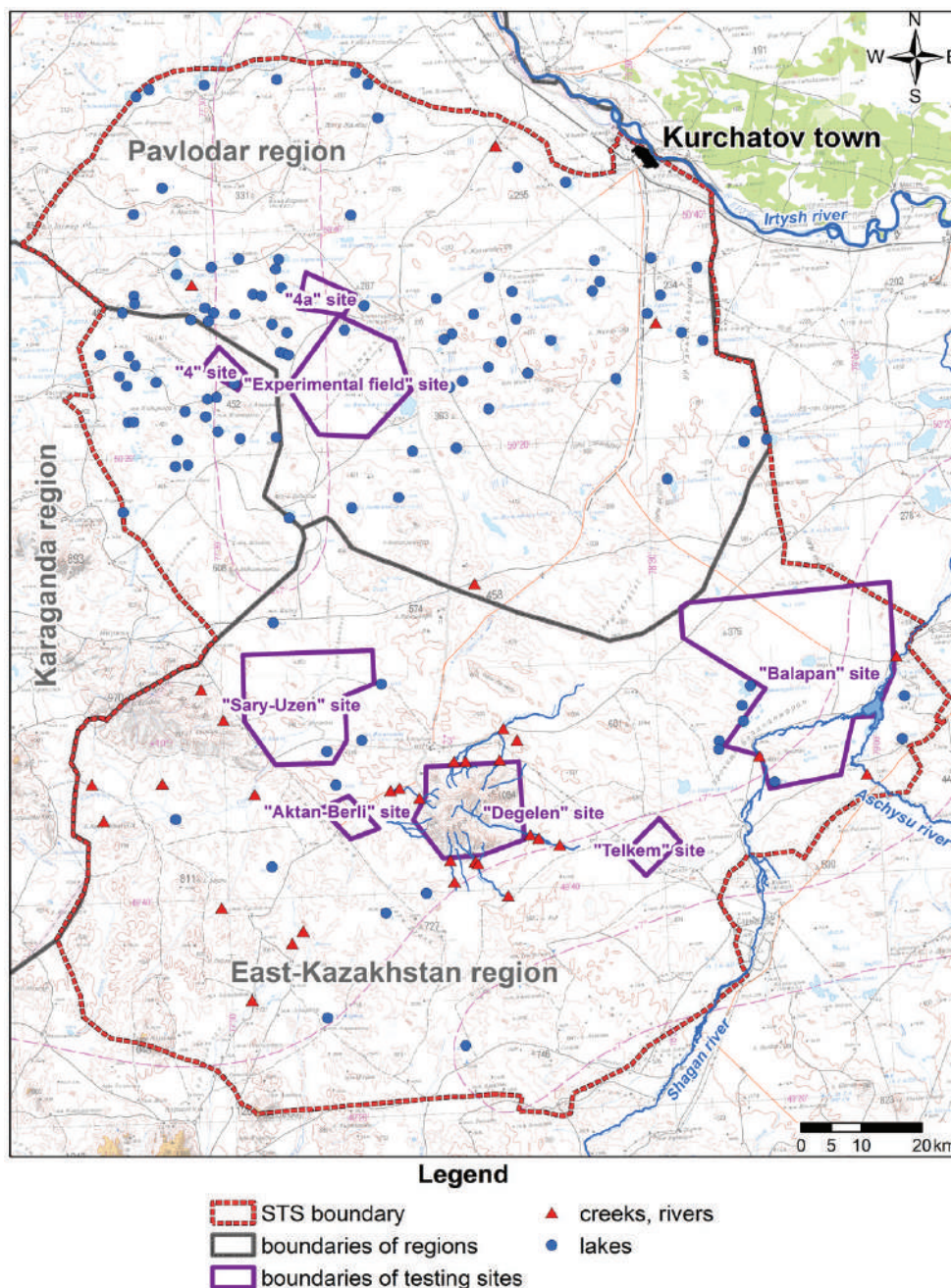


Figure 2.13. Soil sampling spots



Figure 2.14. Surface water sampling

This entails ambiguity in interpreting results. For example, flood waters in the spring period and rainwater in the summer and autumn period are a source of water in regularly intermittent water bodies. Initially, these waters contain no artificial radionuclides. That is to say, ‘zero’ radioactivity of water is knowingly determined by measuring the content of radionuclides in seasonal water bodies, as it is not anyhow related to nuclear consequences. The redistribution process of radionuclides in the ‘bottom sediments-water-bottom sediments’ system can be neglected due to a high sorption capacity of the latter.

Nevertheless, according to findings, in 115 of tested surface water samples collected at a distance from the ‘Balapan’ and ‘Degelen’ sites, activity concentrations of ^3H , ^{90}Sr , ^{137}Cs , ^{241}Am and $^{239+240}\text{Pu}$ are below values of the minimum detectable activity without exceeding the intervention level as per health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48].

Table 2.10. Results of laboratory analyses of surface waters

Radionuclide	^3H	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}$
Activity concentration, Bq/kg	In the vicinity ‘Degelen’ site				
	3400-88700 (w-3,8 %)	<0,09 (w-3,8 %)	<0,2 (w-3,8 %)	<0,8 (w-1,5 %) 4-20 (w-2,3 %)	<0,05 (w-3,8 %)
	In the vicinity ‘Balapan’ site				
	<8 (w-5,4 %) up to 30 (w-0,8 %) 14000-250000 (w-1,5 %)	<0,09 (w-7,7 %)	<0,2 (w-7,7 %)	<0,8 (w-6,1 %) 0,89 (w-0,8 %) 20 (w-0,8 %)	<0,05 (w-7,7 %)
	Objects away from the ‘Degelen’ and ‘Balapan’ sites				
	<8 (w-88,5 %)	<0,09 (w-88,5 %)	<0,2 (w-88,5 %)	<0,8 (w-88,5 %)	<0,05 (w-88,5 %)
Intervention level, Bg/kg	7600	0,69	11	4,9	0,55
Note: ‘w’ – the incidence of a radionuclide’s activity concentration in water, %					

Creeks Uzynbulak, Karabulak, Baitles, Toktakushyk and Aktybai that are in the vicinity of the ‘Degelen’ site contain high concentration levels of radionuclides. ^3H is the major contaminant. ^3H activity concentration in water of creeks exceeds the intervention level by 3 times and more. Its content in water of Baitles creek is 66,000 Bq/kg.

The maximum value of ^3H activity concentration in water of Uzynbulak creek is 35,000 Bq/kg, in water of Toktakushyk creek – 88,700 Bq/kg. ^3H concentration in these creeks is virtually at the same level throughout their beds. A decrease in ^3H concentration with increasing distance from boundaries of the ‘Degelen’ site as far as the final runoff is characteristic of Karabulak and Aktybai creeks: from 33,500 Bq/kg to 10,800 Bq/kg at Aktybai and from 32,400 Bq/kg to 3,400 Bq/kg at Karabulak. An elevated content of ^{90}Sr was registered in Karabulak creek ranging from 10 to 20 Bq/kg in ‘Degelen’ outlet areas. Numerical values for the content of ^{90}Sr are observed in water of Baitles creek. The activity concentration of the radionuclide in this case is 4 Bq/kg and is close to the intervention level (4.9 Bq/kg). In water of Toktakushyk creek, the content of ^{90}Sr is 15 Bq/kg, which is 3 times higher than the intervention level. Concentrations of ^{137}Cs , $^{239+240}\text{Pu}$ and ^{241}Am in water of creeks are below the detection limit and do not exceed the intervention level (11 Bq/kg, 0.55 Bq/kg and 0.69 Bq/kg, respectively).

In the vicinity of the ‘Balapan’ site, artificial radionuclides ^3H , ^{90}Sr , ^{137}Cs , ^{241}Am and $^{239+240}\text{Pu}$ are mostly contained in quantities that are below the detection limit and do not exceed regulatory values for potable water. In water of Lake Shunkursor, values of ^3H were found to reach 30 Bq/kg. However, this activity concentration does not exceed the permissible intervention level either. High concentrations of radionuclides were registered in two objects – Lake Kishkensor and the Shagan river. Contamination with ^3H and ^{90}Sr is observed in water of Lake Kishkensor. The content of ^3H in water of individual sections reaches 250,000 Bq/kg, that of ^{90}Sr – up to 20 Bq/kg. Activity concentrations of other radionuclides are below the detection limit.

In the Shagan river, prior to the inflow into the ‘Atomic Lake’, numerical values of radionuclides were not registered. The content

of radionuclides in this river section is below the detection limit and does not exceed permissible standards. However, at the outlet of the ‘Balapan’ site, levels of activity concentrations of ^3H and ^{90}Sr rise. The content of ^3H is 14,000 Bq/kg, which is 1.8 times higher than the intervention level (7,600 Bq/kg). The content of ^{90}Sr is at the level of 0.89 Bq/kg (5.5 times lower than the intervention level). Concentrations of ^{137}Cs , $^{239+240}\text{Pu}$ and ^{241}Am are below detection limits.

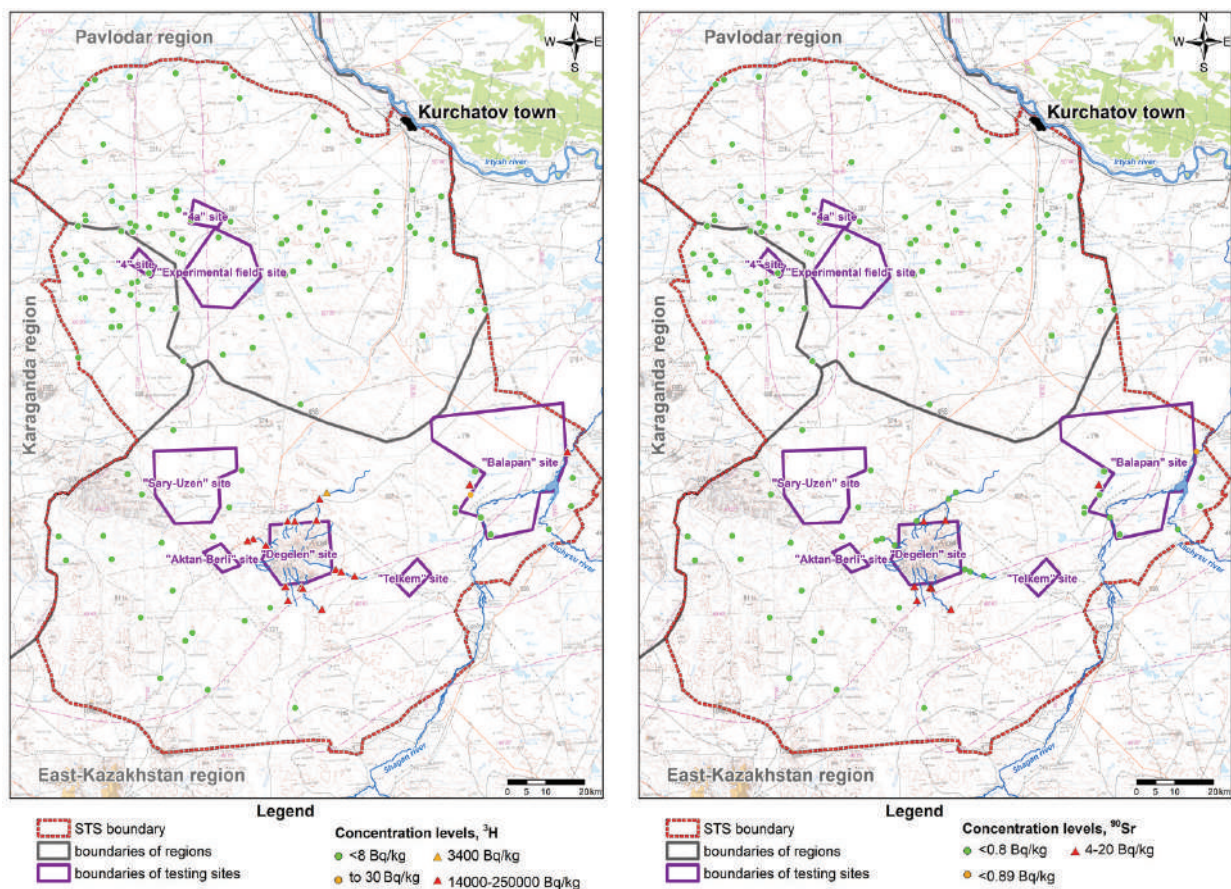


Figure 2.15. Sections with ^3H and ^{90}Sr in surface waters

Conclusions

Thus, water of Karabulak, Uzynbulak, Baitles, Aktybai, Toktakushyk creeks, Lake Kishkensor as well as a section in the Shagan river, at the outlet of the ‘Balapan’ site, can pose a radiation hazard.

In the rest of surveyed surface waters (lakes, creeks, a section of the Shagan river prior to the inflow into the ‘Atomic Lake’), the

content of artificial radionuclides does not exceed the intervention level. Most of these objects are at a distance from test places and sources of secondary contamination (surface waters with high levels of radionuclide concentrations). Radionuclides are also unlikely to enter with ground waters. Thus, subsequently, artificial radionuclides are not expected to be present in water of these lakes, creeks and rivers in quantities that exceed regulatory levels. In terms of radiation, these objects pose no hazard.

Ground waters

Ground waters at the test site are represented in the form of ground and fracture waters (Figure 2.16).

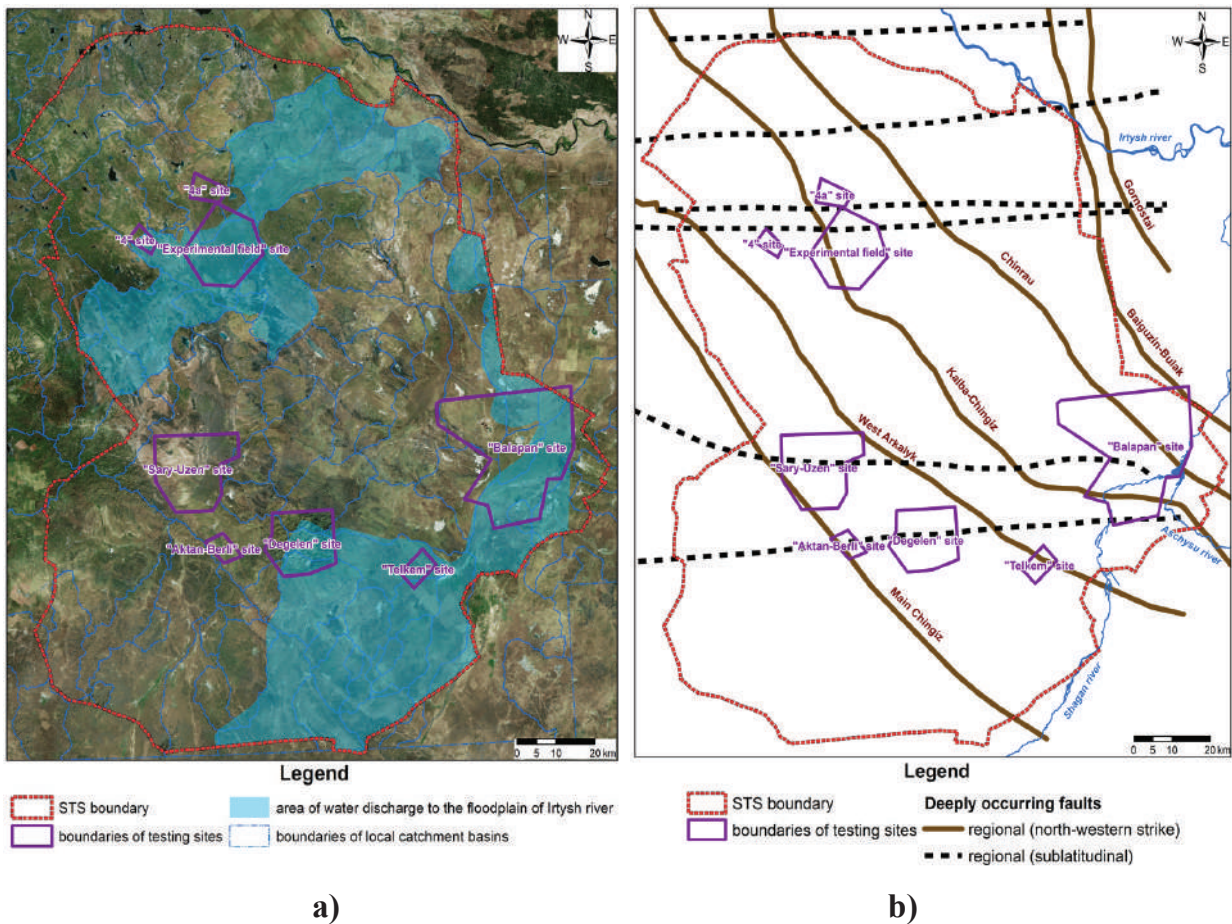


Figure 2.16. STS ground waters: a) catchment areas and direction of ground water movement, b) regional faults of fracture waters

Ground waters circulate in friable quaternary deposits and occur on different impervious bottoms represented by clays and the

weathering crust. The thickness of ground water level is 2.5–50 m. Depending on geological-structural features of the STS territory, ground waters are localized in catchment basins. According to the hydraulic gradient of the ground, the direction of ground water movement is regional towards the floodplain of the Irtysh river, i.e. northward and northeastward [75].

Fracture waters are common in zones of large tectonic disturbances – in bedding rocks of the Paleozoic foundation as well as in subsurface sections of exogenous fracturing. The water movement direction corresponds to that of tectonic faults of the northwestern strike. Depths of regional and fracture waters is 40-100 m.

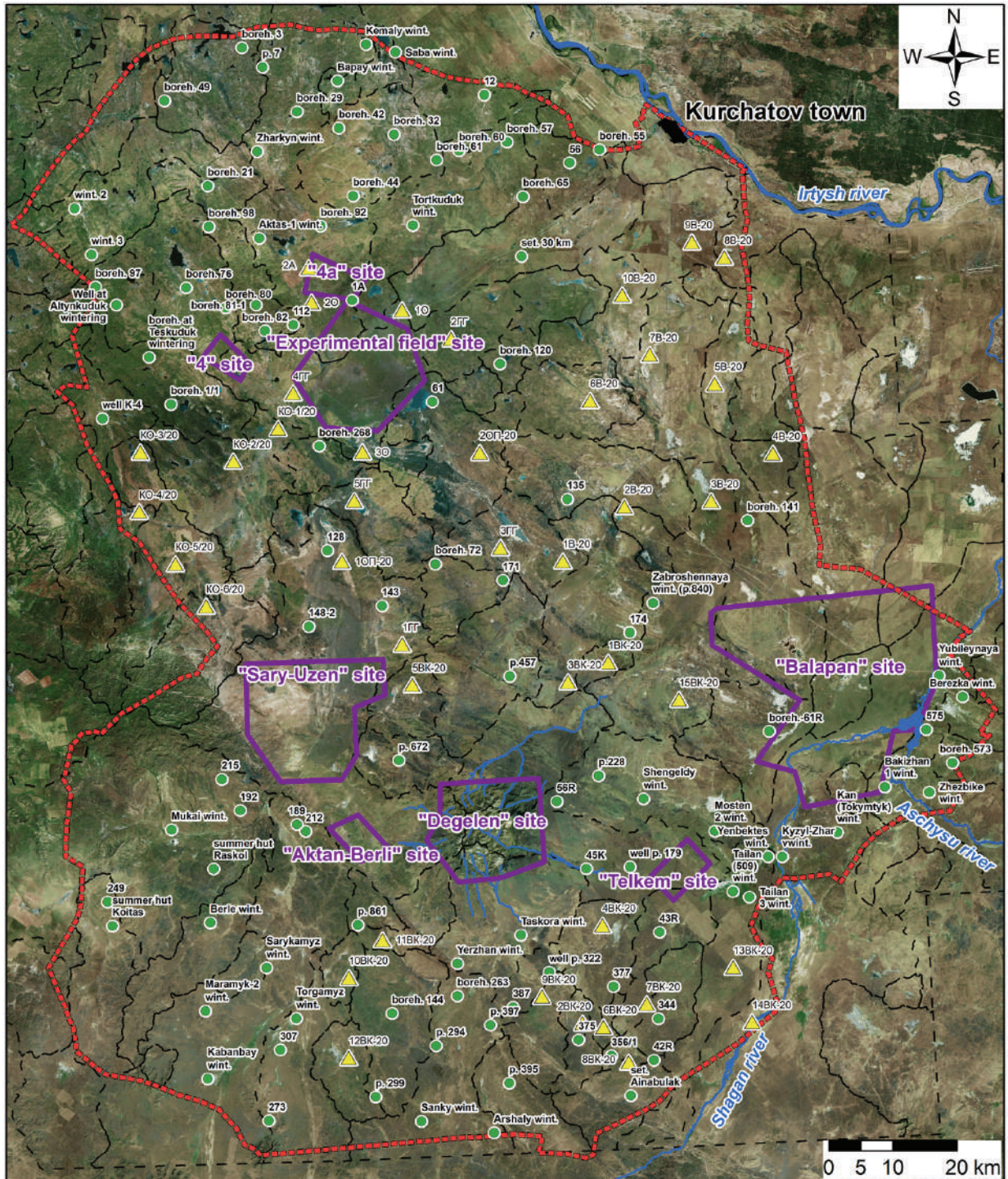
Research into the ground water state in the STS territory included the study of radioactive contamination of both fracture waters in the weathering zone of Upper Proterozoic – Paleozoic deposits and ground waters in friable deposits.

To this end, ground and fracture waters were sampled in existing water wells drilled in the 60-70s and in newly drilled ones.

Radioactive contamination of ground waters was studied in all drainable and drainless catchment areas of STS, which consist of many local basins in places of small hills. To do so, to assess the radiological state of ground waters, 74 existing water intake structures (boreholes, wells) were used as well as 65 extra exploratory auger-type boreholes were drilled (Figure 2.17).

Fracture waters were surveyed in large regional faults such as Kalba-Chingiz, West Arkalyk, Chinrau as well as in different sublatitudinal faults. In this regard, according to the tectonic terrain map, 25 boreholes were drilled in fault zones (Figure 2.18).

The volume of collected samples was 10 l – to analyze ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$ and ^{241}Am , and 20 ml – to analyze ^3H . For quality control of findings, 2-3 duplicate samples were collected in some sections (Figure 2.19).



Legend

- STS boundary
- boundaries of testing sites
- boundaries of local catchment basins
- ▲ boreholes drilled
- already existing boreholes

Figure 2.17. Research sections of ground waters

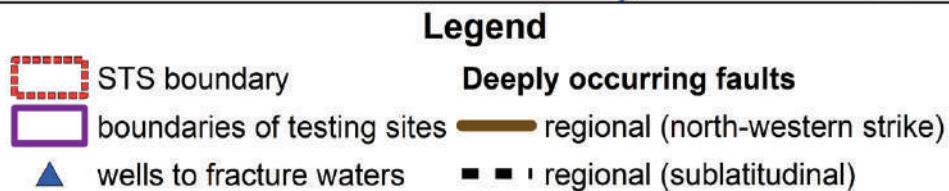
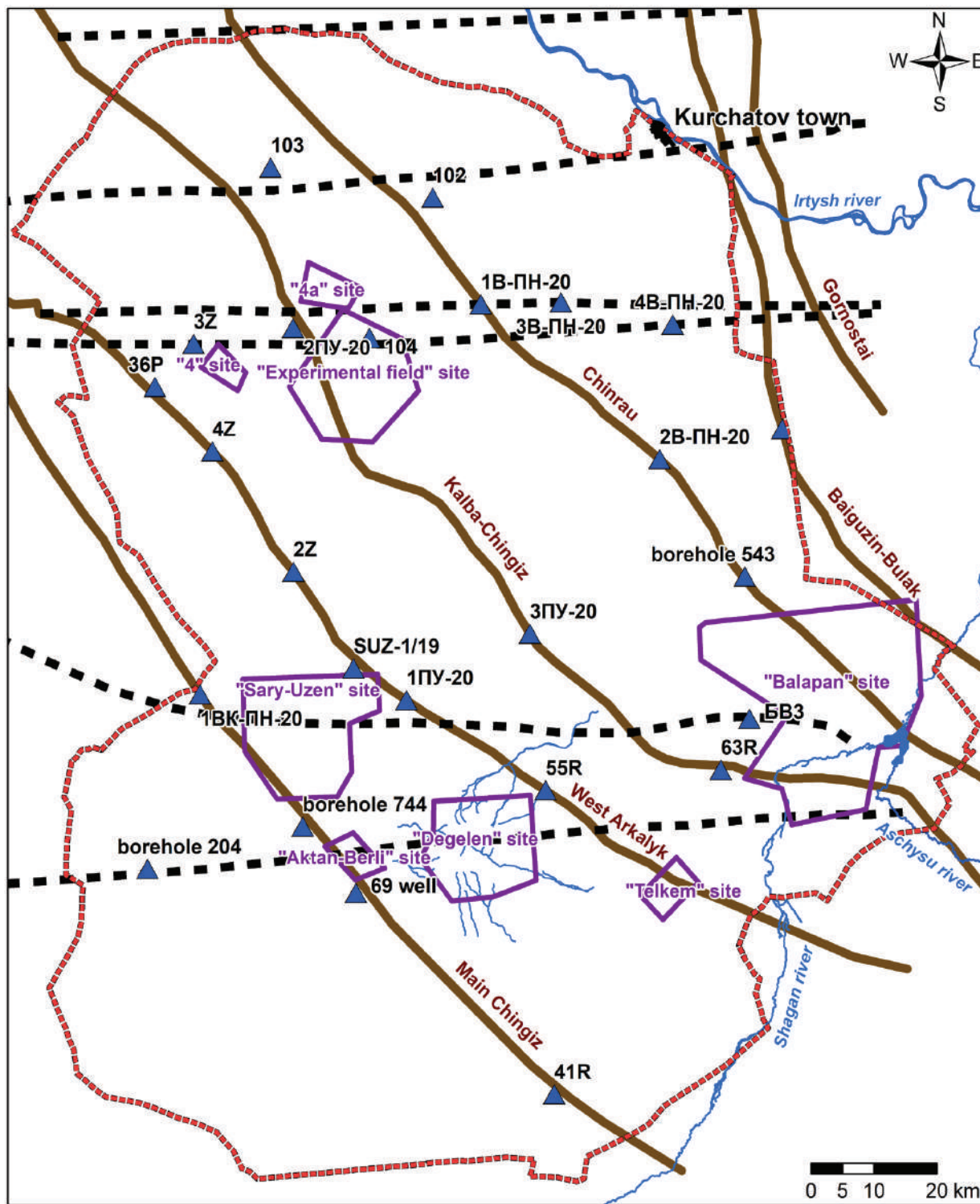


Figure 2.18. Research sections of fracture waters



Figure 2.19. Ground water sampling

Table 2.11. Results of laboratory analyses of ground waters

Radionuclide	^3H	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}$
Activity concentration, Bq/kg	<8 (w-92 %) <8-7000 (w-8 %)	<0,02 (w-100 %)	<0,02 (w-100 %)	<0,02 (w-97 %) <0,02-4,0 (w-3 %)	<0,001 (w-100 %)
Intervention level, Bq/kg [48]	7600	0,69	11	4,9	0,55
Note: 'w' – the incidence of the activity concentration of a radionuclide in water, %					

^3H activity concentration in 10 sections under survey varies from 10 to 7,000 Bq/kg, which does not exceed the intervention level for the content in potable water as per health standards 'Sanitary and Epidemiological Requirements for Radiation Safety Assurance' [48].

The content of ^{90}Sr in ground waters of 4 boreholes is within 0.02-4.0 Bq/kg, which does not exceed the intervention level either.

Sections with ^3H numerical values up to 7,000 Bq/kg and for ^{90}Sr up to 4.0 Bq/kg in ground waters were discovered within catchment basins of Karabulak creek, the hollow of Lake Karasor, the valley of Uzynbulak, Koskudyk natural boundary and the pit of Lake Zhingildy. These catchment basins are located within Degelen mountain range and are in the impact zone of contaminated surface water streams.

According to laboratory analysis data, values of activity concentrations of artificial radionuclides ^{241}Am , ^{137}Cs and $^{239+240}\text{Pu}$ for all 25 investigated sections of fracture waters are below detection limits of the methodological instrumentation in use (Table 2.12). ^3H activity concentration in 3 surveyed sections varies from <8 to 5,000 Bq/kg, which does not exceed the intervention level for the content in potable water as per health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48]. The content of ^{90}Sr in fracture waters of 3 boreholes, is within 0.02-4.0 Bq/kg, which does not exceed the intervention level either.

Table 2.12. Results of laboratory analyses of fracture waters

Radionuclide	^3H	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}$
Activity concentration, Bq/kg	<8 (w-97 %) <8-5000 (w – 3 %)	<0,02 (w-100 %)	<0,02 (w-100 %)	<0,02 (w- 97 %) <0,02-4,0 (w-3 %)	<0,001 (w- 100 %)
Intervention level, Bq/kg [48]	7600	0,69	11	4,9	0,55
Note: ‘w’ – the incidence of the activity concentration of a radionuclide in water, %					

Sections with ^3H and ^{90}Sr in fracture waters were discovered within the ‘Degelen’ site in the West Arkalyk regional fault (borehole 55R) as well as in the vicinity of the ‘Balapan’ site in Kalba-Chingiz fault (borehole S63-R) and in the sublatitudinal fault of the hollow of Karazhurek (borehole BV-3). Contamination of fracture waters in these sections is attributed to the impact of surface waters of the Degelen mountain range and a contaminated area of Lake Kishkensor in the southwestern part of the ‘Balapan’ site.

Thus, numerical values of artificial radionuclides ^3H (30 to 7,000 Bq/kg) and ^{90}Sr (0.4 to 4 Bq/kg), not exceeding intervention levels, are observed both for ground and fracture waters near the ‘Degelen’ and ‘Balapan’ testing sites (Figure 2.20).

Presence of ^3H and ^{90}Sr numerical values for these areas are rather expectable since the level of ground waters was in the impact zone of water streams from adits flowing through the main waterways of Degelen mountain range. There are 12 such water streams at ‘Degelen’, but they are all genetically linked to the main water streams (creeks) that flow far beyond the testing site. These are Uzynbulak, Toktakushyk, Baitles, Aktybai creeks and a number of seasonal unnamed water streams. Presence of ^3H and ^{90}Sr numerical values for the southwestern part of the ‘Balapan’ site is also attributed to the migration of radionuclides by fracture waters.

Taking into account that the ‘Degelen’ mountain range and the southwestern part of the ‘Balapan’ site are surrounded by enclosed aquiferous basins, artificial radionuclides are unlikely to migrate farther beyond discovered sections in the long term. This is also evidenced by long-term data that no artificial radionuclides were found in most of the STS territory beyond testing sites.

Thus, research undertaken has shown that radioactive contamination from the ‘Degelen’ site is carried away by creek water that in turn flow into adit water streams. Such creeks include Uzynbulak, Karabulak, Baitles, Toktakushyk and Aktybai. The major radioactive

component in water of these is ^3H contained in quantities that exceed the intervention level by 1.5-12 times. Besides, ^{90}Sr content in water of the Karabulak and Toktakushyk creeks exceeds the intervention level by 3-4 times.

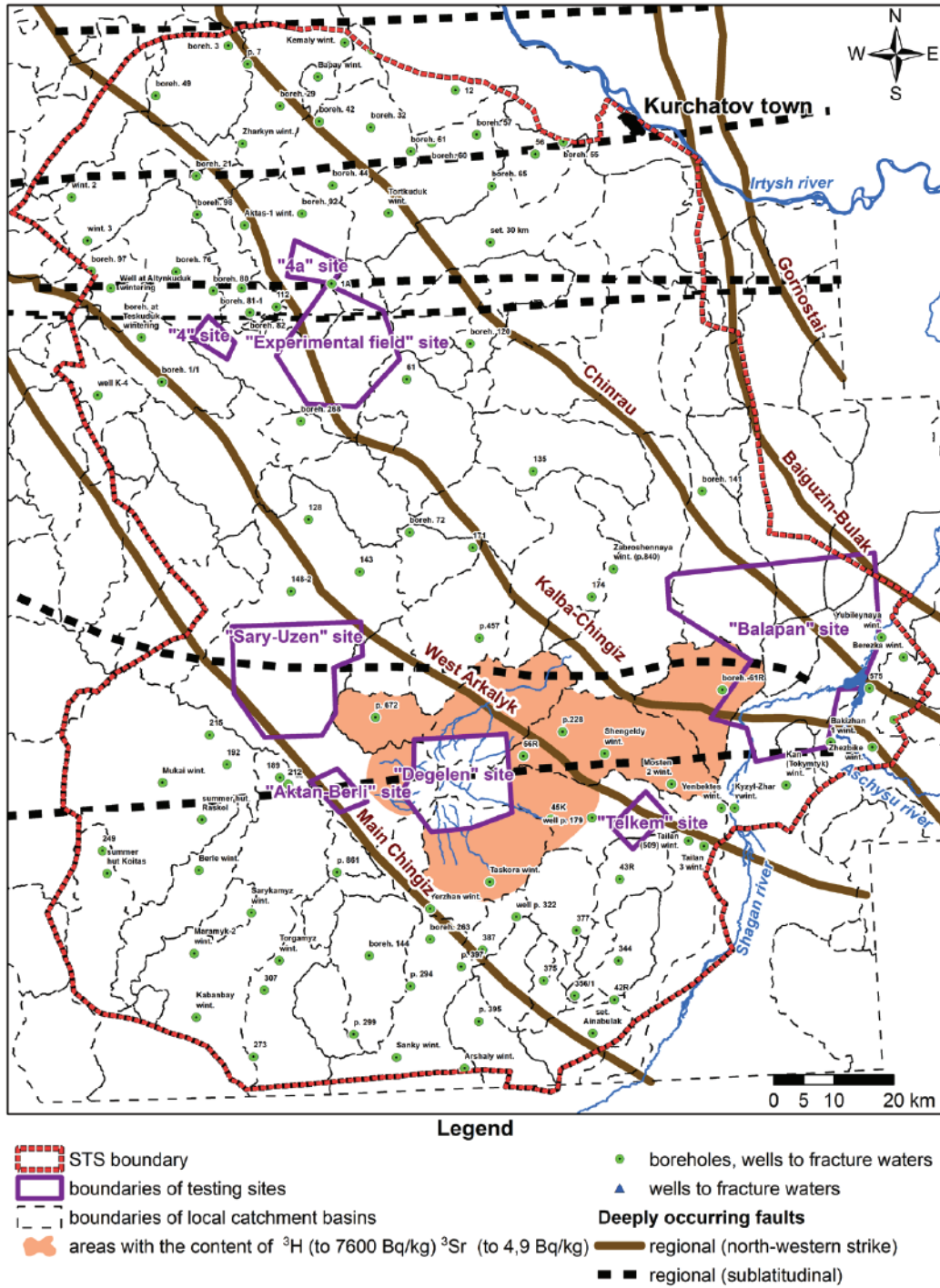


Figure 2.20. Sections of ^3H and ^{90}Sr numerical values for ground and fracture waters

^3H travels beyond the 'Balapan' site through waters from the Shagan river. This is evidenced by data on the content of ^3H in river water at the outlet of the site in quantities exceeding the intervention level twice. Water contamination of Lake Kishkensor with ^{90}Sr and ^3H also indicates the migration of radionuclides from the 'Balapan' site area. The content of these radionuclides in water exceeds the intervention level by 33 (^3H) and 4 times (^{90}Sr). In this case, ground waters serve as a migration path of radioactive contamination. There are no other explicit migration mechanisms.

Conclusions

Based upon findings on ground and fracture waters, artificial radionuclides were found to migrate beyond testing sites in the vicinity of the 'Degelen' and 'Balapan' sites. This is due to the fact that the level of ground waters in these sections is in the impact zone of water streams from adits flowing through the main waterways of the Degelen mountain range as well as sections in the southwestern part of the 'Balapan' site at which artificial radionuclides are observed to migrate in the vicinity of Lake Kishkensor. At the same time, no quantitative content of ^{241}Am , ^{137}Cs and $^{239+240}\text{Pu}$ was registered in most of the STS territory.

2.7 Radiological state of ambient air

The assessment of the radiological state of ambient air is a challenge because the content of particular impurities in air largely depends on climatic conditions at a certain point in time and can vary widely. Because of this, the annual average volumetric activity of radionuclides is a controlled quantity of the radiological state of ambient air. Eventually, this quantity, using relevant coefficients, makes it possible to determine the human exposure dose through inhalation of radionuclides.

The annual average volumetric activity of radionuclides in ambient air is determined by continuous sampling and measurements within a year, which under conditions of STS research, is hardly possible (a vast area, no infrastructure, no road maintenance make it difficult to move in the winter period etc.).

In this regard, an alternative calculation technique was applied to determine the annual average volumetric activity of radionuclides in ambient air of the test site. This technique is based upon the assumption that soil, to be more precise, its fine fraction, which enters air environment in the form of dust, is the main air contaminant where there are no industrial facilities or objects.

Knowing the content of radionuclides in a fine soil fraction as well as the annual average concentration of suspended particles in ambient air (dust load) of a land plot under study, one can calculate the annual average volumetric activity of radionuclides in ambient air.

The main potential sources of entry of radionuclides into air environment of the STS territory are:

- areas with a high content of radionuclides resulted from testing and experiments at testing sites ('Experimental Field', 'Balapan', 'Degelen', 'Sary-Uzen', '4' and '4A');
- fallout plumes beyond testing sites that can pose a hazard in the secondary transport and redistribution of radionuclides in environmental compartments due to adverse weather conditions.

The possibility of the secondary transport of artificial radionuclides by air was proved as part of relevant research [76]. Findings showed that the most adverse ambient conditions (artificial dusting and steppe fire) result in an elevated content of artificial radionuclides in air. Farm operations [77] under conditions of radioactive contamination also contribute to an elevated content of artificial radionuclides in air.

At the same time, in addition to the calculation technique to determine average annual activities of radionuclides in ambient air,

one-time measurements of activities of radionuclides in air of different test site parts were performed.

One-time measurements were performed in the summer period under normal weather conditions typical of this region, i.e. with no strong winds, heavy precipitation and so on, which allowed assessment of concentrations of radionuclides in air, so to speak, 'lower estimate', i.e. under favourable conditions. Elevated concentrations of radionuclides in air under these conditions would indicate serious problems of STS air contamination.

Calculation of the annual average volumetric activities of radionuclides in ambient air

Based upon much epidemiological research, suspended particles from 10 μm and smaller were found to be in the portion of airborne particles that penetrate into the respiratory tract (inhaled fraction) [78, 79].

With known values of concentrations of radionuclides in the fine soil fraction and the average annual concentrations of suspended particles in ambient air (dust load), one can calculate average annual volumetric activities of radionuclides in ambient air as per the formula:

$$A_{vi} = A_{i,10} \times P_{\text{sus}}$$

where:

A_{vi} – the average annual volumetric activity of the i th radionuclide in ambient air, Bq/m^3 ;

$A_{i,10}$ – The activity concentration of the i th radionuclide in the fine soil fraction (as small as 10 μm), Bq/kg ;

P_{sus} – the average annual concentration of suspended particles in ambient air of a land plot under study, kg/m^3 .

That is to say, with known content of radionuclides in the soil fraction finer than 10 μm at any point of the test site, one can calculate

average annual volumetric activities of radionuclides in ambient air at the same point.

However, determination of the content of radionuclides in the soil fraction finer than 10 μm is a rather labour-intensive process to be applied for each point of the test site because these can be so many, thus making this process virtually impossible. At the same time, results of laboratory analyses of about 18 thousand topsoil samples are available. Topsoil is actually the major source of the entry of radionuclides into ambient air.

Therefore, in order not to determine the content of radionuclides in the soil fraction finer than 10 μm in all 18 thousand samples (otherwise, this process would take a few dozens of years), it was only determined for a portion of samples grouped in two sets: samples collected from STS background areas (unaffected by radioactive contamination) and samples collected from areas of elevated values of activity concentrations of radionuclides in soil (radioactively contaminated areas). To this end, a coefficient (K_{fi}) defining the ratio of activity concentrations of radionuclides in the soil fraction finer than 10 μm to the one in the original sample unseparated into particle-size fractions was introduced. That is, a fraction finer than 10 μm , in which the content of radionuclides was also determined, was separated from a measured topsoil sample. Next, the ratio of activities of radionuclides in the fraction finer than 10 μm to the ones in the original sample was determined.

Thereafter, a coefficient having a maximum value was selected from among mean values of coefficients K_{fi} for background and radioactively contaminated areas for further calculations. This allowed upper estimate in calculating average annual volumetric activities of radionuclides in ambient air, i.e. the estimated average annual activity was reported with some safety margin.

The coefficient K_{fi} was calculated as per the formula:

$$K_{fi} = \frac{A_{i,10}}{A_i}$$

where:

$A_{i,10}$ – the activity concentration of the i th radionuclide in a fine soil fraction (up to 10 μm), Bq/kg;

A_i – the activity concentration of the i th radionuclide in topsoil (0-5 cm), Bq/kg.

To determine the coefficient K_{fi} , 168 soil samples were collected from the STS territory. Soil was sampled based on at least one sample per 100 km^2 (without considering areas of STS testing sites). Soil sampling points were uniformly spaced all over the STS territory given areas of elevated concentrations of radionuclides in soils (fallout plumes of aboveground tests) and zones of background concentration levels of radionuclides. When choosing soil sampling sites, research data on the areal contamination of soil cover was used.

A <10 μm fraction was separated from soil samples by sedimentation in the aquatic medium [1].

In K_{fi} calculations, data on activity concentrations of radionuclides in soils and soil fractions below the detection limit of the methodological hardware was ignored. Thus, the sample size to calculate K_{fi} was: ^{241}Am – 60, ^{137}Cs – 132, ^{90}Sr – 46, $^{239+240}\text{Pu}$ – 65 values. The value range of K_{fi} for radionuclides was: ^{241}Am – 0.04-15; ^{137}Cs – 0.14-7.2; ^{90}Sr – 0.02-9.7; $^{239+240}\text{Pu}$ – 0.02-45. Owing to the difference in formation mechanisms of radioactive particles of global and local fallout produced by aboveground explosions, the distribution nature of radionuclides in particle-size fractions in areas of elevated (fallout plumes of aboveground tests) and background concentration levels of radionuclides in soils can differ a lot. In this regard, mean values of K_{fi} were calculated separately for areas of elevated concentration levels of radionuclides in soils (fallout plumes of aboveground tests) and for zones of background concentration levels of radionuclides in soils.

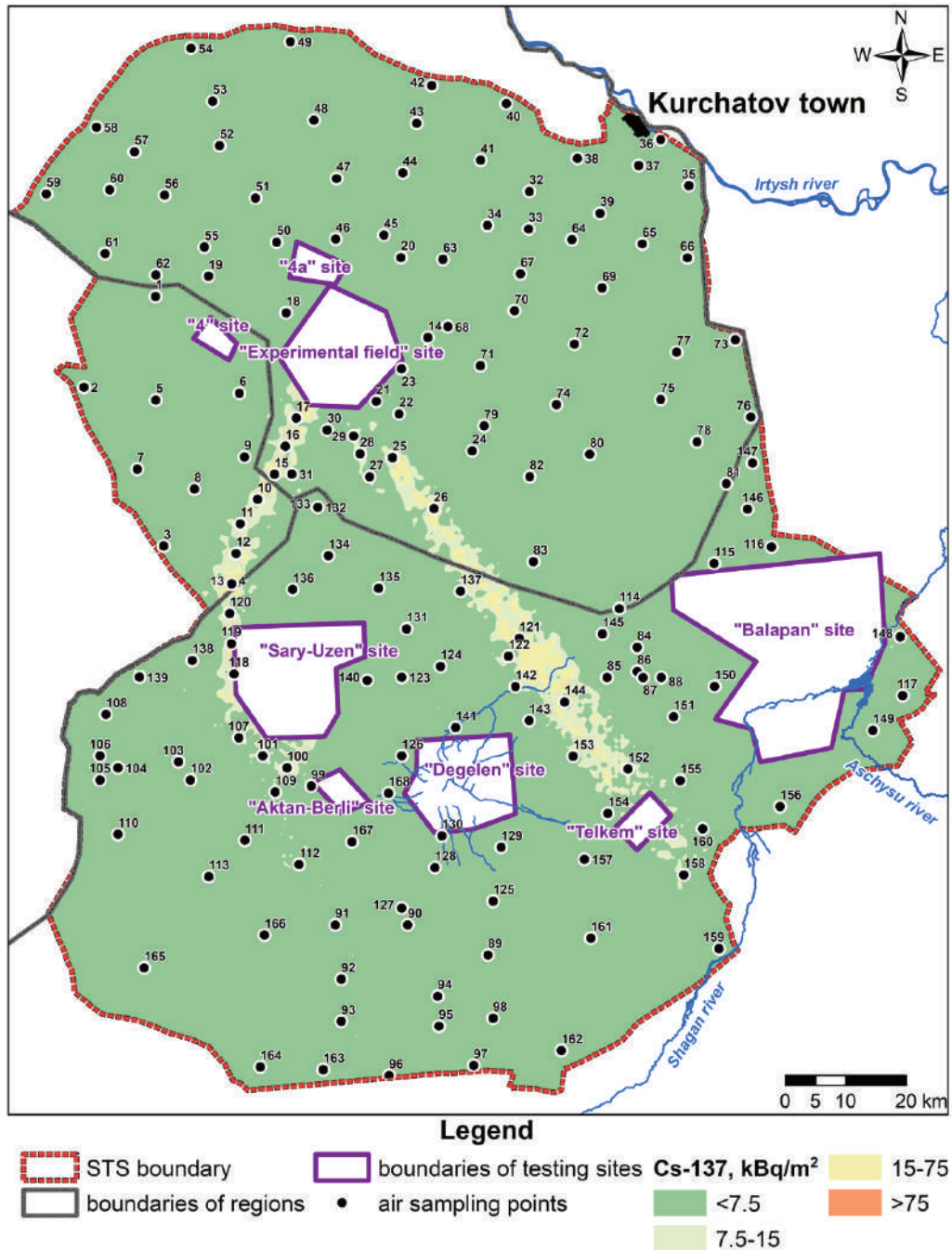


Figure 2.21. Schematic arrangement of soil sampling points using the calculation technique to determine average annual volumetric activities of radionuclides in STS ambient air

Mean values of K_f for areas of elevated (fallout plumes of aboveground tests) and background concentration levels of radionuclides in soils were: ^{241}Am – 2.22 and 1.43; ^{137}Cs – 1.25 and 2.41; ^{90}Sr – 1.77 and 2.57; $^{239+240}\text{Pu}$ – 3.37 and 2.38, respectively. Maximum mean values of K_f for ^{241}Am , $^{239+240}\text{Pu}$ were determined in

areas of elevated concentration levels of radionuclides in soils (fallout plume of aboveground tests), for ^{137}Cs , ^{90}Sr – in zones of background concentration levels of radionuclides in soils.

At the same time, when calculating the average annual volumetric activity, maximum mean values of K_{fi} were used in the conservative estimate: ^{241}Am – 2.22; ^{137}Cs – 2.41; ^{90}Sr – 2.57; $^{239+240}\text{Pu}$ – 3.37.

However, there is one more difficulty in the calculation technique to determine the average annual volumetric activity – determination of the average annual concentration of suspended particles in ambient air, that is to say, that of the average annual air dust load.

Based upon analytical results of experimental research and meteorological observations, concentrations of suspended particles in surface air was found to have the main impact on air environment in the STS territory under conditions of radioactive contamination [81]. At the same time, this indicator depends on meteorological parameters such as velocity, wind direction, relative air humidity and the amount of precipitation. During the precipitation event (rainfall), concentrations of suspended particles in air increase by 2-3 times for a short while. As the topsoil is saturated with moisture, concentrations of suspended particles in ambient air decrease. One can assume that subsequently, when weathered by wind and in evaporation of precipitation from the soil surface, fine soil particles are able to transfer to the suspended state partly, thereby affecting air contamination.

At the same time, average annual concentrations of suspended particles in ambient air are experimentally determined by sampling air aerosols daily within a year taking into account physical and chemical characteristics of the location of an object of interest, such as wind regime, (wind velocity and direction), air temperature, atmospheric pressure, weather conditions and state of the underlying surface [82].

No research into air dust load at the test site has been undertaken by virtue of inexpedient all-the-year-round measurements in the vast STS territory.

Therefore, the mean value of average annual concentrations of suspended particles in ambient air was used in calculations for large settlements closest to the test site – Karaganda city, Pavlodar city and Semey city. RSE ‘Kazgidromet’ provides data on average annual concentrations of suspended particles in ambient air of cities of the Republic of Kazakhstan in the annual information bulletin on environmental health of the Republic of Kazakhstan [83].

This data can also be regarded as conservative (upper estimate) because air dust load in cities, by virtue of objective reasons, exceeds the one in a rural area, to which the test site territory can refer to. The test site has no industrial facilities capable of significantly increasing concentrations of suspended particles in the area of several thousand square kilometers. There is not much vehicle traffic or other man-made sources of atmospheric dust load at the test site either.

Mean values of average annual concentrations (between 2016 and 2021) of suspended particles in ambient air of Karaganda, Pavlodar and Semey cities, according to official sources, were 0.1119, 0.1036 and 0.1045 mg/m³, respectively.

Further on, values of average annual volumetric activities of radionuclides in ambient air of the STS territory A_{vi} were calculated based upon mean maxima of K_{fi} for radionuclides, derived experimentally, mean values of average annual concentrations of suspended particles in ambient air ρ_{sus} as well as values of activity concentrations of radionuclides in topsoil (0-5 cm) of soil cover at each point of areal survey (based on one point per a square kilometer) A_i .

Maxima of annual average volumetric activities of radionuclides in ambient air of the STS territory area are characteristic of areas that are in close proximity to the ‘Experimental Field’ site. The range of values of annual average volumetric activities of radionuclides in ambient air of the STS territory A_{vi} , calculated using a theoretical technique, vary within five orders of magnitude (10^{-8} – 10^{-3} Bq/m). At the same time, maxima of A_{vi} are lower than permissible PVA_{pop} values by one order

of magnitude or more [48]. Based upon research undertaken, one can conclude that the ambient air in the STS territory beyond testing sites currently poses no hazard to the public.

Table 2.13. Determinations of average annual volumetric activities of radionuclides in air of the STS territory reported using a theoretical technique

Radionuclide	Average annual volumetric activity of radionuclides in air of STS calculated using a theoretical technique, A_{vi} , Bq/m ³		Public permissible volumetric activity of radionuclides in air, PVA_{pop} , Bq/m ³	Ranges of volumetric activity values of radionuclides in air of STS reported by experiment, Bq/m ³
	Range	Mean		
²⁴¹ Am	$1,14 \times 10^{-8} - 2,75 \times 10^{-4}$	$1,13 \times 10^{-6}$	$2,9 \times 10^{-3}$	$< 5,0 \times 10^{-5}$
¹³⁷ Cs	$6,34 \times 10^{-9} - 3,84 \times 10^{-4}$	$7,46 \times 10^{-6}$	27	$4,5 \times 10^{-7} - 9,0 \times 10^{-6}$
⁹⁰ Sr	$3,38 \times 10^{-8} - 2,04 \times 10^{-3}$	$3,98 \times 10^{-5}$	2,7	$< 6,0 \times 10^{-5}$
²³⁹⁺²⁴⁰ Pu	$2,43 \times 10^{-7} - 9,1 \times 10^{-4}$	$2,41 \times 10^{-5}$	$2,9 \times 10^{-3}$	$< 1,8 \times 10^{-7} - 3,3 \times 10^{-5}$

One-time measurements of volumetric activities of radionuclides in ambient air

As opposed to the calculation technique, one-time measurements of volumetric activities of radionuclides in ambient air are based upon direct sample measurements.

However, before addressing measurements, one should say a few words about general climatic conditions at the test site because, as mentioned above, one-time measurements were performed in the summer period in the absence of strong winds, precipitation and so on, which allows, so to speak, a lower estimate of radionuclide concentration in air, i.e. under favorable meteorologic conditions.

In the STS territory, average monthly air temperatures in July vary from +19 to +22°C and in January, -14 to -18 °C define the regional climate as sharply continental. At the same time, climatic zones here are observed to change from dry (along the valley of the Irtysh river with annual average temperatures varying from +0.6 to +5 °C and annual average amount of precipitation being 250-300 mm) to subhumid (in the region rimmed by mountains, in which annual average temperatures vary from +1 to -4 °C, and the annual average amount of precipitation reaches 400-600 mm). Maximum precipitation falls in May – June and October – November.

Wind regime. Wind regime is largely continental and is mostly defined by local barometric circulation conditions. In cold spells, wind regime is formed by the Siberian anticyclone that determines steady frosty weather. In winter, according to long-term data, southeastern (38.4 %) and southern winds (16.3 %). Winds opposite in direction are observed far less frequent (9.8 % – northwestern, 1.8 % – northern, 1.1 % – northeastern, 3.2 % – southwestern). Winter conditions are characterized by frequently occurring anticyclones, therefore, windless conditions often occur.

In summer, wind regime sharply changes, winds of the northwestern (27.4 %), western (16.8 %) and northern (14.9 %) horizon predominate with more frequent windless conditions. Wind conditions in spring and autumn are intermediate between winter and summer ones. This is due to the change in barometric fields of the cold and warm half years. May tends to exhibit turns of predominant wind directions from southeast to northwest. In June-July, this alteration is already complete.

In October, the summer system of winds alters to the winter one, which is attributed to the beginning of seasonally developing Siberian anticyclone and sharply attenuating thermal depression.

The annual course of mean values of wind velocity has a maximum and a minimum. The highest average monthly wind velocities per

annum are observed from February to June (3–3.6 m/s), the lowest – in July-August and October (2.9 m/s).

Strong winds are mainly noted in spring (April, May) as well as in February and November. Based upon observations it was found that the maximum wind velocity reached 35-43 m/s. Windless conditions were observed in 10 % of cases of the total number of observations. Windless conditions are mostly observed in summer – early in Autumn (2 % of the total number of observations).

Very strong and long-lasting winds cause dust storms, their velocities reach 20-30 m/s and higher. Soil particles are raised easier from the dry rough surface poor in vegetation under conditions that are typical of arid and semi-arid regions, and rough soil surfaces and soil cover destruction due to cattle grazing, vehicle traffic and human economic activities strengthen dust raise by wind.

Dust storms most commonly occur May through July. On average, dust storms were observed 5 times per annum. The average wind velocity in passing dust storms varies from 15 to 20 m/s. Several cases of dust storms beginning at relatively low values of wind velocities (6-8 m/s) were registered.

Precipitation. The test site area is among regions lacking precipitation. This is attributed to the fact that barometric circulation features of Eurasia determine the entry of mostly arctic air and middle-latitude air of continental origin being poor in moisture. Aridity of the local climate also strengthens by desert of Central Asia and South Kazakhstan. Besides, the eastern part of Kazakhstan's steppe zone is more frequently affected by anticyclones and therefore it is less humid than the western part.

Local continental conditions define the unstable nature of precipitation fluctuating insignificantly from year to year. In this part of Kazakhstan, no precipitation at all or negligible precipitation is possible, and in certain years, monthly precipitation can reach a significant amount.

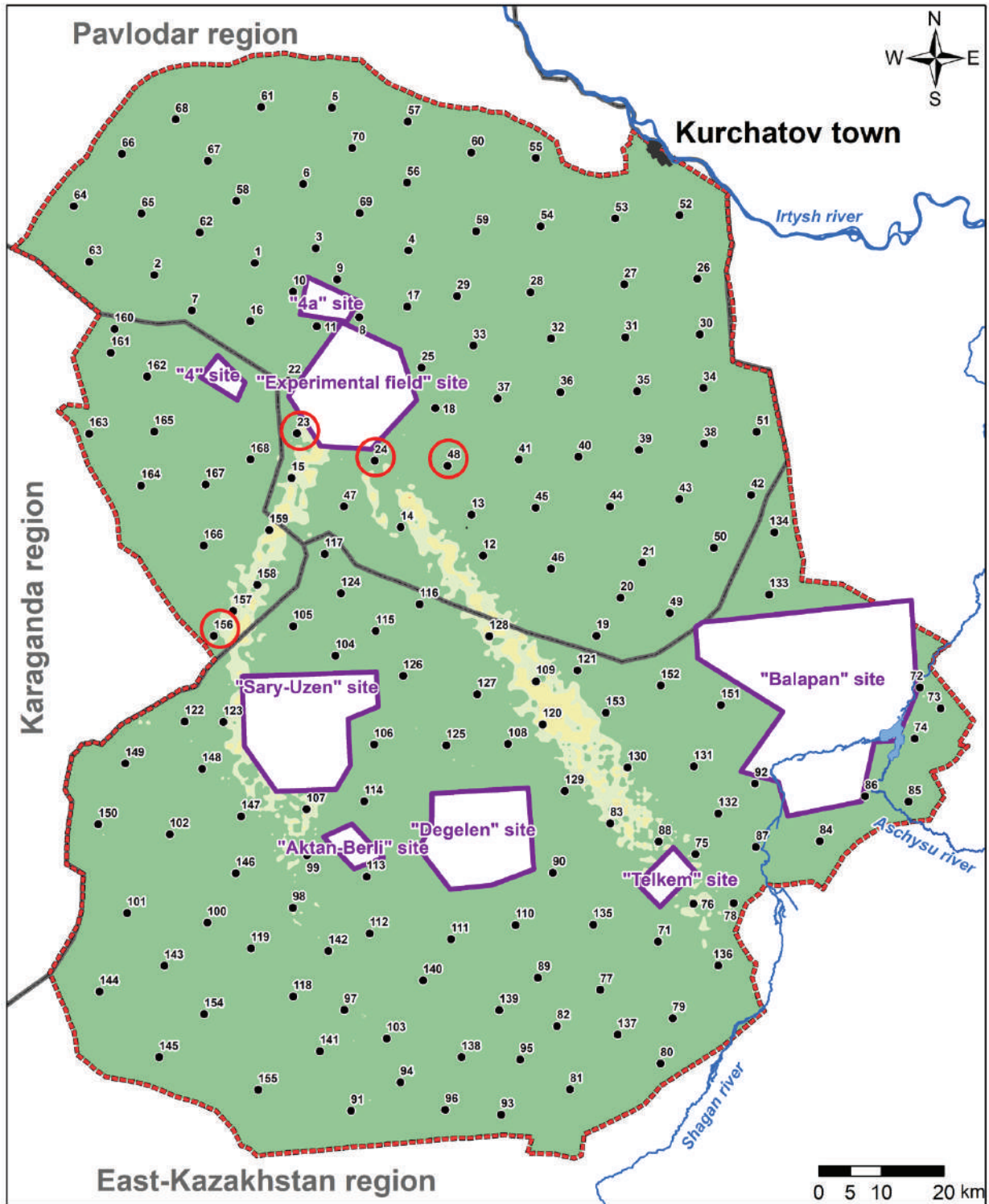
Precipitation is clearly traced to be at the peak in summer. Barometric circulation conditions of the warm half year contribute to significant precipitation event May through August, when 50 to 60 % of the total amount falls in the form of heavy rain. Significant precipitation is also observed in the winter season in the form of rare plentiful snowfalls. However, precipitation in the warm half year is combined with high temperatures, which makes it less important as a humidity factor – when evaporation rate significantly increases, natural soil moistening is insufficient. In winter, because of low temperatures, precipitation remains on the surface for quite a long time (on average, 2-3 months). In the autumn period, compared to summer months, the amount of precipitation is small but due to a decrease in air temperature, evaporation is significantly reduced in these months and precipitation event is sufficient to moisten soil.

Measurements of volumetric activities of radionuclides

To determine volumetric activities of radionuclides in air of the STS territory, research points were chosen followed by sampling aerosols and laboratory analyses using γ -spectrometric and radiochemical techniques.

Air aerosol sampling points were uniformly distributed all over the STS territory. A total of 168 research points were selected (≈ 1 point per 100 km²).

For numerical values of radionuclides, in air of background areas, the volume of each air aerosol sample was at least 3,000 m³. A fixed-site 1,500 m³/h sampler was used for air aerosol sampling. The collection of 1 air aerosol sample took 2 to 2.5 h depending on climatic conditions. Air aerosols were sampled at a height of 1.5 m above the ground at the open firm ground site with free air access on all sides – thus, measurement distortions by structures and vegetation were prevented [84].



Legend

STS boundary	points of maxima	Cs-137, kBq/m²	15-75
boundaries of testing sites	air sampling points	<math><7.5</math>	>75
		7.5-15	

Figure 2.22. Location map of air aerosol sampling points in the STS territory, soil cover contamination with ¹³⁷Cs

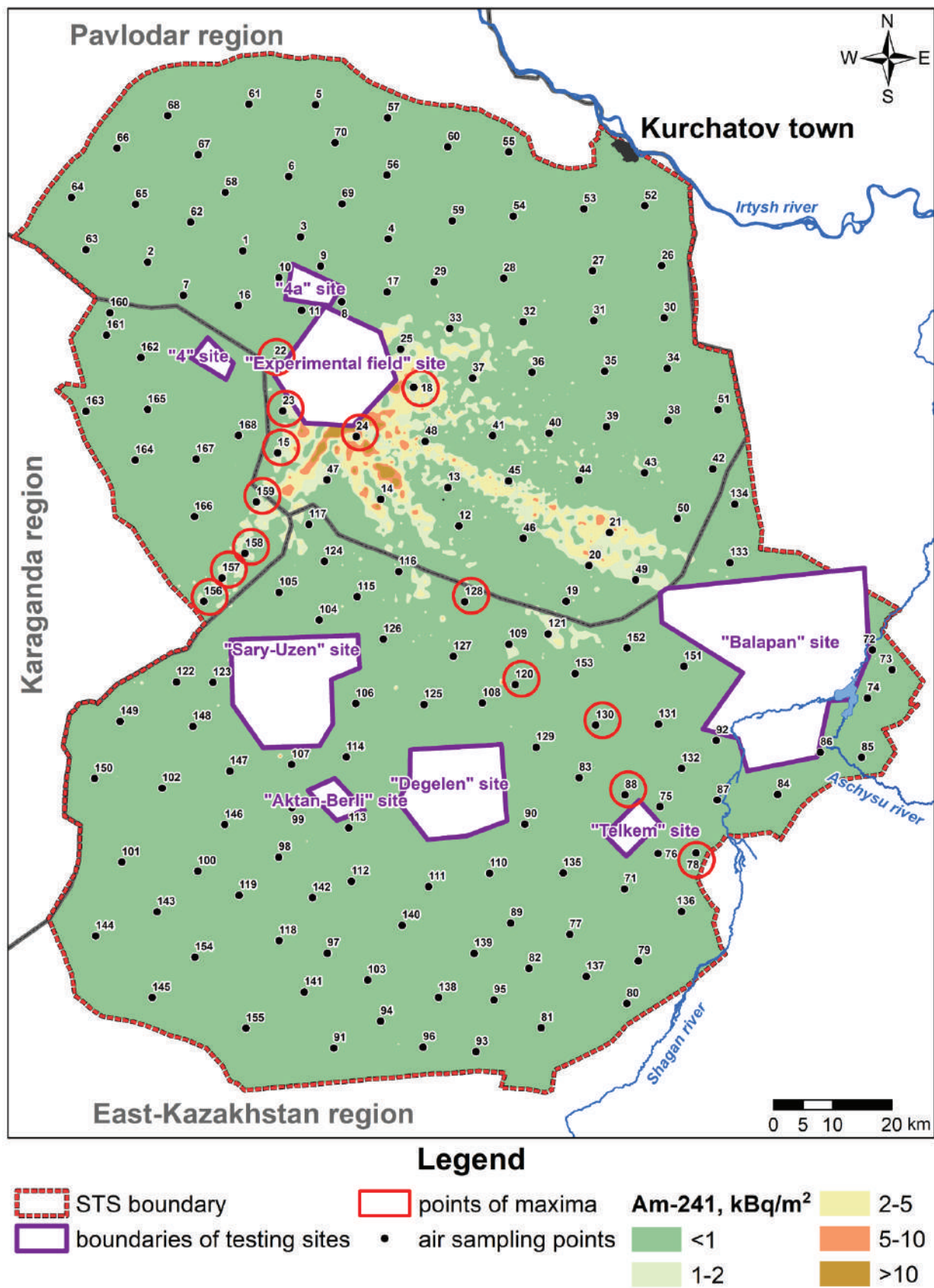


Figure 2.23. Location map of air aerosol sampling in the STS territory, soil cover contamination with ²⁴¹Am

To exclude a possible impact of adverse weather conditions, air aerosols were sampled in the absence of precipitation, the wind velocity did not exceed 5 m/s, concentration of suspended particles – not higher than 20 mg/m³. In case these parameters were exceeded, air aerosol sampling ceased and only continued following parameter standardization.

Air aerosol samples were prepared in vitro by ashing and analyzed using a gamma-spectrometric technique to determine the content of ²⁴¹Am, ¹³⁷Cs. Air aerosol samples were ashed in the muffle furnace for 6 hours at 390 °C. To improve the detection limit, air aerosol samples were measured with a well-type gamma-spectrometer having a high registration efficiency – up to 100 %. Following the gamma-spectrometric analysis, air aerosol samples were analyzed for ⁹⁰Sr and ²³⁹⁺²⁴⁰Pu by radiochemistry.

Maxima of ¹³⁷Cs volumetric activity of were registered at points 23, 24, 48 and 156 (Figure 2.22). Maxima of ¹³⁷Cs volumetric activity ranged from 1.5×10^{-6} to 9.0×10^{-6} Bq/m³.

Maxima of ²³⁹⁺²⁴⁰Pu volumetric activity were registered at several spots (Figure 2.23): Spot 1 (points 18, 22, 23, 24) is near the boundary of the ‘Experimental Field’ site; spot 2 (points 15, 156, 157, 158, 159) is in the plume of a 24.09.1951 test; spot 3 (points 78, 88, 120, 128 and 130) is in the plume of a 12.08.1953 test. Maxima of ²³⁹⁺²⁴⁰Pu volumetric activity ranged from 5.1×10^{-6} to 3.3×10^{-5} Bq/m³.

No numerical values of ²⁴¹Am and ⁹⁰Sr volumetric activities were detected in air of the STS territory. ²⁴¹Am and ⁹⁰Sr volumetric activities in air were determined at the level of the detection limit of methodological instrumentation.

Data on ²³⁹⁺²⁴⁰Pu volumetric activity was sorted by zones (background area, plume area) and mean values of radionuclide volumetric activities were calculated for each zone. The table presents

mean values of volumetric activities of artificial ^{241}Am , ^{137}Cs , ^{90}Sr , and $^{239+240}\text{Pu}$ in the STS territory (Table 2.14). When calculating mean values, the detection limit was taken as a numerical value. The number of averaged samples was stated in brackets.

Table 2.14. Mean values of radionuclide volumetric activities in the STS territory

Radionuclide	Background area	Radioactively contaminated spots
^{241}Am , Bq/m ³	$< 1,7 \times 10^{-5}$ (55)	$< 4,6 \times 10^{-5}$ (14)
^{137}Cs , Bq/m ³	$< 2,3 \times 10^{-6}$ (65)	$6,5 \times 10^{-6}$ (4)
^{90}Sr , Bq/m ³	$< 2,3 \times 10^{-5}$ (55)	$< 5,1 \times 10^{-5}$ (14)
$^{239+240}\text{Pu}$, Bq/m ³	$9,8 \times 10^{-7}$ (55)	$5,6 \times 10^{-6}$ (14)

According to reported experimental data, volumetric activities of artificial radionuclides in the STS territory ranged as follows: for ^{241}Am – $< 5.0 \times 10^{-5}$ Bq/m³, for ^{137}Cs – 4.5×10^{-7} to 9.0×10^{-6} Bq/m³, for ^{90}Sr – $< 6.0 \times 10^{-5}$ Bq/m³, for $^{239+240}\text{Pu}$ $< 1.8 \times 10^{-7}$ to 3.3×10^{-5} Bq/m³, which did not exceed the permissible volumetric activity for each listed radionuclide for the population category as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [84].

The value range of average annual volumetric activities of radionuclides in ambient air reported by calculation overlaps the region of values for one-time experimental determinations of the volumetric activity in air of STS. This makes it possible to use data from the calculation technique reasonably to assess the exposure dose through inhalation of radionuclides.

Conclusions

If we speak of the radiological state of STS air environment in general, one can state the fact that values of volumetric activities of

radionuclides in ambient air (beyond testing sites), reported both by calculation and by direct measurements, are over hundreds of times lower than permissible values.

2.8 Radiological state of plant cover

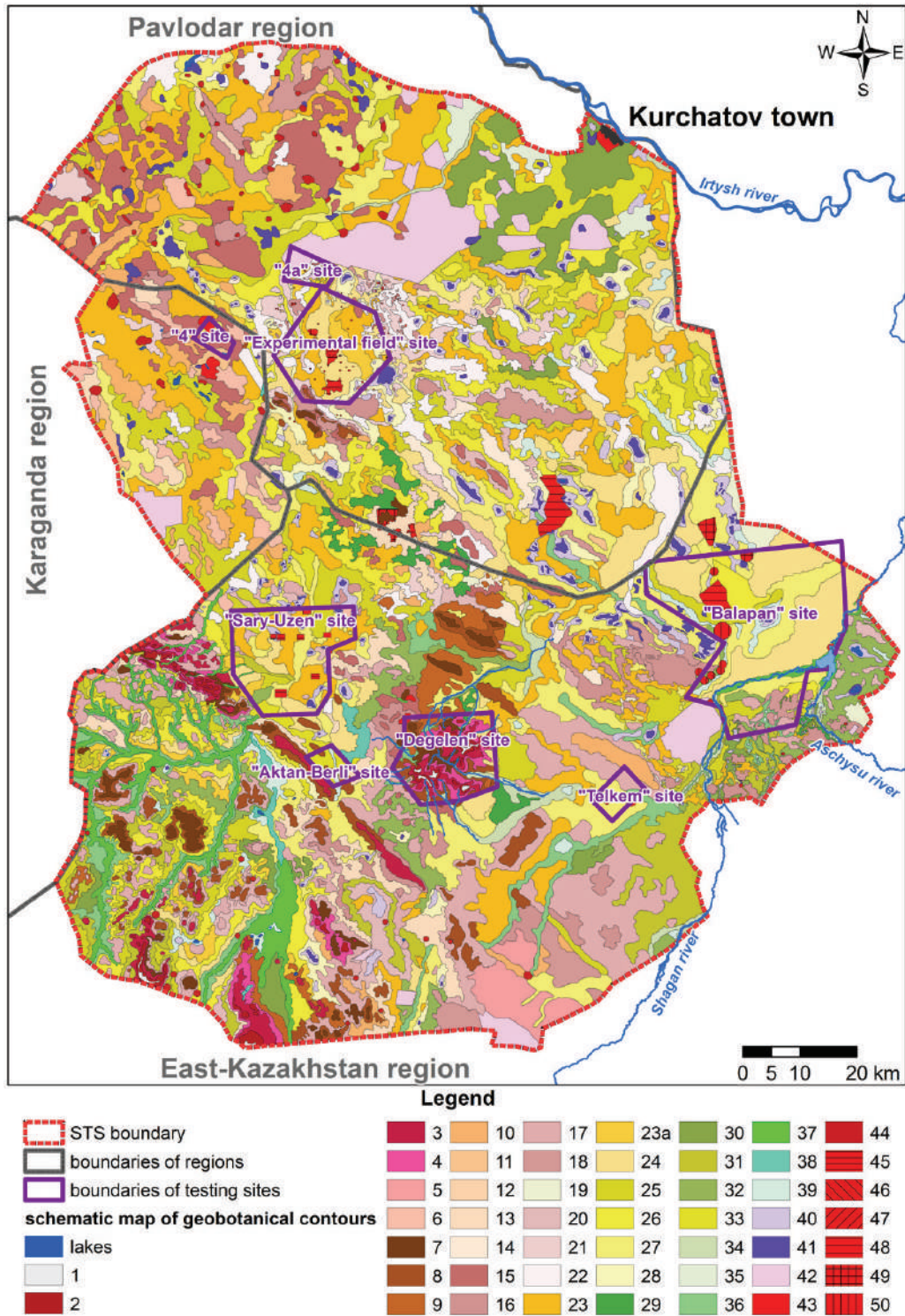
Assessment of the radiological state of STS flora is of great importance since plants are the integral link on the way of possible migration of radionuclides in the food chain 'plant-animal-man'. In this aspect, the major STS phytocenoses are represented by numerous species included in forage resources for both wild and farm hoofed animals.

In terms of phytogeographical zoning of the steppe part of central Kazakh Hummocks, the STS territory is within dry sheep fescue-feather grass steppes on chestnut soils and desertified absinthial-feather grass steppes on light-chestnut soils; included in Semipalatinsk and Ekibastuz districts of the East Kazakhstan subprovince [85].

More than 90 % of the STS territory is represented by steppe vegetation on chestnut and light-chestnut soils. The other part is fragmentarily occupied by a shrub vegetation, desert type (on sodic and saline soils) as well as by forest and meadow vegetation (the most common at the 'Degelen' site) [86].

Due to testing activities, vegetation at some spots of the 'Experimental Field', 'Degelen', 'Balapan', 'Sary-Uzen' sites was partly destroyed and, as of today, it is represented by different stages of communities restoration [87].

The community of the steppe vegetation type is formed in plains, on gently sloping depositional plains and bald peak slopes and low-hill-terrain. Dry steppes (*Stipa capillata*, *Festuca valesiaca*, *Artemisia frigida*, *Caragana pumila*) in deluvial-proluvial plains and on slopes of the hummocks are typical of the northwestern STS part. Communities with dominating *Stipa kirghisorum*, *Helictotrichon desertorum* are typical of high hummocks of this test site part.



1, 2, 3, 4, 5, 6 – low-hill terrain ecosystems;
 7, 8, 9, 10, 11, 12, 13, 14 – high hummocks ecosystems;
 15, 16, 17, 18, 19, 20, 21, 22 – small hummocks ecosystems;
 23, 24, 25, 26, 27, 28, 29 – ecosystems of deluvial-proluvial plains;
 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40 – ecosystems of deluvial plains;
 41 – sor ecosystems; 42, 43, 44, 45, 46, 47, 48, 49, 50, 51 – man-made ecosystems

Figure 2.24. Schematic distribution map of plant ecosystems

Plain types of desertified steppes (*Stipa sareptana*, *Festuca valesiaca*, *Artemisia gracilescens*) on light-chestnut loamy soils are typical of slightly sloping plains in the northeastern and eastern STS part. Absinthial-sheep fescue-sandy needle-grass (*Stipa lessingiana*, *Festuca valesiaca*, *Artemisia sublessingiana*, *A. albida*) steppes on light-chestnut rotted rock and crushed stony soils are characteristic of plains amidst bald peaks and piedmont plains of granite low-hill terrain in the central and south-western test site part. Hemipsamophytic steppe variants – *Stipa sareptana*, *Festuca valesiaca*, *Artemisia marschalliana* involving *Spiraea hypericifolia* on light-chestnut slightly loamy and sandy loam soils are represented by old alluvial plains in the eastern STS part.

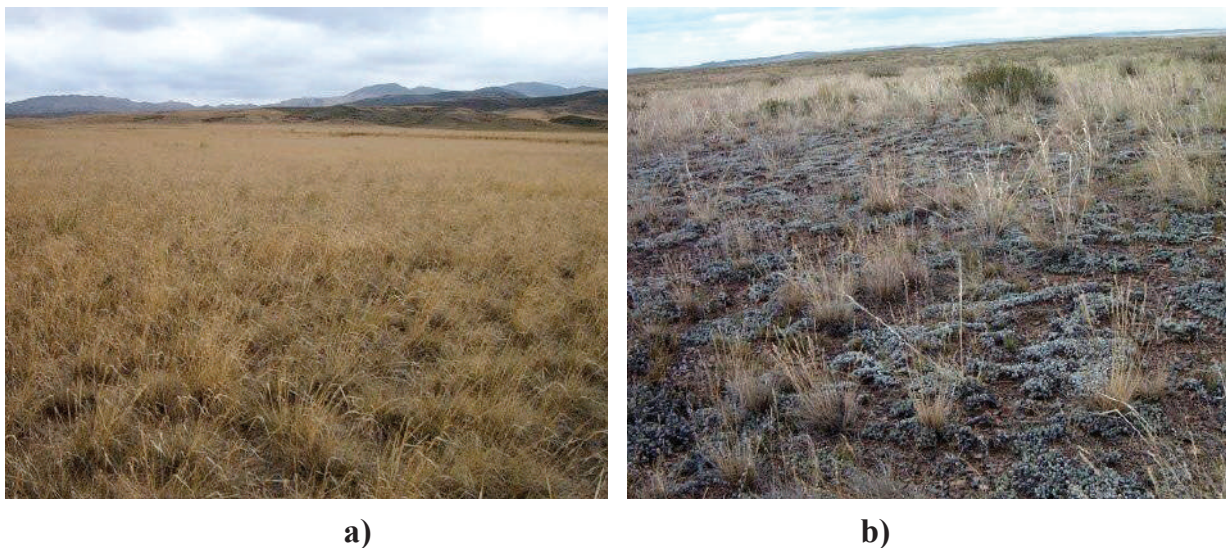


Figure 2.25. Sheep fescue-feather grass steppe (a); cold absinthial submontane steppe with sod grasses (b)

Brushwood groups found in the STS territory are associated with certain habitats. Steppe shrubs of *Spiraea hypericifolia*, *Caragana pumila*, sometimes *Halimodendron halodendron* are associated with hollows amidst bald peaks and steppe kettles. Shrubby cenoses involving *Spiraea trilobata*, *Rosa spinosissima*, *Cotoneaster oliganthus*, *C. melanocarpus*, *Lonicera microphylla*, *Pentaphylloides parvifolia*, sometimes incorporating *Berberis sibirica*, *Ribes saxatile*, *Juniperus*

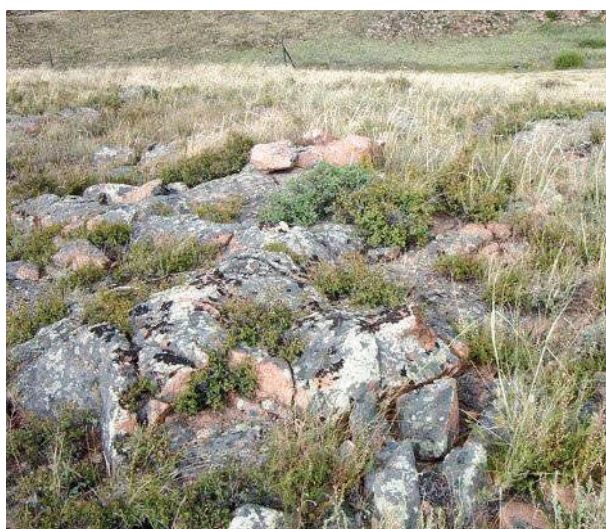
sibirica are typical of mat-like laminated granites. *Juniperus sabina* thickets are common in screes of creek valleys. *Caragana pumila*, *Atraphaxis frutescens*, *Convolvulus fruticosus* cenoses are common in screes and sandy pebble dry beds. Brushwoods involving *Rosa majalis*, *R. glabrifolia*, *Padus avium*, *Lonicera tatarica*, *Ribes nigrum*, *Rubus idaeus* are typical of shadowy gorges and beneath the canopy of birch-aspen woodlets. Willow thickets built up by *Salix cinerea*, *S. viminalis*, *S. rosmarinifolia*, *S. triandra* grow in flood plains of creeks, around springs and man-made water bodies.



a) **b)**
**Figure 2.26. Pea shrub-sod grass steppe in the plain (a),
shrubby sod grass steppe in high hummocks (b)**

In the STS territory, petrophyte variants of steppes are common. Granite low-hill-terrains, for example, Degelen mountain range, high and small hummocks create the diversity of ecological conditions for petrophyte vegetation to form. Altitude zonal plant succession is well-marked in granite low-hill terrains. Pea shrub-cold absinthial-sheep fescue-feather grass associations (*Stipa capillata*, *Festuca valesiaca*, *Artemisia frigida*, *Caragana pumila*) are characteristic of submontane plains and gently sloping depositional plains of low-hill terrains. Communities with dominating *Ziziphora clinopodioides*, *Thymus serpyllum*, *Veronica incana*, *Festuca valesiaca* can be

found on slopes of rotted rock. Motley grass-sedgy-graminous communities (*Helictotrichon desertorum*, *Stipa kirghisorum*, *Festuca valesiaca*, *Carex pediformis*, *Thalictrum foetidum*, *Bupleurum aureum*, *Chamaerhodos erecta*, *Pulsatilla patens*) are formed on underdeveloped and incompletely developed soils of slopes in the north and northeastern direction. Gramineous-motley grasses communities (*Fragaria viridis*, *Dianthus acicularis*, *Veronica spuria*, *Artemisia latifolia*, *A.rupestris*, *Festuca valesiaca*, *Stipa capillata*, *Agropyron cristatum*) involving shrubs (*Spiraea trilobata*, *S.hypericifolia*, *Caragana pumila*, *Lonicera microphylla*) are characteristic of southern slopes. Petrophyte-motley grass shrubby cenoses (*Spiraea trilobata*, *Rosa spinosissima*, *Cotoneaster oliganthus*, *Lonicera microphylla*, *Pentaphylloides parvifolia*, *Orostachys spinosa*, *Sedum hybridum*, *Onosma simplicissima*, *Thalictrum simplex*) are common on granite slabs. Petrophyte-motley grass-lichen clusters with dominating *Parmelia vagans*, *P.cetrata*, *Diploschistes scropsus*, *Orostachys spinosa*, *Euphorbia humilis*, *Patrinia intermedia*, *Onosma simplicissima*, *Silene suffrutescens*, *Hieracium echioide* are commonly found on stony peaks.



a)



b)

Figure 2.27. Petrophytes in high hummocks (a), fragments of the forest vegetation type with *Pinus sylvestris* at the ‘Degelen’ site (b)

Fragments of the forest vegetation type can be found under extra favourable conditions: small aspen-birch (*Betula pendula*, *Populus tremula*) woodlets involving *Populus canescens*, *Crataegus chlorocarpa*, *Rosa majalis*, *Padus avium*, *Lonicera tatarica*, *Ribes nigrum*, *Rubus caesius* and the abundant gramineous-motley grass (*Angelica sylvestris*, *Sanguisorba officinalis*, *Thalictrum flavum*, *Galium boreale*, *Agrimonia pilosa*, *Calamagrostis epigeios*, *Poa angustifolia*, *Melica transsilvanica*) herbaceous layer are formed in creek valleys and on slopes of shadowy gorges of granite low-hill terrains.

The only location at the 'Degelen' site in which *Pinus sylvestris* is growing has been discovered in a slightly disturbed high granite ridge. The tree layer is formed by *Pinus sylvestris* and *Betula pendula*. Ferns of *Asplenium* and *Woodsia* *geni* are characteristic of shadowy crevices of granite slabs. Moss-lichen layer with dominating *Parmelia vagans*, *P. cetrata*, *Cladonia sylvatica* is well-developed on the surface of granite slabs, and single plants *Pentaphragma parvifolia*, *Orostachys spinosa*, *Sedum hybridum*, *Veronica incana* rim fractures with fine earth inside.

Swamp meadows with dominating *Phragmites australis*, *Typha angustifolia*, *T. laxmannii*, *Bolboschoenus planiculmis*, *Carex omskiana* are characteristic of near-spring meadow grounds, the impact zone of Chagan water reservoir, depressions of intermittent beds, edges of percolating water bodies at the 'Atomic Lake' and edges of man-made water bodies. Polydominant genuine meadows of *Calamagrostis epigeios*, *Elytrigia repens*, *Bromopsis inermis*, *Glycyrrhiza uralensis* are found fragmentarily in river flood plains. Steppe meadows involving *Leymus angustus*, *Poa angustifolia*, *Bromopsis inermis*, *Medicago falcata*, *Potentilla bifurca* are characteristic of hollows amidst bald peaks, slopes of river terraces, interior submontane valleys. Halophytic variants of meadows are represented by cenoses with dominating *Puccinellia dolicholepis*,

Hordeum brevisubulatum, *H. bogdani*, *Aeluropus littoralis*, *Achnatherum splendens*. These are common in river flood plains and terraces above the flood plain, lacustrine depressions and around man-made water bodies. Meadow vegetation is very common in creek flood plains of the Degelen mountain range.

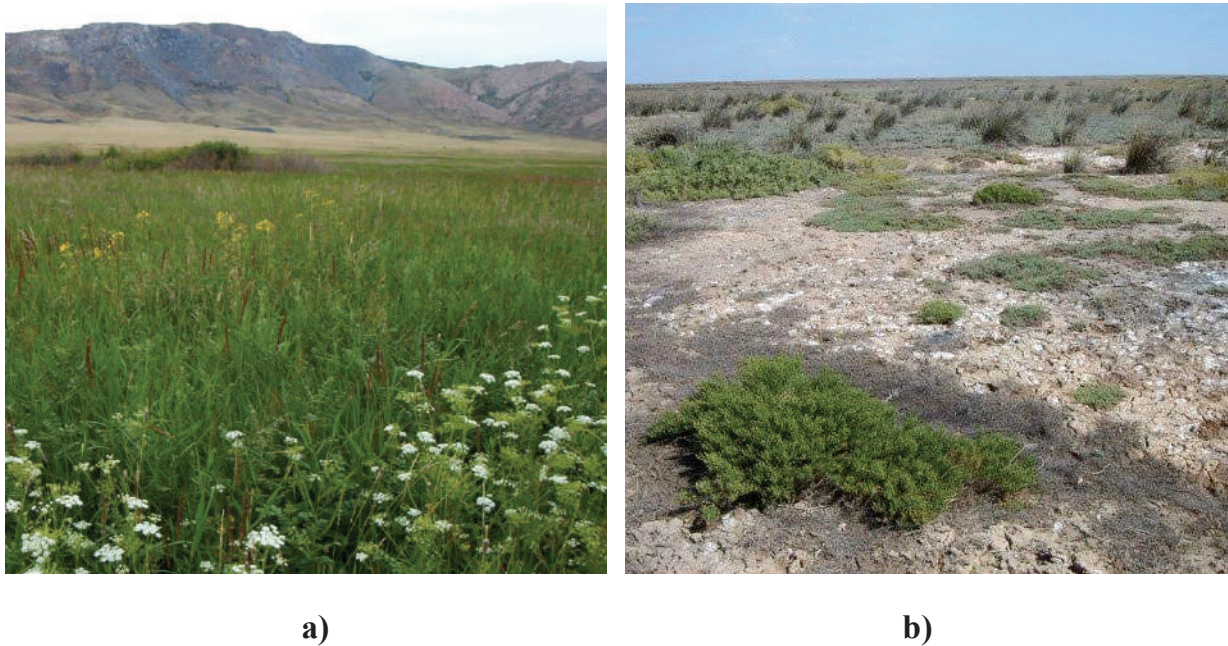


Figure 2.28. Meadow vegetation in the creek flood plain of the Degelen mountain range (a), saltwort-sorghum community on meadow saline soil (b)

Desert communities within the steppe region are formed under special habitat conditions – on soils of the salinized series (sodic and saline soils). Such habitats are found in saline depressions of plains, outcropping spots of salinized Paleozoic clays, lacustrine hollows as well as in river terraces above the flood plain. A desert vegetation species is represented by communities formed by hyperxerophilous and haloxerophilous dwarf semishrubs – the goosefoot family and by some species of *Artemisia* genus. Desert communities are formed by the following dominant species: *Atriplex cana*, *Anabasis salsa*, *Halimione verrucifera*, *Nanophyton erinaceum*, *Halocnemum strobilaceum*, *Kalidium schrenkianum*, *Artemisia schrenkiana*, *A. pauciflora*, *A. nitrosa*.

Research findings.

In order to obtain data on the content of radionuclides in plant cover of the STS territory, research areas were prepared to sample plants. For correct assessment of the radiological state of flora, the following conditions were taken into account first of all when deciding upon sampling areas:

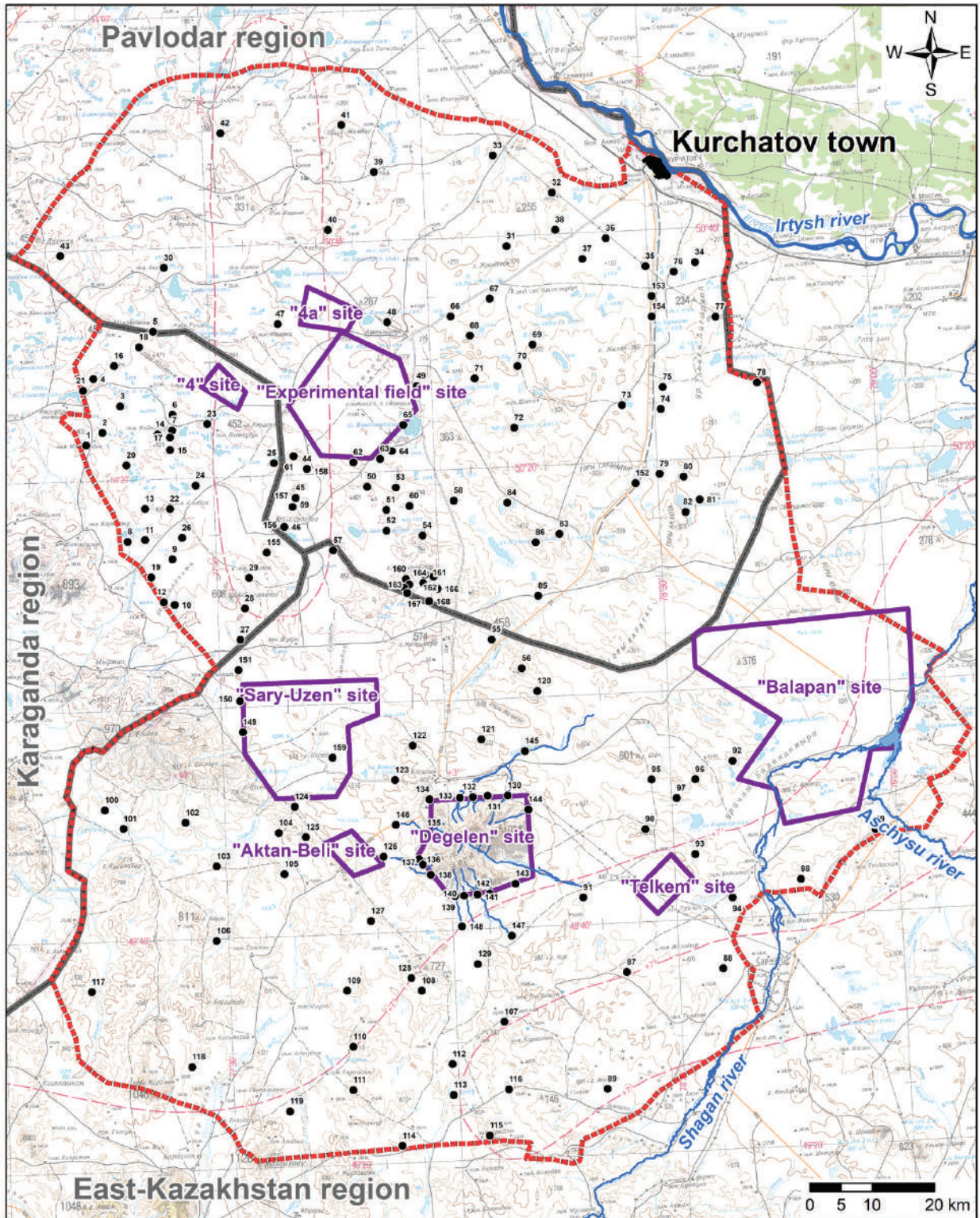
- 1) fallout locations;
- 2) zones of radionuclide carry-away with water streams;
- 3) conventionally 'background' STS areas.

Thereafter, locations of selected areas were adjusted given the distribution scheme of geobotanical contours in the study area. Selected areas covered STS ecosystems identified as much as possible, especially the ones that are characterized by a relatively high productivity (ecosystems of alluvial and depositional plains etc.). A total over 160 research areas were prepared given all conditions: of which 30 – in the fallout region, more than 10 – in the zone of radionuclide carry-away with water streams and over 120 – in the conventionally 'background' STS territory.

Plants were sampled in each research area. Plants were sampled in a 1 m² area or larger depending on the projective cover. Plant samples included mixed aboveground parts of steppe motley grasses with dominating feather grass (*Stipa capillata*, *S. sareptana*, *S. lessingiana*), sheep fescue (*Festuca valesiaca*) and sagebrush (*Artemisia gracileccens*, *A. Frigida* and others) because these forms of STS phytocenoses form the basis of the forage resources for hoofed animals. Aboveground parts of plants were cut off 3 cm above the soil surface.

Activity concentrations of ¹³⁷Cs, ²⁴¹Am, ⁹⁰Sr and ²³⁹⁺²⁴⁰Pu were determined in all plant and soil samples collected.

Results of the variational and statistical analysis of reported values of ¹³⁷Cs, ²⁴¹Am, ⁹⁰Sr and ²³⁹⁺²⁴⁰Pu activity concentrations in plant samples are listed in the table.



Legend

- STS boundary
- boundaries of regions
- boundaries of testing sites
- vegetation sampling points

Figure 2.29. Schematic map of plant and soil sampling

Table 2.15. Statistical indices for values of ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$ activity concentrations in STS plant cover

Radionuclide	Variation and statistical indices			
	Q-ty	min – max, Bq/kg arithmetic mean (SD)	Median	V, %
Fallout region				
^{137}Cs	61	$\frac{(0,3 - 79)}{4,4 (2,2)}$	2,3	98
^{241}Am		$\frac{(0,12 - 22)}{1,6 (0,8)}$	0,6	87
^{90}Sr		$\frac{(1,9 - 171)}{17 (15)}$	5,7	106
$^{239+240}\text{Pu}$		$\frac{(0,1 - 160)}{8,6 (26)}$	0,7	299
Region of radionuclide carry-away with water streams				
^{137}Cs	15	<d.l.	-*	-*
^{241}Am		<d.l.	-*	-*
^{90}Sr		$\frac{(0,6 - 330)}{34 (98)}$	3,6	286
$^{239+240}\text{Pu}$		$\frac{(0,1 - 1,5)}{0,5 (0,5)}$	0,2	112
Conventionally 'background' territory				
^{137}Cs	92	$\frac{(0,2 - 4,4)}{1,1 (0,8)}$	0,9	78
^{241}Am		$\frac{(0,1 - 0,3)}{0,2 (0,04)}$	0,2	23
^{90}Sr		$\frac{(0,9 - 42)}{7,0 (8,5)}$	5,0	120
$^{239+240}\text{Pu}$		$\frac{(0,1 - 0,6)}{0,2 (0,2)}$	0,2	67
d.l. – detection limit; *- n/a				

As a result of plant sample measurements, the content of ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$ in plant cover of the STS study area was found to vary widely. For instance, the comparison of mean values

of activity concentrations in plants with medians has shown that the widest spread of concentrations is noted for ^{90}Sr and $^{239+240}\text{Pu}$ in plant cover of the fallout region as well as for ^{90}Sr – in the region where they are carried away with radioactive water streams. High indices of variation factors for activity concentrations indicate a significant nonuniformity of the content of radionuclides in plant cover of the STS study area. This is especially characteristic of ^{90}Sr and $^{239+240}\text{Pu}$. A wide spread and nonuniformity of concentrations of radionuclides in plant cover are obviously attributed by both the nature of radioactive soil contamination and by physical-chemical properties of radionuclide species therein.

Distribution maps of ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$ in flora objects of the STS study area were constructed based upon findings (Figure 2.30, Figure 2.31, Figure 2.32, Figure 2.33).

The content of radionuclides in plant cover of the conventionally STS ‘background’ area is characterized by minima or is below detection limits of the methodological instrumentation in use.

The fallout region shows elevated values of activity concentrations in plant cover for all radionuclides of interest. For instance, the excess of maximum permissible levels of radioactive contamination of forage plants with ^{137}Cs and ^{90}Sr (^{137}Cs – 74 Bq/kg; ^{90}Sr – 111 Bq/kg) was detected in the fallout ‘plume’ region after a nuclear test conducted on September 24, 1951, on the boundary with the ‘Sary-Uzen’ site (Figure 2.30) [88].

Concentrations of transuranic radionuclides ^{241}Am and $^{239+240}\text{Pu}$ in plants are not standardized but proceeding from the degree of their radiotoxicity, one can assume that permissible levels will be approximately one order of magnitude lower than for ^{90}Sr (111 Bq/kg) [88]. Considering estimated maximum permissible levels of transuranic radionuclides, the excess of their content is also noted along the fallout plume of the 1951 nuclear test: 2 to 3 times – for ^{241}Am and 2 to 15 times – for $^{239+240}\text{Pu}$ (Figure 2.30).

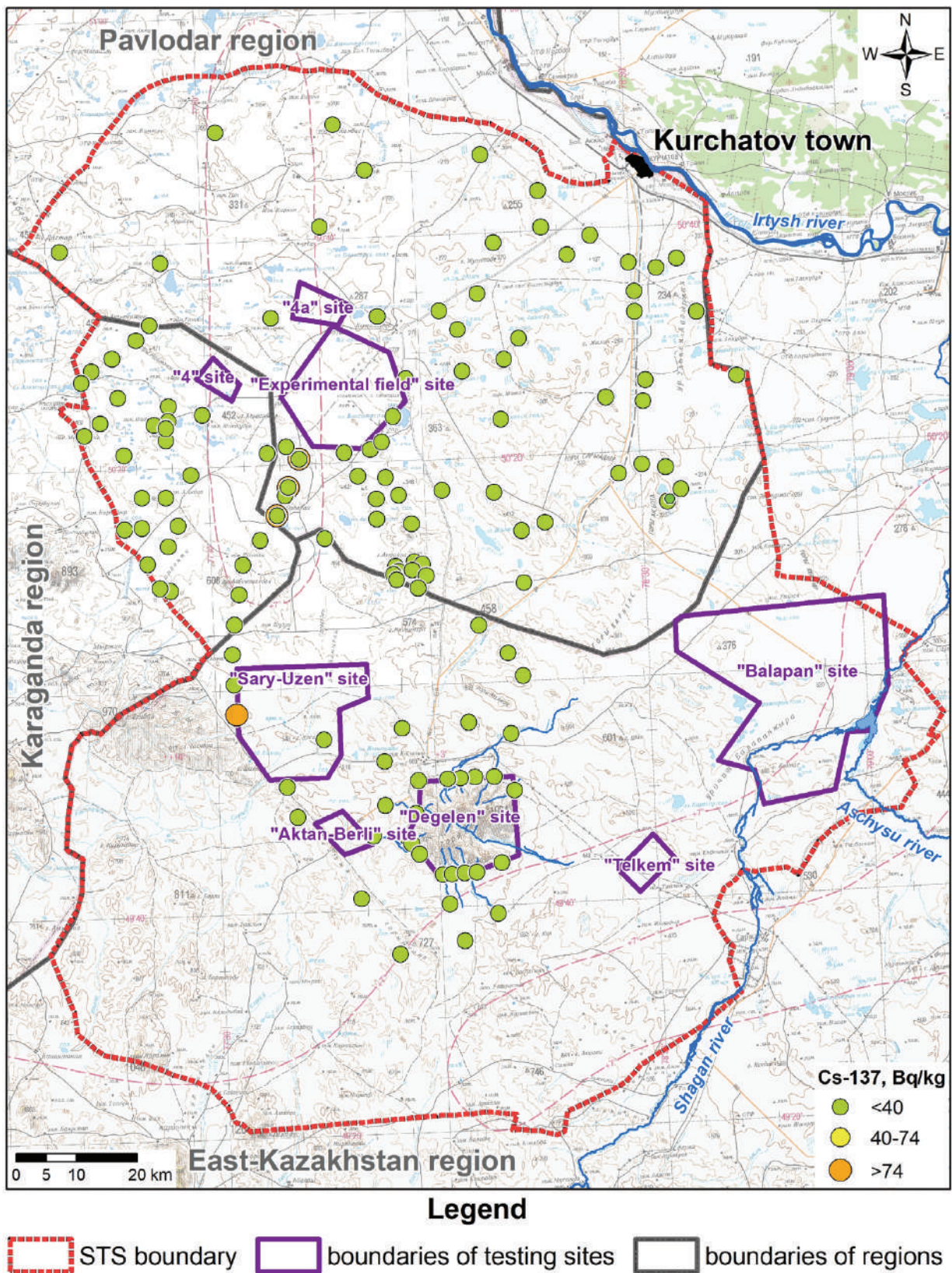


Figure 2.30. Distribution of ¹³⁷Cs in STS plant cover

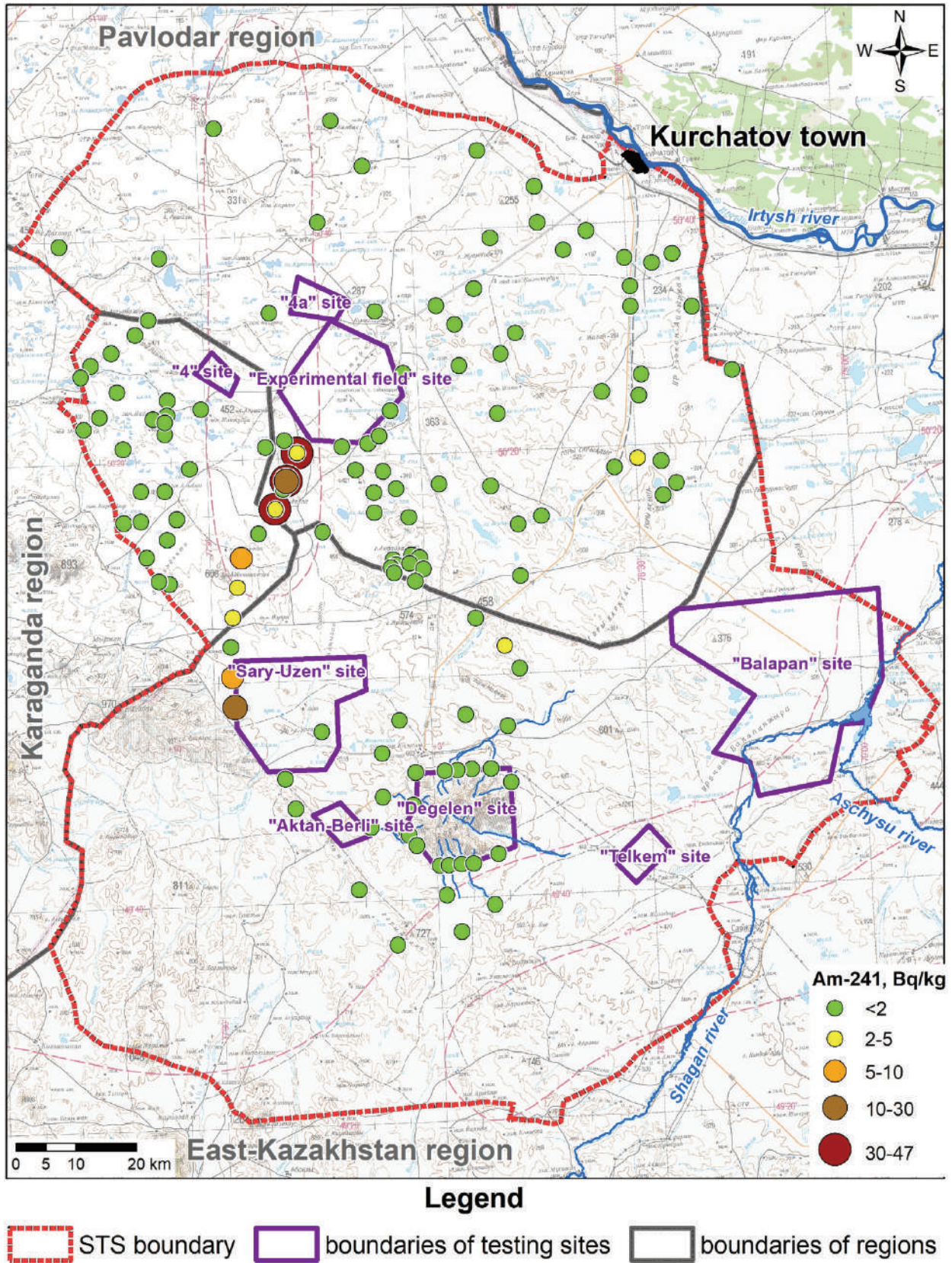


Figure 2.31. Distribution of ^{241}Am in STS plant cover

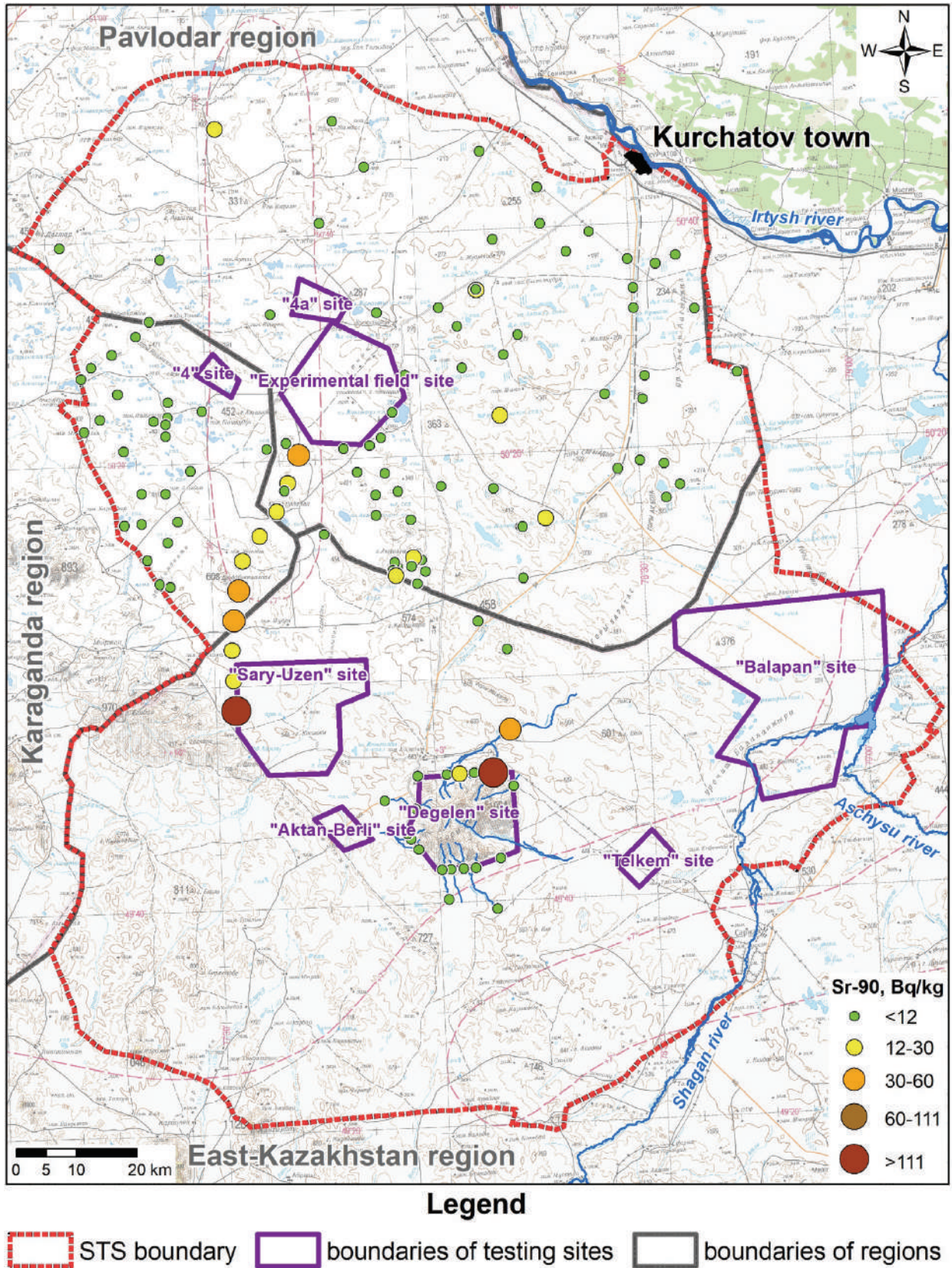
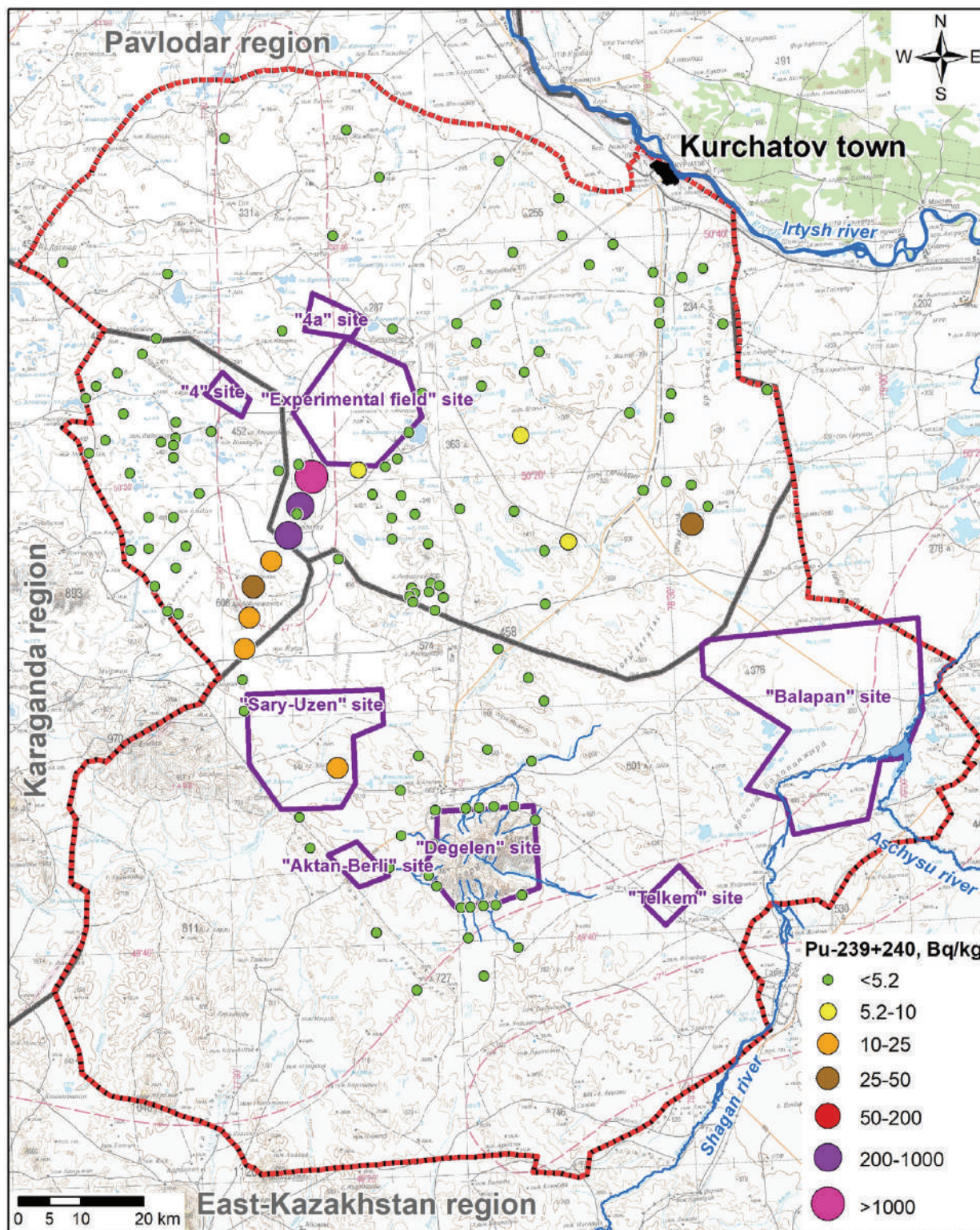


Figure 2.32. Distribution of ⁹⁰Sr in STS plant cover



Legend

- STS boundary
- boundaries of testing sites
- boundaries of regions

Figure 2.33. Distribution of $^{239+240}\text{Pu}$ in STS plant cover

In the region of radioactive water stream outlet, ^{137}Cs and ^{241}Am activity concentrations in plant cover is below detection limits of the methodological instrumentation in use. The content of $^{239+240}\text{Pu}$ in most cases does not exceed 0.2 Bq/kg, which is below the estimated maximum permissible level. For ^{90}Sr , plants show the excess of the maximum permissible level (^{90}Sr – 111 Bq/kg) [88] only in one research area on the boundary with the ‘Degelen’ site in the bed of the Karabulak creek.

The content of all radionuclides in plant cover of rest of STS territory is characterized by minima without exceeding permissible levels [88].

Conclusions

As a whole, the radiological state of flora in most of the STS territory including the former testing sites (beyond) poses no hazard from the perspective of the content of ^{241}Am , $^{239+240}\text{Pu}$, ^{90}Sr , ^{137}Cs when this area is used in the economic activities. The only exception is the fallout ‘plume’ region after the nuclear test conducted on September 24, 1951 and the outlet area of radioactive water streams on the boundary of the ‘Degelen’ site in the vicinity of Karabulak creek.

2.9 Radiological state of fauna

Fauna of vertebrate and invertebrate animals in the STS territory is rather diverse.

According to observations during the field work as well as the analysis of literature materials [1, 2; 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13], fauna of vertebrate animals in the study area was found to consist of 199 species including birds species – 147, mammal species – 45, reptile species – 7. 16 species are entered in Red Books of the International Union for Nature Protection and Kazakhstan.

It has to be noted that the existing variety of animal species in the STS study area should be regarded as probable based upon available literature data on habitats and points of their identification within earlier terms.

Ichthyofauna. Ichthyofauna's habitat in the study area is mostly in the Irtysh and Shagan river, the 'Atomic Lake', creeks of the Degelen mountain range as well as in numerous saline lakes. It is represented by 2 species of cyclostomes and 18 species of bony fishes (of 104 inhabiting Kazakhstan). The most numerous is the order of cyprinid fishes – 11 species. Valuable commercial fishes include sturgeons (Siberian sturgeon, sterlet), salmonids (pike) and anacantho (burbot). One form of salmonids order – nelma – is entered in Kazakhstan's Red Book.



Figure 2.34. Fishing out carp at the 'Atomic Lake' for research

Reptile class. Reptiles in the STS study area are represented by 7 species (49 species in Kazakhstan). The most numerous is the suborder of lizards – sunwatcher, stepperunner and sand lizard, which may populate the habitat very densely. The snake suborder is represented by 4 species, the most common and dominant of which is Pallas' coluber. The other 3 are rather rare and scarce [100].

Amphibian class. Amphibians are represented by two species – green toad (*Bufo viridis*) and moor frog (*Rana arvalis*). Both species were registered in the territory of the Degelen mountain range.



Figure 2.35. Male sand lizard

Bird class. Avifauna of the STS study area is highly diverse numbering 147 bird species of 15 orders (a total of 488 bird species in Kazakhstan). The most diverse are semi-aquatic birds. Anseriformes inhabit and nest along banks of rivers and lakes – 13 species; wading birds – 23 species. The number of small perching birds is also great – 51 species. The order of diurnal vermin (birds of prey) numbers 19 species. Rare and protected birds are a great many. 14 species are entered in Kazakhstan’s Red Book [89, 93, 102, 103, 104].

Mammal class. Of 178 mammal species inhabiting the territory of Kazakhstan, 45 species of 6 orders can be found in the STS territory. Most species belong to the order of rodents. Two species – mottled polecat (*Vormela peregusna*) of the order of vermin and argali (*Ovis ammon*) of the artiodactyle order are entered in Kazakhstan’s Red Book [103, 93, 97].



Figure 2.36. Steppe eaglelet



Figure 2.37. Argali captured by the trail camera at the 'Degelen' site

In the course of the field work, 4 species of mammals were registered in the STS territory. These refer to commercial and amateur hunting. They are European hare (*Lepus europaeus*),

common badger (*Meles meles*), red fox (*Vulpes vulpes*) and Siberian roe (*Capreolus pygargus*). 8 bird species were also registered being objects of commercial and amateur hunting. They are black grouse (*Lururus tetrix*), partridge (*Perdix perdix*), gray goose (*Anser anser*), mallard (*Anas platyrhynchos*), common teal (*A. crecca*), gadwall (*A. strepera*), pintail (*A. acuta*), common shoveler (*A. clupeata*). The International Union for Nature Protection categorized a sufficiently great number of saigas (*Saiga tatarica*) as CR (in the critical state). Individual groups of these animals exceeded 700-800 head. Up to 54 species of this animal were registered within the Degelen testing site.

The radiological state of fauna was assessed in two ways: by direct measurements of radionuclide concentrations in wild animals that were trapped as well as by calculation to determine the content of radionuclides in animals. The latter is based upon measurements of animals' diet and faeces, i.e. without capturing animals.

Direct measurements

To assess the radiological state of STS fauna, the content of radionuclide was determined in muscular tissues (in game) of wild animals. To this end, wild animals referring to amateur and commercial hunting were captured – European hare (*Lepus europaeus*), common badger (*Meles meles*), Siberian roe (*Capreolus pygargus*). Birds of being objects of commercial and amateur hunting were also selected – black grouse (*Lururus tetrix*), partridge (*Perdix perdix*), gray goose (*Anser anser*), mallard (*Anas platyrhynchos*), common teal (*A. crecca*), gadwall (*A. strepera*), pintail (*A. acuta*), common shoveler (*A. clupeata*). Activity concentrations of ^{137}Cs , ^{90}Sr , ^{241}Am and $^{239+240}\text{Pu}$ were determined in muscular tissues (in game) of captured animals.

Reported determinations of the content of radionuclides in muscular tissues (in game) of wild animals captured in STS areas, in which

nuclear tests were not conducted, showed that activities of ^{137}Cs , ^{90}Sr , ^{241}Am and $^{239+240}\text{Pu}$ do not exceed detection limits of the methodological instrumentation in use. For ^{137}Cs and ^{90}Sr , reported values of activity concentrations do not exceed permissible levels as specified by health standards 'Sanitary and Epidemiological Requirements for Radiation Safety Assurance' for game [48]. ^{241}Am and $^{239+240}\text{Pu}$ in game are not standardized.

Estimated radiological state of fauna

Due to a complicated capture of wild animals necessary for sampling muscular tissues (game) over a uniform grid, because of various factors (no animals around at the time of capture etc), a calculation technique was additionally applied to determine activity concentrations of radionuclides in fauna forms. This one is based upon the assumption that natural components included in the diet are the major contaminants of wild animals at places with no industrial facilities or other facilities of economic activities. Taking into account that the habitat of a wild animal may reach several hundred of square kilometers, it is hardly possible to determine activity concentrations of radionuclides in its diet. Therefore, it is assumed that activity concentrations of radionuclides in an animal's diet corresponds to the ones in faeces of that animal. Hence, the calculation technique is based upon the measurement of activity concentrations of radionuclides in an animal's faeces followed by conversion to the ones in an animal's body.

Since activity concentrations of ^{241}Am and $^{239+240}\text{Pu}$ in game are not standardized, game is not used in calculating radiation exposure. In addition, these radionuclides' migration properties are very low for food chains. Therefore, the estimate was only given to ^{137}Cs and ^{90}Sr . To determine activity concentrations of ^{137}Cs and ^{90}Sr in muscular tissues (in game) of wild animals, 168 hoofed animals' faeces samples

were collected (both wild and farm animals freely grazing) – roes, saigas, argali, horses by calculation. Samples were collected based on one sample per 100 km² in the study area over a relatively uniform grid (Figure 2.38).

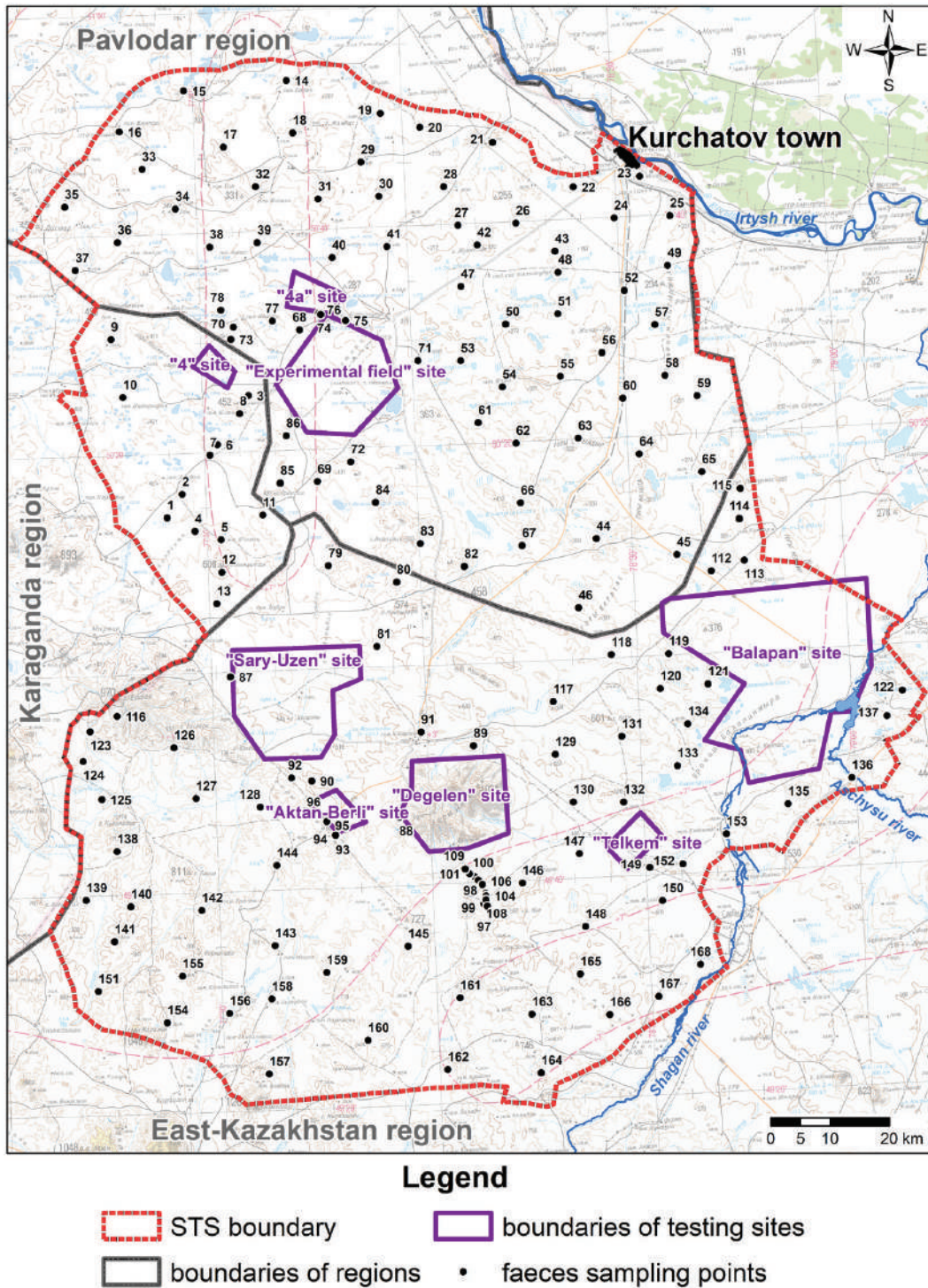


Figure 2.38. Schematic arrangement of sampling points of hoofed animals' faeces

Figures (Figure 2.39, Figure 2.40) show the distribution of activity concentrations of ^{137}Cs and ^{90}Sr in faeces of big hoofed animals relative to their locations in STS areas, in which no nuclear tests were conducted (beyond testing sites).

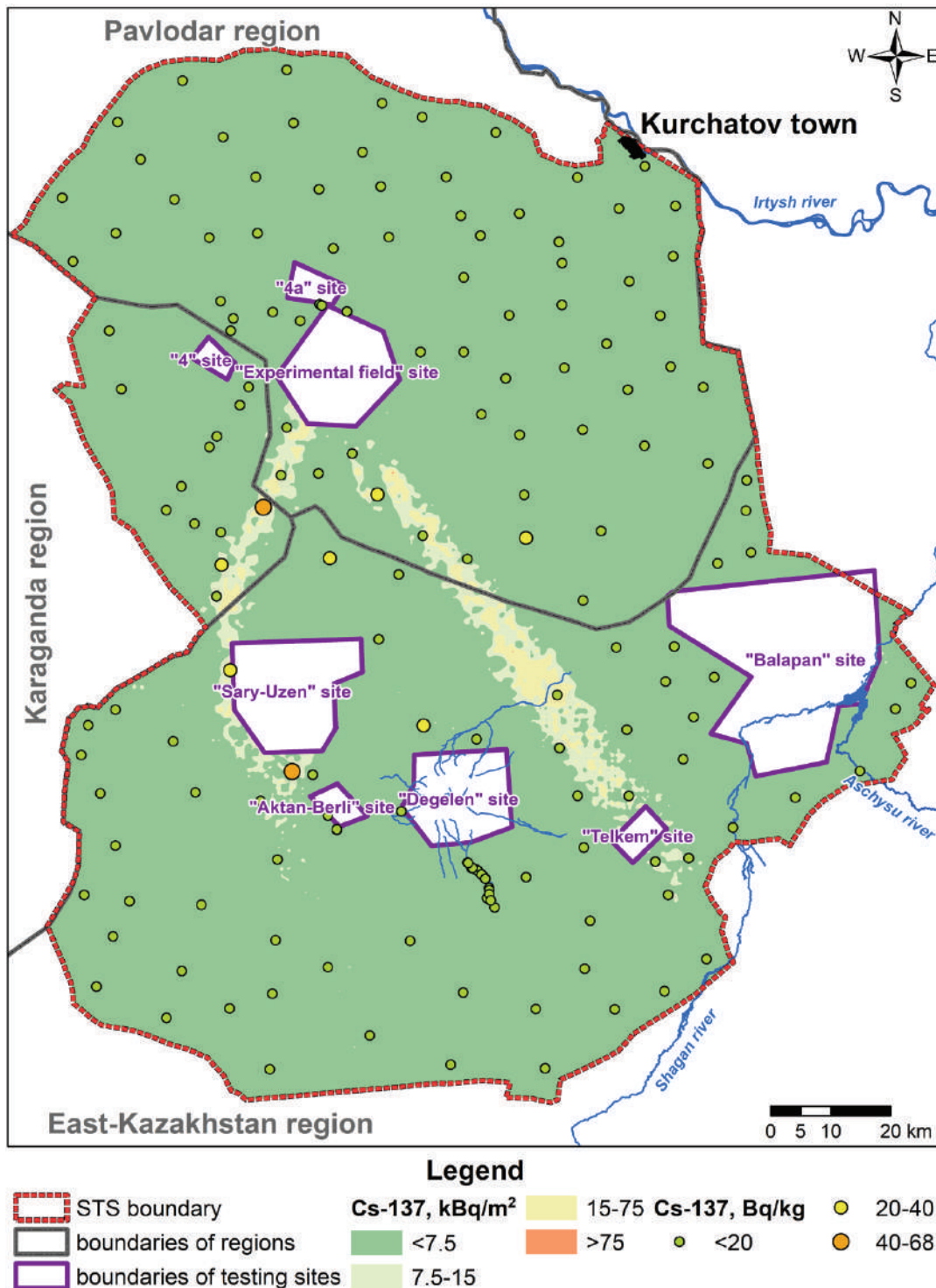


Figure 2.39. ^{137}Cs activity concentration in faeces of big hoofed animals

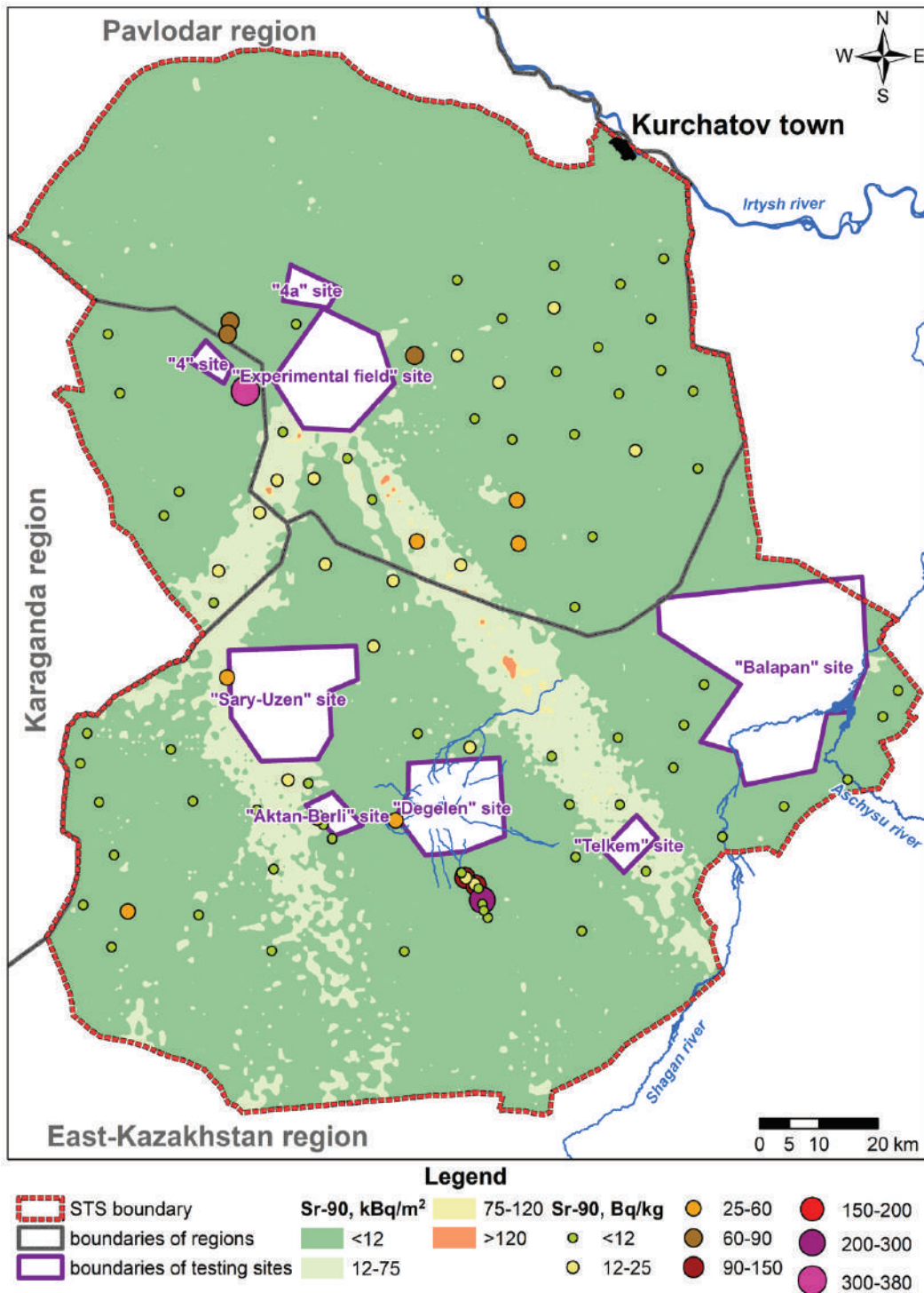


Figure 2.40. ⁹⁰Sr activity concentration in faeces of big hoofed animals

It is clear that elevated values of activity concentrations of radionuclides are registered in faeces of big hoofed animals inhabiting or grazing in areas adjacent to '4' and '4A', the 'Experimental Field', the 'Degelen' testing sites or in areas of elevated values of activity

concentrations of radionuclides in soil cover attributed to fallout in the form of nuclear plumes. At the same time, cases when elevated values of activity concentrations of radionuclides are single. For instance, with reported values of ^{137}Cs activity concentration, varying between <0.1 and 66.5 Bq/kg, the mean value for animals' faeces all over the STS territory was 4.9 Bq/kg. When ^{90}Sr activity concentration varied between <0.6 and 353.5 Bq/kg, its mean value was 22.6 Bq/kg. Because animals are moving around the STS territory freely including testing sites, it was unreasonable to consider an area of elevated values of activity concentrations of radionuclides in faeces of big hoofed animals. Therefore, when calculating possible concentrations of radionuclides in wild animals (in muscular tissues), mean values of activity concentrations of radionuclides were used for faeces of big hoofed animals ($^{137}\text{Cs} - 4.9$ Bq/kg, $^{90}\text{Sr} - 22.6$ Bq/kg).

Reported values of activity concentrations of radionuclides in faeces are used to calculate a possible intake of radionuclides by wild animals with the diet when feeding in the study area.

Activity concentrations of radionuclides in game were calculated by the ones in wild animals' faeces as per the formula below:

$$A_{m,i,n, \max} = V_{\text{forage}} \times A_{m,i,k,\text{forage}} \times K_{n,i,\text{forage}}$$

where:

$A_{m,i,n, \max}$ – the activity concentration of the i^{th} radionuclide in game;

V_{forage} – daily intake of forage, kg/day;

$A_{m,i,k,\text{forage}}$ – the activity concentration the i^{th} radionuclide in forage (faeces), Bq/kg;

$K_{n,i,\text{forage}}$ – transfer factor of the i^{th} radionuclide from forage per 1 kilogram (liter) of products.

Daily intake of the vegetative forage by saiga and roe was taken to be equal to 2 kg per day (as by sheep), by moose – 18 kg (as by horse) [105].

Transfer factors of radionuclides for the muscular tissue (game) are listed in the IAEA's document – TRS-472 (Ff – 'Feed transfer

coefficient') [106]. The assessment was given for hoofed animals that are the most common on the land plot under survey (moose, saiga, roe). For saiga and roe, Ff for sheep were taken, for moose – as with cattle. The table (Table 2.16) lists mean values of transfer factors of radionuclides for mutton and beef.

Table 2.16. Mean values of transfer factor of radionuclides for animals

Type of product	F _f for forage per 1 kg (l) of product	
	¹³⁷ Cs	⁹⁰ Sr
Mutton (for saiga, roe)	1,9×10 ⁻¹	1,5×10 ⁻³
Beef (for moose)	2,2×10 ⁻²	1,3×10 ⁻³

Values of activity concentrations of radionuclides in muscular tissues (in game) of wild animals were computed by a calculation technique as per the formula (1) and are presented in the table (Table 2.17).

Table 2.17. Predicted activity concentrations of radionuclides in meat of wild animals inhabiting STS areas, in which no nuclear weapon tests were conducted (areas between sites)

Type of product	The content of a radionuclide, Bq/kg					
	¹³⁷ Cs			⁹⁰ Sr		
	mean	minimum	maximum	mean	minimum	maximum
Meat (saiga, roe)	1,9	0,01	172,9	0,07	0,0004	2,8
Meat (moose)	1,9	0,08	114,9	0,5	0,002	58,5
Permissible level [48]		300			100	

Reported values of expected activity concentrations of ¹³⁷Cs in game vary between 0.01 and 173 Bq/kg, those of ⁹⁰Sr – between 0.0004 and 58.5 Bq/kg, which does not exceed permissible levels as specified by health standards 'Sanitary and Epidemiological Requirements for radiation Safety Assurance' for game [48].

Thus, it was found using direct measurements and a calculation technique that in the STS territory, in which no nuclear weapon tests were conducted, the excess of permissible values of activity concentrations of ^{137}Cs and ^{90}Sr in game is not expected. Expected maxima of ^{137}Cs and ^{90}Sr activity concentrations in game are 1.7 times (for both radionuclides) lower than permissible levels of the content of radionuclides in game according to health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48].

Conclusions

Thus, using direct measurements and a calculation technique, it was found that in the STS territory, beyond testing sites, no excess of permissible values of activity concentrations of ^{137}Cs and ^{90}Sr is expected in game. Because activity concentrations of ^{241}Am and $^{239+240}\text{Pu}$ in game are not standardized, game is not used in calculating radiation exposure. In addition, these radionuclides’ migration properties are very low for food chains. Therefore, their content in game was not assessed. However, direct measurements of the content of ^{241}Am and $^{239+240}\text{Pu}$ in game showed that these do not exceed detection limits of the methodological instrumentation in use.

2.10 Assessment of the radiological state of farm products

To calculate the public exposure dose, besides the data on the content of radionuclides in environmental compartments, the information on the content of radionuclides in crop and animal products produced on land plots under survey is also necessary. Therefore, the radiological state of these products was assessed as part of the comprehensive STS survey.

Virtually the entire study area by its natural features (soil-plant characteristics, relief) is represented by grazing lands. Therefore,

the major agricultural branch in the long term is cattle husbandry. However, owing to the introduction of unrestricted grazing, plant cover and, consequently, forage resources degrade since in this area grazing lands produce at least 80-90 % of the annual forage balance [107]. Therefore, subject to science-based arrangement of pasture areas, the development of small livestock farms engaged in breeding farm animals typical of this region – sheep, cows, horses, is prospective.

Steppe haymaking may also become common – periodically mown off farmlands, i.e. pastures with zonal vegetation of a steppe type. When comprehensive reclamation techniques are applied (application of mineral and organic fertilizers, microelements, irrigation etc.), it is possible to cultivate cereals in the study area (rye, wheat, barley, oats). However, this type of activity is most likely to be cost-ineffective due to the need for constructing lengthy irrigation systems related to the Irtysh river because there are hardly any fresh water bodies in the STS territory (except for creeks at the Degelen mountain range). To meet the needs of farm enterprise workers, it is possible to cultivate allotment crops at garden plots of these farms.

Thus, cattle husbandry is a potential agricultural branch in the study area based upon the principle ‘A farmer engaged in subsistence farming’. Of the crop production branch, garden plots may become common if arranged at these farms to meet the needs of farm enterprise workers for allotment crops.

The radiological state of crop products to be cultivated on the land plot under survey

No crop products are cultivated in the STS territory. However, data on a possible content of radionuclides in crop products is necessary to assess public radiation exposure through internal exposure at intake with foodstuffs. Therefore, it was decided to assess the radiological

state of crop products to be cultivated on the land plot under survey by calculation based upon data on the content of radionuclides in soil cover and transfer factors of radionuclides from soil to crops. The procedure in use to calculate human internal exposure doses [108] uses values of activity concentrations of radionuclides in such types of products as wheat (grain), potato (tubers), vegetables and fruits (berries). Therefore, calculation was performed exactly for these crops.

To assess the radiological state of crop products, activity concentrations of the major long-lived artificial radionuclides ^{137}Cs , ^{241}Am , $^{239+240}\text{Pu}$, ^{90}Sr therein were calculated.

Activity concentrations of radionuclides in crop products were calculated as per the following formula:

$$A_{m,i,n,prod} = A_{i,0-20} \times F_v \times \frac{K_{\%}}{100}$$

where:

$A_{m,i,prod}$ – the activity concentration of the i^{th} radionuclide in crop products, Bq/kg;

$A_{i,0-20}$ – the activity concentration of the i^{th} radionuclide in the 0-20 cm soil layer, Bq/kg;

F_v – transfer factors of radionuclides from soil to plants that determines the ratio of the activity concentration of the i^{th} radionuclide in crop products to the one in the 0-20 cm soil layer;

$K_{\%}$ – the percentage of the content of dry matter in the total mass of a crop sample.

When selecting values of transfer factors of radionuclides from soil to plants (F_v), first of all, the fact that they existed exactly in this region was taken into account. Specialists of the National Nuclear Center RK conducted a series of full-scale experiments in the STS territory aimed at obtaining parameters of the transfer of radionuclides to crop products at so-called ‘experimental farm enterprises’ arranged in radioactively contaminated areas. As a result of research undertaken, transfer parameters of artificial radionuclides from soil to the major

crop products cultivated in the region were obtained. These parameters can be applied in different predictive models to assess the migration of radionuclides in food chains, in assessing human radiation exposure and risks. The main outputs were published in reports and publications [109, 110, 111, 112].

Thus, transfer factors of radionuclides, reported from the series of 2010-2013 full-scale experiments conducted at the ‘Experimental Field’ site, were used to calculate activity concentrations of radionuclides in wheat, potato and vegetables [110]. Such coefficients were not reported for fruits, for which reason data from IAEA’s materials – TRS-472 was used instead (Table 2.18) [113].

Table 2.18. Values of transfer factors of radionuclides from soil to plants (F_v) for crop products

Crop products	F_v			
	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}$	^{241}Am
Wheat	$4,1 \times 10^{-4}$	$2,6 \times 10^{-2}$	$8,1 \times 10^{-4}$	$1,1 \times 10^{-3}$
Potato (tubers)	$3,3 \times 10^{-3}$	$1,9 \times 10^{-2}$	$4,3 \times 10^{-4}$	$1,1 \times 10^{-3}$
Vegetables	$1,1 \times 10^{-2}$	$1,1 \times 10^{-1}$	$1,2 \times 10^{-3}$	$8,1 \times 10^{-4}$
Fruits (berries)	$3,6 \times 10^{-2}$	$3,6 \times 10^{-1}$	$6,2 \times 10^{-5}$	$7,9 \times 10^{-4}$

Values of transfer factors of radionuclides from soil to plants in use were derived for dry weight of plants, and the dose calculation procedure uses values of radionuclide activities for raw crop products. Therefore, percentage values of dry matter in crop products listed in IAEA’s materials were used to convert the activity concentration on wet weight basis (Table 2.19) [114].

Table 2.19. Percentage of dry matter in the total weight of a crop sample ($K_{\%}$)

Plant species	Dry matter, %
Wheat (grain)	88,0

Potato (tubers)	49,0
Vegetables	28,0
Fruits (berries)	18,4

Values listed for cabbage and grapes accordingly (as maxima in their subgroups) were used to convert dry weight to wet weight of vegetables and fruits.

Expected activity concentrations of radionuclides were calculated for each areal survey point (over 20,000 points). As a reminder, values of activity concentrations of radionuclides in the 0-20 soil layer ($A_{i,0-20}$) were derived based upon values of activity concentrations of radionuclides in the 0-5 cm soil layer and upon the information on the vertical distribution nature of radionuclides in the soil profile. It is this depth, as mentioned above, that is used with transfer factors of radionuclides from soil to crop products. Since the comprehensive survey of the STS territory was conducted 2008 through 2021, activity concentrations of radionuclides in the 0-5 cm given their half-lives as of 2021 were previously recalculated.

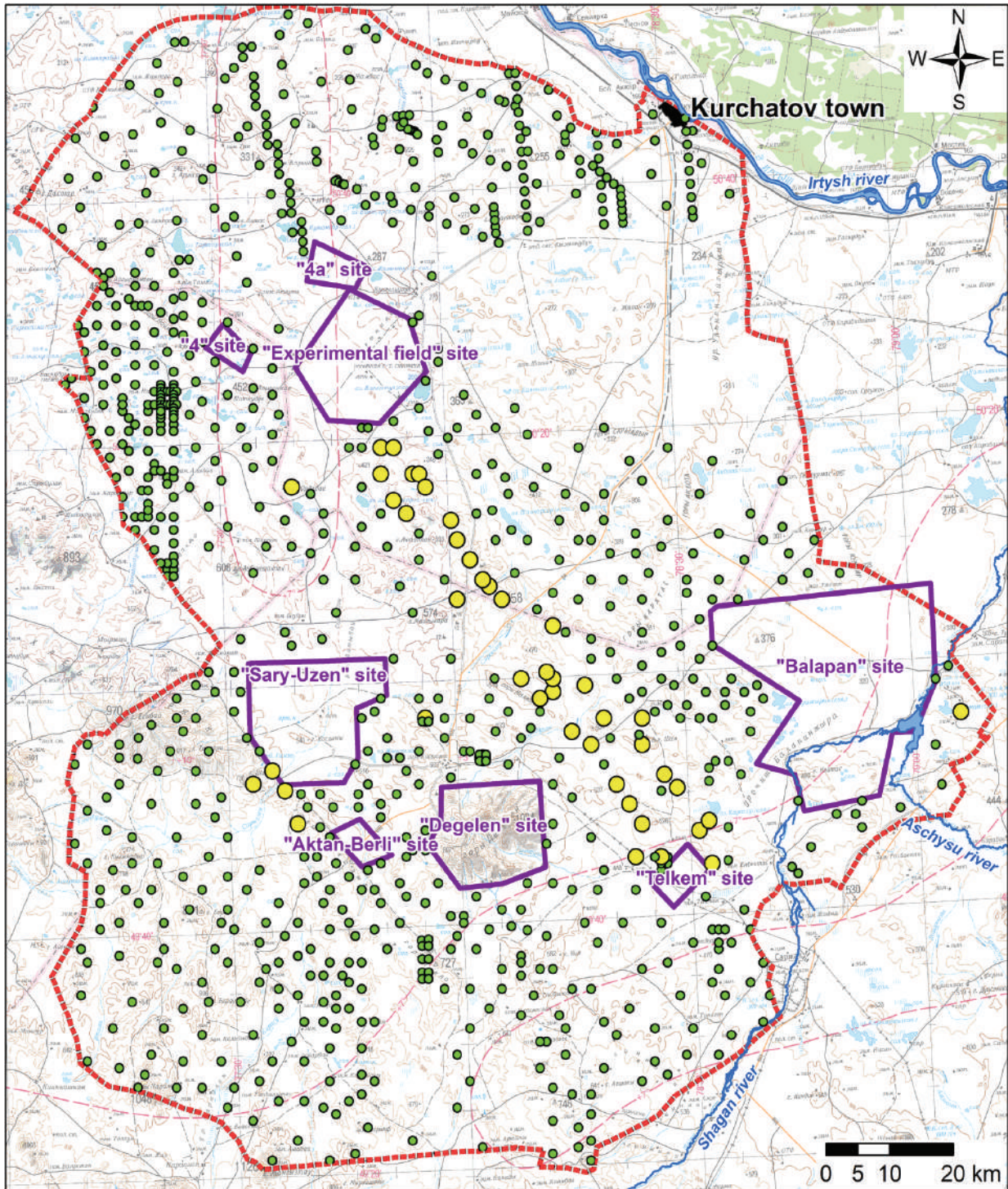
Thus, value ranges and mean values of calculated activity concentrations of ^{137}Cs , ^{241}Am , $^{239+240}\text{Pu}$ and ^{90}Sr for crop products compared to permissible levels of their content in products are listed in the table (Table 2.20).

Table 2.20. Activity concentrations of radionuclides in crop products

Type of product	Radionuclide	Mean	Minimum	Maximum	Permissible level
Wheat (grain)	^{241}Am	0,001	$1,3 \times 10^{-5}$	0,3	4
	^{137}Cs	0,003	$2,4 \times 10^{-6}$	0,1	70
	^{90}Sr	0,61	0,0002	72	40
	$^{239+240}\text{Pu}$	0,007	$5,5 \times 10^{-5}$	3,1	4
Potato (tubers)	^{241}Am	0,0007	$6,9 \times 10^{-5}$	0,2	5
	^{137}Cs	0,1	$1,1 \times 10^{-5}$	0,7	500
	^{90}Sr	0,3	$9,7 \times 10^{-5}$	29	50
	$^{239+240}\text{Pu}$	0,002	$1,6 \times 10^{-5}$	0,9	5

Vegetables	²⁴¹ Am	0,0003	$2,9 \times 10^{-6}$	0,07	4
	¹³⁷ Cs	0,02	2×10^{-5}	1,2	120
	⁹⁰ Sr	0,8	0,0003	97	40
	²³⁹⁺²⁴⁰ Pu	0,003	$2,6 \times 10^{-5}$	1,5	4
Fruits (berries)	²⁴¹ Am	$8,4 \times 10^{-5}$	$8,6 \times 10^{-6}$	0,02	3
	¹³⁷ Cs	0,05	4×10^{-5}	2,4	40
	⁹⁰ Sr	1,8	0,0007	209	30
	²³⁹⁺²⁴⁰ Pu	0,00012	$8,7 \times 10^{-5}$	0,05	3

Permissible levels of the content of ¹³⁷Cs and ⁹⁰Sr in crop products are specified in Health Standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48]. The content of ²³⁹⁺²⁴⁰Pu and ²⁴¹Am in foodstuffs is not standardized. However, because the annual limit on intake with food for the public as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48] is one order of magnitude lower than the same quantity for ⁹⁰Sr (²³⁹⁺²⁴⁰Pu – 2.4×10^3 Bq/year, ²⁴¹Am – 2.7×10^3 Bq/year, ⁹⁰Sr – 1.3×10^4 Bq/year), given ²³⁹⁺²⁴⁰Pu and ²⁴¹Am high radiotoxicity, one can assume that their permissible levels will be one order of magnitude lower than for ⁹⁰Sr. Permissible levels of ²³⁹⁺²⁴⁰Pu and ²⁴¹Am in the table (Table 2.20) are listed on this basis. Thus, expected maxima for ¹³⁷Cs in crop products were: for wheat – 0.1 Bq/kg, for potato – 0.7 Bq/kg, for vegetables – 1.2 Bq/kg and for fruits – 2.4 Bq/kg. This is 700, 714, 100 and 16.7 times, respectively, is lower than permissible levels. Expected maxima for ⁹⁰Sr in crop products were: for wheat – 72 Bq/kg, for vegetables – 97 Bq/kg and for fruits – 209 Bq/kg. This is 1.8, 2.4 and 7 times, respectively, higher than permissible levels. The maximum content of ⁹⁰Sr in potato is 29 Bq/kg, which is 1.7 times lower than permissible levels. It has to be noted that all values of activity concentrations of ⁹⁰Sr exceeding permissible levels [48], were registered in the vicinity of the ‘4’ testing site and in fallout areas in the form of plumes (Figure 2.41, Figure 2.42, Figure 2.43, Figure 2.44).



Legend


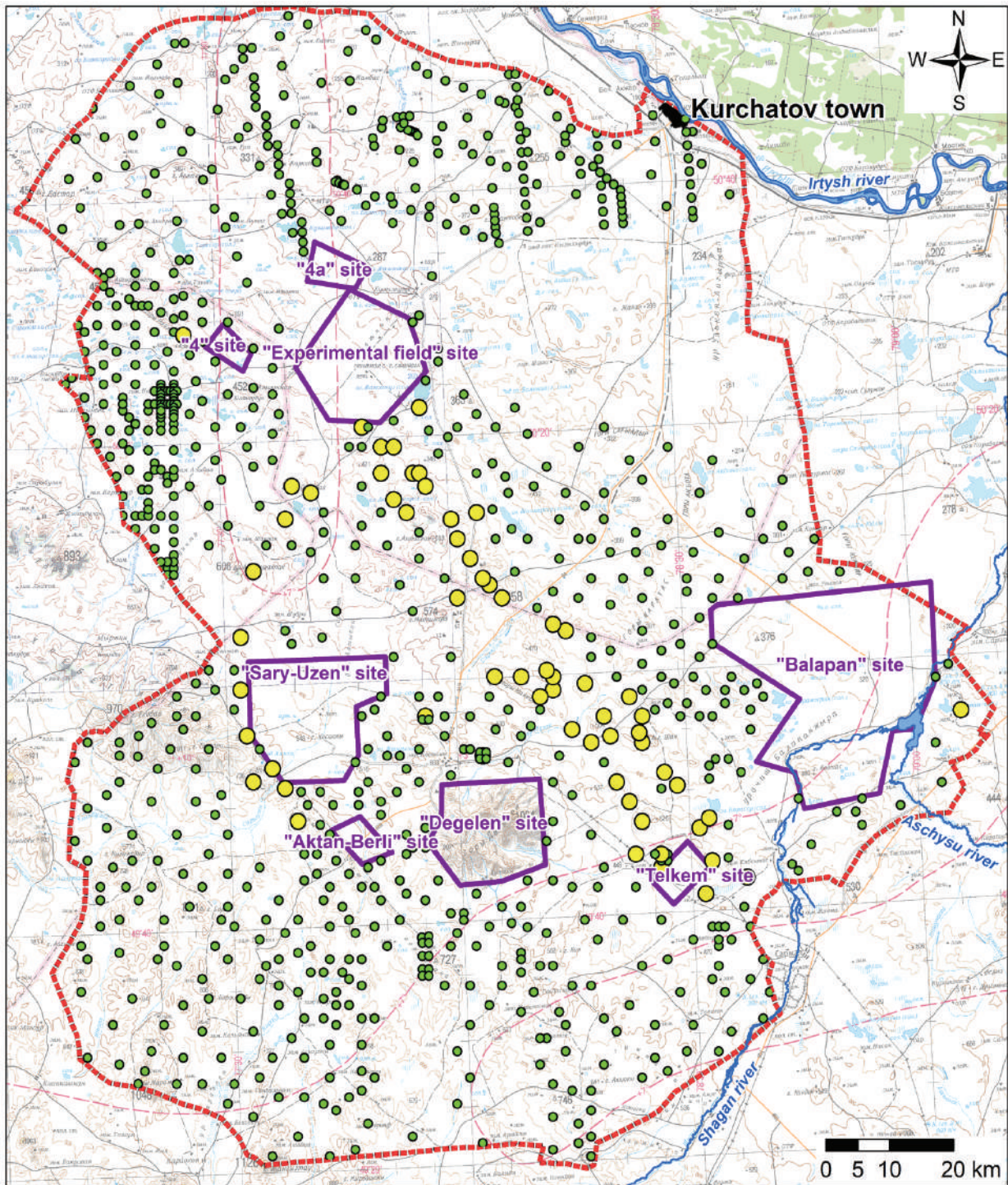
- | | | |
|---|-----------------------------|---|
|  | STS boundary | Sr-90 in potatoes, Bq/kg |
|  | boundaries of testing sites |  <math>< 50</math> |
| | |  >50 |

Figure 2.41. Distribution of predicted ^{90}Sr activity concentration in potato of the STS territory



Legend





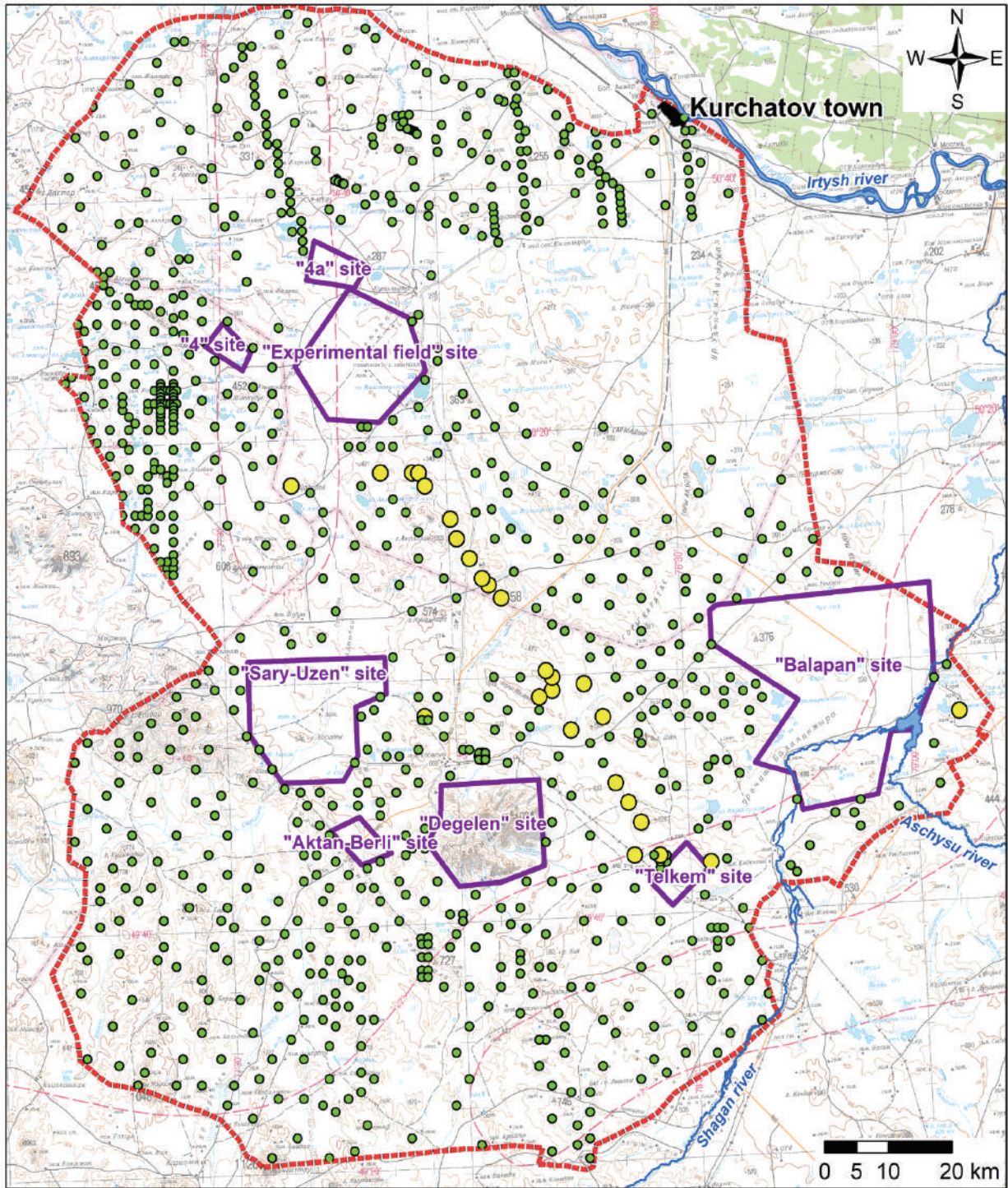
- | | | |
|---|-----------------------------|---|
|  | STS boundary | Sr-90 in vegetables, Bq/kg |
|  | boundaries of testing sites |  <40 |
| | |  >40 |

Figure 2.42. Distribution of predicted ⁹⁰Sr activity concentration in vegetables of the STS territory



Legend





- | | |
|---|---|
|  STS boundary | Sr-90 in wheat, Bq/kg |
|  boundaries of testing sites |  <40 |
| |  >40 |

Figure 2.43. Distribution of predicted ⁹⁰Sr activity concentration in wheat of the STS territory

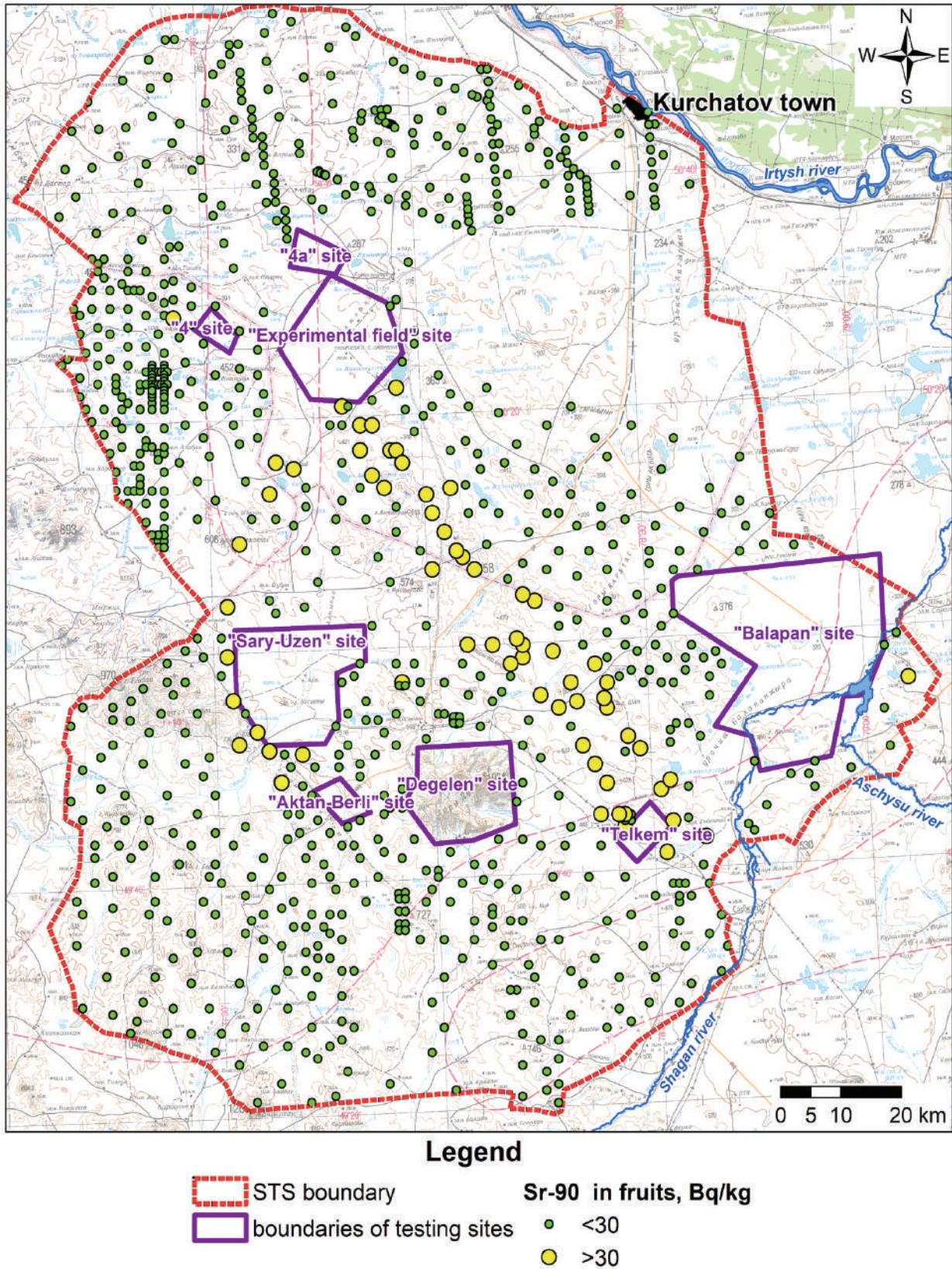


Figure 2.44. Distribution of predicted ^{90}Sr activity concentration in fruits of the STS territory

Expected maximum activity concentrations of $^{239+240}\text{Pu}$ and ^{241}Am for all species of crop products do not exceed estimated permissible levels.

Conclusions

Thus, based upon survey results on the radiological state of crop products, it was found using a calculation technique that if crop products (wheat, potato, fruits and vegetable) are cultivated in the test site area, on average, no excess of activity concentrations of radionuclides is expected. However, in areas of lengthy fallout plumes and in the vicinity of the '4' testing site, the permissible level of the content of ^{90}Sr is exceeded for wheat, vegetables and fruits. It is worth noting that the calculation made is rather conservative because it does not take into account a range of agrotechnical measures prior to cultivation of crop products. For instance, to improve soil fertility under STS conditions, it is necessary to apply organic fertilizers, which will undoubtedly result in significant dilution of radionuclide concentrations in soil cover. Application of potassium and phosphorous fertilizers entails a reduced transfer of ^{137}Cs and ^{90}Sr since the latter are potassium and phosphorous analogs, respectively. Soil plowing deeper than 20 cm will cause the initial activity in soil prepared for planting crop products to decrease.

Radiological state of animal products produced in the land plot under survey

Farm animals bred in the STS study area are fat-tailed rough-haired sheep, cattle – cross breeds of beef and dairy breeds as well as horses of the Kazakh breed (Djabe, Abai).

Farm animals are kept stabled. Cattle grazing system – free or unrestricted. Pastures of this territory are used all the year round. Some areas are only used in the summertime when cattle grazing on

natural pastures begins in the first decade of May and finishes early in October.

Assessment of the radiological state of animal products by experiment

To assess the quality of crop products cultivated in the STS territory in which no nuclear weapon tests were conducted, animal products were sampled in individual summer and winter huts. Meat and milk were mostly sampled. Bone tissues to determine ^{90}Sr were also additionally sampled because they are the major accumulation spots of this radionuclide. A total of 20 milk, 20 meat (mutton, beef, horse beef), 6 bone tissue samples were collected in the course of research.

Meat products were sampled raw and/or frozen weighing from 0.7 to 1.2 kg, dairy products – 0.5 to 1 l. Slaughter date and animal species were recorded for meat products.

The major dose-forming and the most common radionuclides at STS are ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$. Therefore, when assessing the radiological state of animal products obtained at STS, exactly these radionuclides were addressed. To determine activity concentrations of studied radionuclides in samples of crop products, γ -spectrometric and radiochemical analyses were carried out as per standardized guidelines with calibrated equipment [114, 115]. Previously, samples were prepared for the analysis. The gamma-spectrometric measurement (^{137}Cs , ^{241}Am) of raw meat and milk samples was performed. At the same time, meat was cleared of connective-fatty tissue and homogenized. To determine ^{90}Sr , milk, meat and bone tissue were dried and ashed at 500°C (bone tissue was previously deboned). Next, using a radiochemical technique, ^{90}Sr isotopes were isolated in ash.

As a result of laboratory analyses, no quantitative values of activity concentrations of radionuclides were derived for any milk, meat and

bone tissue samples. All values proved to be below the detection limit of the methodological instrumentation in use and, hence, did not exceed permissible levels of the content of radionuclides in animal products listed in the table (Table 2.21).

The content of $^{239+240}\text{Pu}$ and ^{241}Am in foodstuffs is not standardized. Because the annual limit on intake with food for the public is one order of magnitude lower than the same quantity for ^{90}Sr ($^{239+240}\text{Pu}$ – 2.4×10^3 Bq/year, ^{241}Am – 2.7×10^3 Bq/year, ^{90}Sr – 1.3×10^4 Bq/year) as per the health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48], one can assume that their permissible levels will be one order of magnitude lower than for ^{90}Sr . Data on $^{239+240}\text{Pu}$ and ^{241}Am is listed on this basis.

Table 2.21. Permissible levels of the content of radionuclides in animal products

Groups of foodstuffs	Activity concentrations of radionuclides, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}\text{Pu}^*$	$^{241}\text{Am}^*$
Meat, meat products and subproducts	200	50	5	5
Raw milk, raw dairy cream	100	25	2,5	2,5
Note: *– values derived by calculation				

Conclusions

Thus, the experimental assessment of the content of radionuclides in animal products obtained in the study area showed that products by their radiological characteristics pose no hazard if consumed and comply with health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ (estimated maximum permissible levels were used for ^{241}Am and $^{239+240}\text{Pu}$ as their content is not standardized) [48].

Assessment of the radiological state of animal products by calculation

Since it is impossible to assess the radiological state of animal products all over the STS territory due to the absence of farm enterprises in most of the test site, because there are no quantitative values of activity concentrations in samples of animal products that were analyzed and that are necessary for assessing the internal exposure dose from animal products, the radiological state of animal products was additionally assessed by calculation. This technique for determination of activity concentrations of radionuclides in animal products is based upon measurements of the ones in faeces of big hoofed animals captured in the STS territory proceeding from the assumption that activity concentrations of radionuclides in an animal's diet correspond to the ones in that animal's faeces. That is, activity concentrations of radionuclides in an animal's faeces are equal to the ones in forage eaten by that animal. Meat and dairy products were assessed. Sheep meat (mutton), horse beef and beef were chosen as meat products and cow milk as a dairy product being the most common in the study area.

Activity concentrations ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$ in animal products were determined by calculation as per the procedure described in Section 2.9 Radiological state of fauna. Section 2.9 also describes the distribution nature of activity concentrations of ^{137}Cs and ^{90}Sr in faeces of big hoofed animals by their locations in STS areas in which no nuclear weapon tests were conducted (Figure 2.36, Figure 2.37).

Distributions of activity concentrations of ^{241}Am and $^{239+240}\text{Pu}$ in faeces of big hoofed animals in the STS territory are depicted in figures (Figure 2.45, Figure 2.46).

Activity concentrations of ^{137}Cs , ^{90}Sr , ^{241}Am and $^{239+240}\text{Pu}$ in faeces samples were determined by means of γ -spectrometric and radiochemical analyses as per standardized guidelines with calibrated equipment [115, 116].

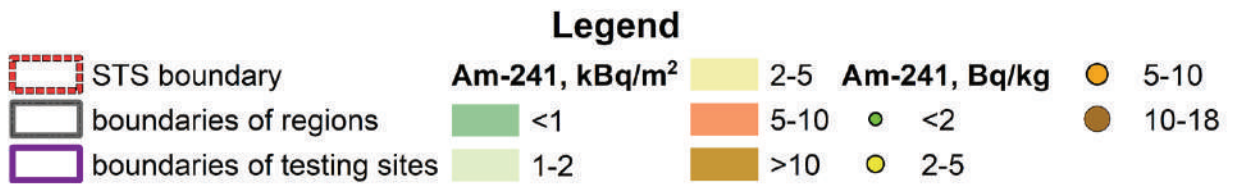
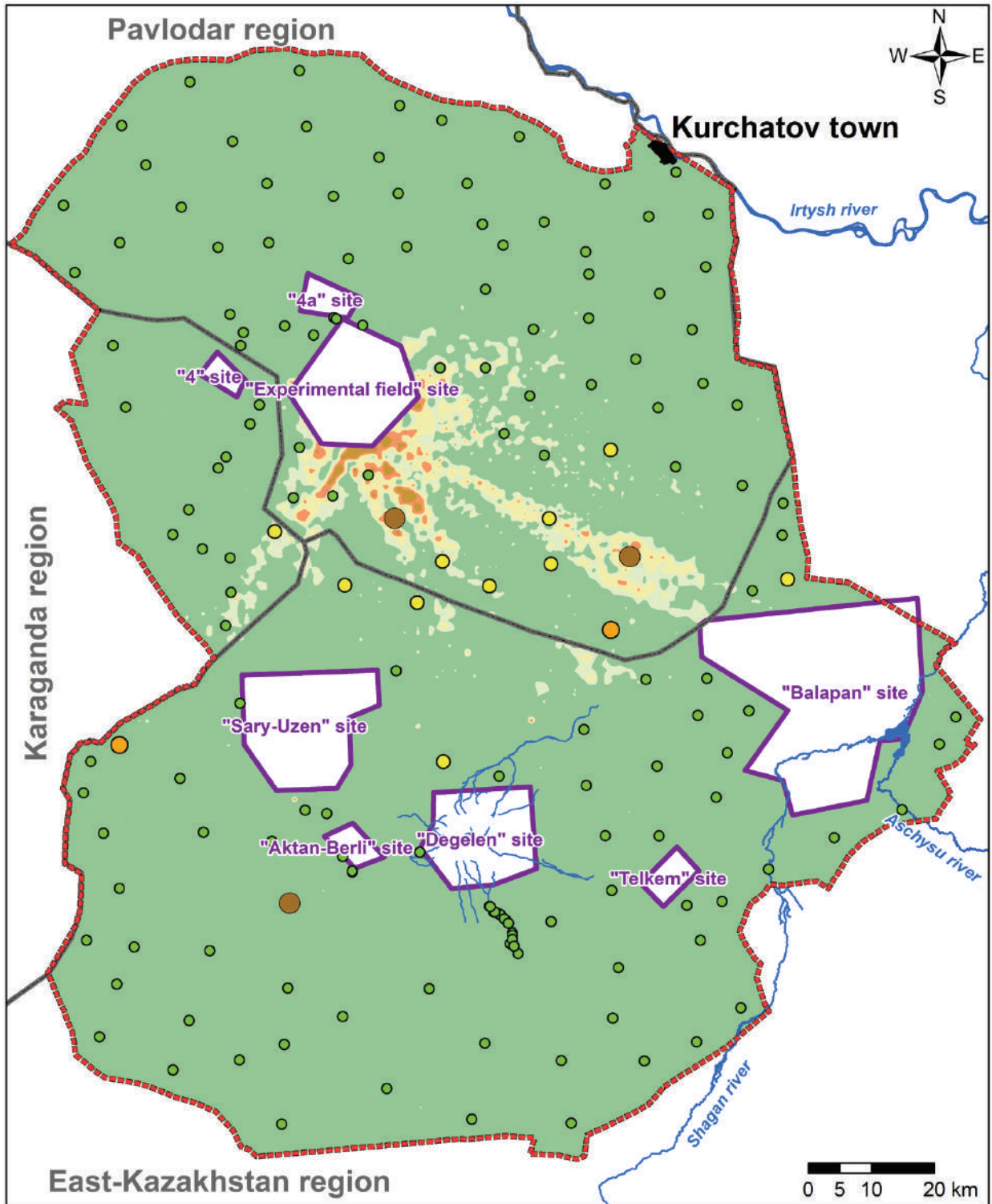


Figure 2.45. ²⁴¹Am activity concentration in faeces of big hoofed animals

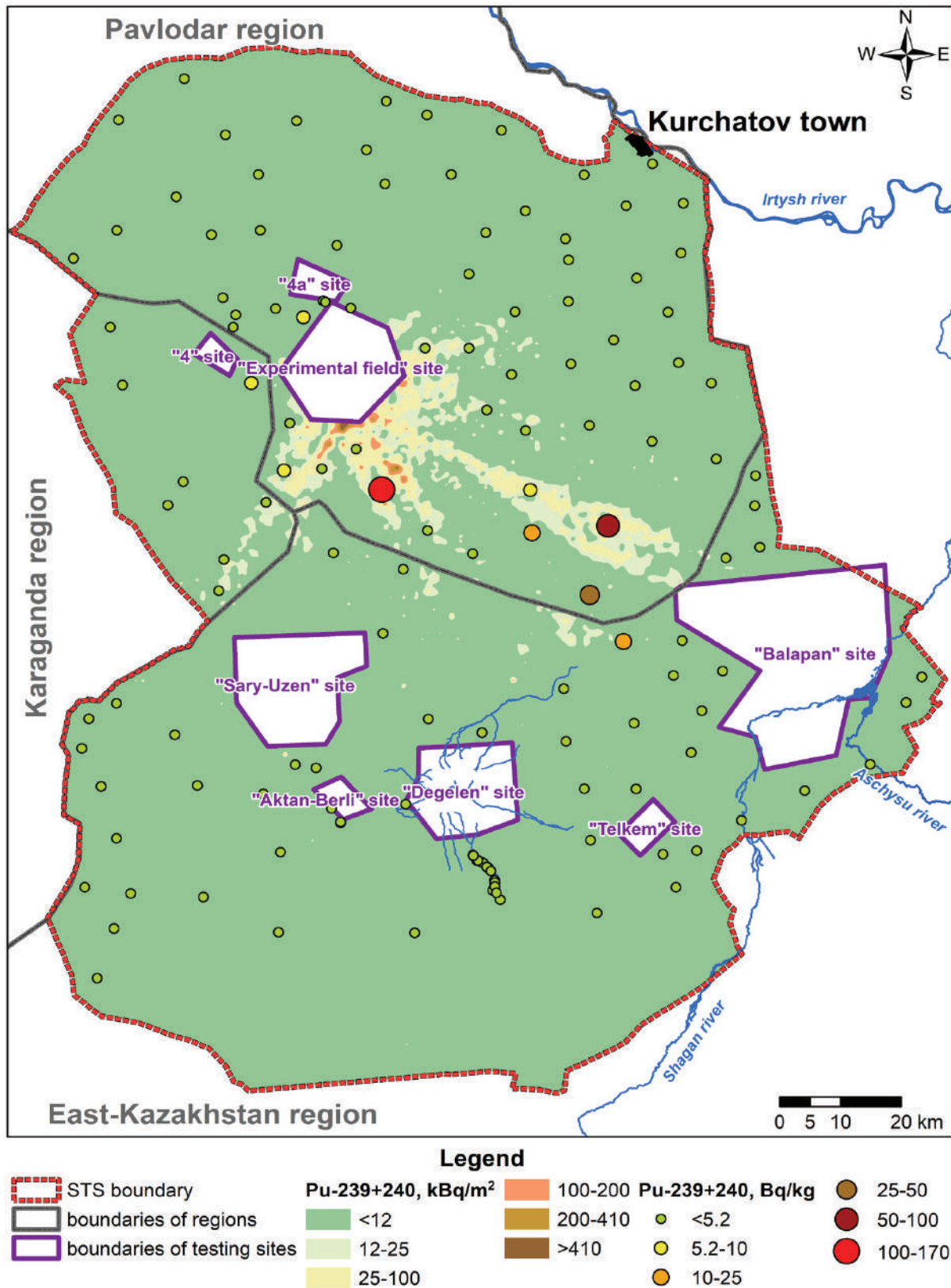


Figure 2.46. ²³⁹⁺²⁴⁰Pu activity concentration in faeces of big hoofed animals

As with ¹³⁷Cs and ⁹⁰Sr, one can note that elevated values of activity concentrations of ²⁴¹Am and ²³⁹⁺²⁴⁰Pu are registered in faeces of big

hoofed animals inhabiting or grazing in areas adjacent to testing sites, in particular, to the ‘Experimental Field’ site or in regions of elevated activity concentrations of radionuclides in ground cover caused by fallout in the form of nuclear plumes. At the same time, elevated values of activity concentrations of these radionuclides as with ^{137}Cs and ^{90}Sr are few. With ^{241}Am activity concentration varying between <0.06 and 18 Bq/kg, the mean value was 0.9 Bq/kg. With $^{239+240}\text{Pu}$ activity concentration varying between <0.01 and 170 Bq/kg, its mean value was 3.0 Bq/kg. Due to the fact that animals move around the STS territory freely including around testing site areas, it is unreasonable to consider a region of elevated values of activity concentrations of radionuclides in faeces of big hoofed animals. Therefore, when calculating activity concentrations of radionuclides in animal products, mean values of these were used for faeces of big hoofed animals ($^{137}\text{Cs} - 4.9$ Bq/kg, $^{241}\text{Am} - 0.9$ Bq/kg, $^{90}\text{Sr} - 22.6$ Bq/kg, $^{239+240}\text{Pu} - 3.0$ Bq/kg).

Activity concentrations of radionuclides in animal products were calculated as per the formula below:

$$A_{m,i,prod.} = V_{forage} \times A_{m,i,forage} \times T_{f,i,forage},$$

where:

V_{forage} – daily intake of forage, kg/day;

$A_{m,i,forage}$ – the activity concentration of the i^{th} radionuclide in herbivores’ faeces, Bq/kg;

$T_{f,i,forage}$ – transfer factor of the i^{th} radionuclide from forage per 1 kilogram (liter) of products.

Transfer factors of radionuclides for products were taken from the IAEA’s document – TRS-472 (F_f – ‘Feed transfer coefficient’) [1]. The assessment was given to hoofed animals that are the most common on the land plot under survey (cattle, small cattle, horses). The table (Table 2.22) lists mean values of transfer factors of radionuclides for mutton, beef, horse beef and cow milk.

Table 2.22. Transfer factors of radionuclides for animal products ($K_{n,i,forage}$)

Type of product	T_f from forage per 1 kg (l) of products			
	^{137}Cs	^{90}Sr	^{241}Am	$^{239+240}\text{Pu}$
Mutton	$1,9 \times 10^{-1}$	$1,5 \times 10^{-3}$	$1,1 \times 10^{-4}$	$5,3 \times 10^{-5}$
Cow milk	$4,6 \times 10^{-3}$	$1,3 \times 10^{-3}$	$4,2 \times 10^{-7}$	$1,0 \times 10^{-5}$
Beef	$2,2 \times 10^{-2}$	$1,3 \times 10^{-3}$	$5,0 \times 10^{-4}$	$1,1 \times 10^{-6}$
Horse beef	$2,2 \times 10^{-2}$	$1,3 \times 10^{-3}$	$5,0 \times 10^{-4}$	$1,1 \times 10^{-6}$

To calculate activity concentrations of radionuclides in animal products, daily intake of forage (V_{forage}) by sheep, cows and horses is taken to be equal to 2 kg/day, 15 kg/day and 18 kg/day, respectively. [117]. Based upon listed data, expected values of activity concentrations of radionuclides in animal products were calculated.

Table 2.23. Expected values of activity concentrations of radionuclides in animal products

Type of product	Radionuclide	Mean	Minimum	Maximum	Permissible level
Cow milk	^{241}Am	$5,7 \times 10^{-6}$	$3,8 \times 10^{-7}$	$1,1 \times 10^{-4}$	2,5
	^{137}Cs	$3,4 \times 10^{-1}$	$9,0 \times 10^{-4}$	67,8	100
	^{90}Sr	$4,4 \times 10^{-1}$	$3,1 \times 10^{-3}$	22,8	25
	$^{239+240}\text{Pu}$	$4,5 \times 10^{-4}$	$1,5 \times 10^{-6}$	$2,6 \times 10^{-2}$	2,5
Mutton	^{241}Am	$2,0 \times 10^{-4}$	$1,3 \times 10^{-5}$	$4,0 \times 10^{-3}$	5
	^{137}Cs	1,9	$1,1 \times 10^{-2}$	172,9	200
	^{90}Sr	$6,8 \times 10^{-2}$	$3,6 \times 10^{-4}$	2,8	50
	$^{239+240}\text{Pu}$	$3,2 \times 10^{-4}$	$4,0 \times 10^{-7}$	$2,9 \times 10^{-2}$	5
Beef	^{241}Am	$6,8 \times 10^{-3}$	$4,5 \times 10^{-4}$	$1,4 \times 10^{-1}$	5
	^{137}Cs	1,6	$7,1 \times 10^{-3}$	95,8	200
	^{90}Sr	$4,4 \times 10^{-1}$	$1,8 \times 10^{-3}$	48,8	50
	$^{239+240}\text{Pu}$	$5,0 \times 10^{-5}$	$1,3 \times 10^{-8}$	$7,7 \times 10^{-1}$	5

Horse beef	^{241}Am	$8,1 \times 10^{-3}$	$5,4 \times 10^{-3}$	$1,6 \times 10^{-1}$	5
	^{137}Cs	1,9	$8,5 \times 10^{-3}$	115,0	200
	^{90}Sr	$5,3 \times 10^{-1}$	$2,2 \times 10^{-3}$	58,5	50
	$^{239+240}\text{Pu}$	$5,9 \times 10^{-5}$	$1,6 \times 10^{-8}$	$9,2 \times 10^{-1}$	5
–					

Permissible levels of the content of ^{137}Cs and ^{90}Sr in animal products as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48]. Permissible levels of the content of $^{239+240}\text{Pu}$ and ^{241}Am were reported by calculation. According to findings, maxima of ^{137}Cs activity concentration in meat and milk were 172.9 Bq/kg and 67.8 Bq/kg, for ^{90}Sr – 58.5 Bq/kg and 22.8 Bq/kg, respectively. Maxima of $^{239+240}\text{Pu}$ activity concentration in meat and milk were 7.7×10^{-1} Bq/kg and 2.6×10^{-2} Bq/kg, respectively, ^{241}Am – 1.6×10^{-1} Bq/kg and 1.1×10^{-4} Bq/kg, respectively.

Conclusions

Determination of a possible content of radionuclides in animal products if produced in areas in which no nuclear weapon tests were conducted, showed that no excess of permissible levels as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ is expected in meat and dairy products (estimated maximum permissible levels were used for ^{241}Am and $^{239+240}\text{Pu}$ as their content is not standardized) [48].

2.11 Assessment of public radiation exposure

Regulation of activities in the STS territory and justification of rehabilitation measures require radiation risks to be assessed due to an activity, which in fact takes place or is planned in this territory. This requires average annual effective exposure doses to man when living and carrying out economic activities at the test site to be calculated.

Categorization of radioactively contaminated areas by levels of potential hazard to the public and the environment is also based upon exposure doses. The dose approach is specified in the main legislative and regulatory acts that govern radiation safety matters [118]. According to assessment criteria for environmental situation in areas, the main criterion defining the degree of human radioecological safety is a mean annual value of the effective dose received from man-made sources of ionizing radiation.

Artificial radionuclides entering a human body with inhaled air, water and food additionally contribute to the committed annual effective exposure dose to the public defining the degree of radiological hazard in the STS territory.

In order to take into account all parameters in assessing radiation exposure, it is necessary to define human behavior conditions. I.e., in assessing doses objectively, one has to address a typical behavior scenario for a man who is engaged in plant cultivation or cattle husbandry while consuming crop and animal products in this territory. Foodstuffs of vegetative and animal origin are one more link in the biological chain through which radioactive substances may directly enter a human body. Therefore, determination of the contamination level of foodstuffs with radioactive substances was a condition necessary to define the radiological situation completely since these were consumed by residents living in settlements of the impact zone of nuclear tests.

To assess public internal exposure doses for those who live in the STS territory and consume local products, one has to know the amount of radionuclides to enter a human body with food and water. As reported by the inquiry of residents living in Dolon, Kanonerka, Beskaragai settlements located in areas adjacent to the test site as well as residents of summer and winter huts that are also in the STS territory, it was found that the amount and pattern of their food are not the same. Therefore, to assess internal exposure doses from the intake of radionuclides with foodstuffs, values for the annual consumption

were chosen from minimum consumption rates of the main foodstuffs for different social RK's population groups [119].

Public exposure doses were calculated based upon determinations of the content of radionuclides in environmental compartments, crop and animal products produced in the STS territory.

Doses were calculated as per methodological recommendations for determination of the effective dose of ionizing radiation to personnel and population [120]. Both variables such as the content of radionuclides in environmental compartments and constants such as consumption rate of foodstuffs and water, the volume of inhaled air, transfer factors of radionuclides for food chains and the average annual dust load, breathing rate etc. were source data for calculations.

Potential human exposure pathways in the STS territory are:

- external exposure to gamma-radiation from artificial radionuclides contained in topsoil;
- external exposure from contaminated soil on skin;
- internal exposure through inhalation of radionuclides;
- internal exposure from the intake of radionuclides with water and foodstuffs produced in the study area;
- internal exposure through accidental ingestion of contaminated soil.

Earlier assessments of doses to the public living and carrying out activities in the STS territory showed that the contribution to the total annual effective dose of external exposure from beta-radiation, external exposure from contaminated soil on skin and internal exposure through accidental ingestion of contaminated soil is less than 0.1 % of the total dose for all human exposure pathways of ionizing radiation in question [121, 122]. Estimated committed annual dose of internal exposure through ingestion of radionuclides to a human body with contaminated food showed that the contribution of this exposure pathway will be 2-4 orders of magnitude lower than the external gamma dose from a contaminated soil surface.

Thus, exposure pathways to be mainly contributing to the formation of the committed annual effective dose to the public when living in the STS territory are:

- external exposure to gamma-radiation from artificial radionuclides contained in topsoil;
- internal exposure through inhalation of radionuclides;
- internal exposure from the intake of radionuclides with water and foodstuffs produced in the study area.

The major dose-forming artificial radionuclides in the STS territory are ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$, ^{241}Am and ^3H in water.

General dose calculation procedure

The committed annual effective dose E_{ef} from artificial radionuclides is expressed as the sum of partial doses of the j^{th} factors of exposure to radiation:

$$E_{ef} = E_{\gamma} + E_{inh} + E_{ing}$$

where:

E_{ef} – average annual effective exposure dose to the public from artificial radionuclides, Sv;

E_{γ} – external exposure dose from gamma-radiation of artificial radionuclides contained in topsoil, Sv/year;

E_{inh} – internal exposure dose through inhalation of radionuclides, Sv/year;

E_{ing} – internal exposure dose from the intake of radionuclides with water and foodstuffs produced in the study area, Sv/year.

External gamma dose

The dose from external gamma-radiation of radionuclides from the underlying surface was estimated by calculation based upon values of areal activities of artificial radionuclides.

$$E_{\gamma} = \sum E_{\gamma i}$$

$$E_{\gamma i} = P_{\gamma i} \times T,$$

where:

E_{γ} – external gamma dose for the i^{th} radionuclide from the underlying surface, Sv/year;

$P_{\gamma i}$ – equivalent gamma dose rate, Sv/s; T – exposure time per annum, s/year.

The equivalent gamma dose rate at a height of 1 m above the earth's surface was calculated as per the following formula:

$$P_{\gamma i} = \sum K_{\gamma \text{isurf}} \times A_{Si}$$

where:

$P_{\gamma i}$ – equivalent gamma dose rate 1 meter above the earth's surface, Sv/s;

$K_{\gamma \text{isurf}}$ – equivalent dose rate in case of contamination with the i^{th} radionuclide 1 Bq per 1 m², Sv×m²/(s×Bq);

A_{Si} – the areal activity of the i^{th} artificial radionuclide, Bq/m².

Table 2.24. Values of coefficients used in estimating radiation exposure from external gamma-radiation

Coefficient	Values of coefficients			
	¹³⁷ Cs	⁹⁰ Sr	²³⁹⁺²⁴⁰ Pu	²⁴¹ Am
$K_{\gamma \text{isurf}}$ Sv×m ² /(s×Bq)	2,9×10 ⁻¹⁶	2,8×10 ⁻¹⁹	3,6×10 ⁻¹⁹	1,3×10 ⁻¹⁷

Internal exposure dose at inhalation intake of radionuclides

The internal exposure dose at inhalation intake was calculated based upon estimated values of average annual volumetric activities of radionuclides with respect to their concentrations in topsoil.

The committed effective dose from the intake of radionuclides through inhalation was determined as per the formula:

$$E_{\text{inhi}} = \sum q_i \times e_{\text{inhi}}$$

where:

E_{inhi} – internal exposure dose at inhalation intake of the i^{th} radionuclide by a body, Sv/year;

q_i – annual intake of the i^{th} radionuclide by a body through the respiratory channel, Bq/year;

e_{inhi} – dose factor of the i^{th} radionuclide through inhalation, Sv/Bq, as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48].

The quantity of annual intake was calculated as per the formula:

$$q_i = A_{v,i} \times V,$$

where:

q_i – annual intake of the i^{th} radionuclide by a body through the respiratory channel, Bq/year;

$A_{v,i}$ – average annual volumetric activity of the i^{th} radionuclide in air, Bq/m³;

V – volume of inhaled air per annum, m³/year as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48]).

The internal exposure dose from the intake of radionuclides with water and foodstuffs produced in the study area

The committed effective dose from the intake of artificial radionuclides through the digestive tract was calculated as per the formula:

$$E_{ingi} = \sum q_{ingi} \times e_{ingi}$$

where:

E_{ingi} – annual internal exposure dose through ingestion of the i^{th} radionuclide, Sv/year;

q_{ingi} – annual intake of the i^{th} radionuclide with foodstuffs and water, Bq/year;

e_{ingi} – dose factor of the i^{th} radionuclide at intake through the digestive tract, Sv/Bq as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48].

The annual intake of artificial radionuclides was determined by the content of radionuclides in the main foodstuffs of the diet and by the quantity of the annual consumption of these products.

$$q_{ingi} = A_{mi} \times V_p,$$

where:

q_{ingi} – annual intake of the i^{th} radionuclide with foodstuffs and water, Bq/year;

A_{mi} – activity concentration of the i^{th} radionuclide in the p^{th} foodstuff and water, Bq/kg;

V_p – annual consumption of the p^{th} foodstuff and water, kg/year.

The table (Table 2.25) lists diet consumption rates of foodstuffs per capita approved by the order of the minister of the National Economy of RK dated December 9, 2016 No. 503 [123].

Table 2.25. RK's diet consumption rates of foodstuffs per capita

Product name	Water	Milk and dairy products	Meat	Bread	Potato	Vegetables
Amount consumed, kg/year	730	301*	78,4	109	100	149
*– cow milk is 45 l/year						

Results of the assessment of public radiation exposure when living and carrying economic activities in the test site area

Doses were assessed using a conservative technique, which is understood to use maxima (the content of radionuclides, consumption amount) and the maximum impact time in dose assessments. Doses were calculated for a conventionally adult person who lives in the STS territory and consumes products of vegetative and animal origin that are produced in that territory. Values of the committed annual effective human dose ranged from 0.02 to 8.4 mSv. Maxima of doses

were reported near testing sites and the fallout plume area. In the other STS territory (beyond testing sites and plumes), the committed annual effective dose is less than 0.3 mSv.

Figures (Figure 2.47, a, b) show the contribution by the major exposure pathways from artificial radionuclides to the total committed annual effective dose to the public when living and carrying out economic activities in the study area.

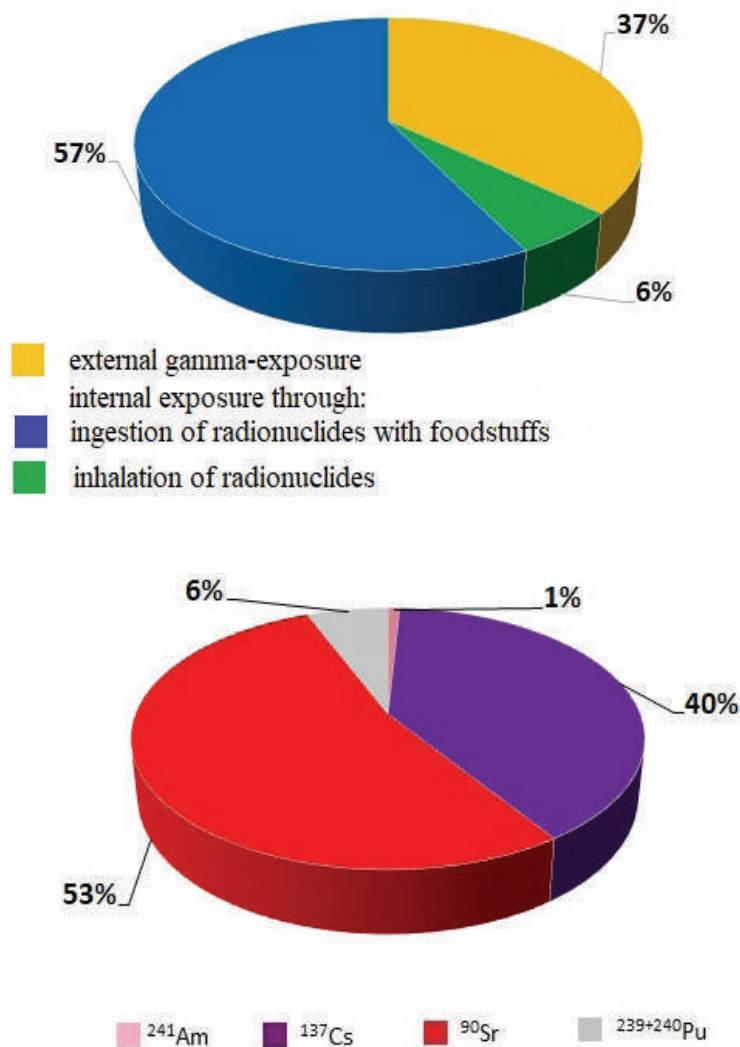


Figure 2.47. Contribution by the major exposure pathways (a) and by the major dose-forming radionuclides (b) to the total committed annual effective dose to the public when living in the STS territory

The main contribution to human radiation exposure when living in the STS territory will be made by the internal exposure dose at ingestion intake of radionuclides with foodstuffs to which ^{90}Sr mainly

contributes. The internal exposure dose from foodstuffs produced in the study area is ~57 % of the total annual effective dose.

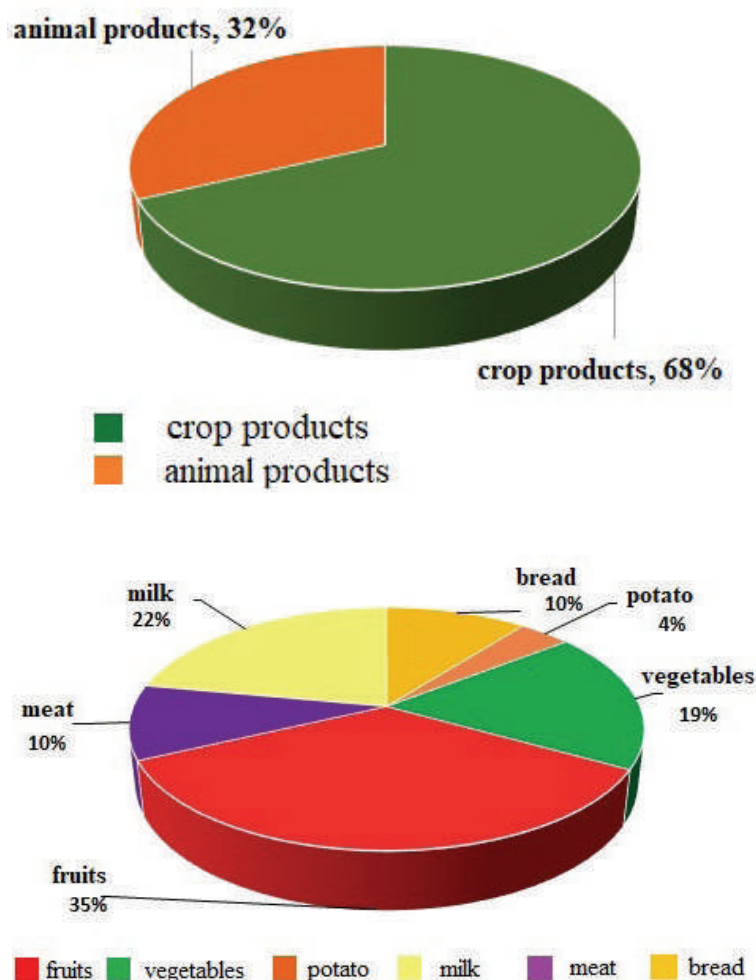


Figure 2.48. The contribution by products to the committed annual effective dose of internal exposure through ingestion

The contribution to the annual effective dose at intake with foodstuffs for an adult person is ~68 % in crop products and 32 % in animal products. The main categories of products contributing to the internal exposure dose through ingestion most of all – fruits (35 %), vegetables (19 %) and milk (22 %).

The next figure depicts the contribution by artificial radionuclides to the committed annual effective dose of internal exposure on consumption of foodstuffs produced in the STS territory.

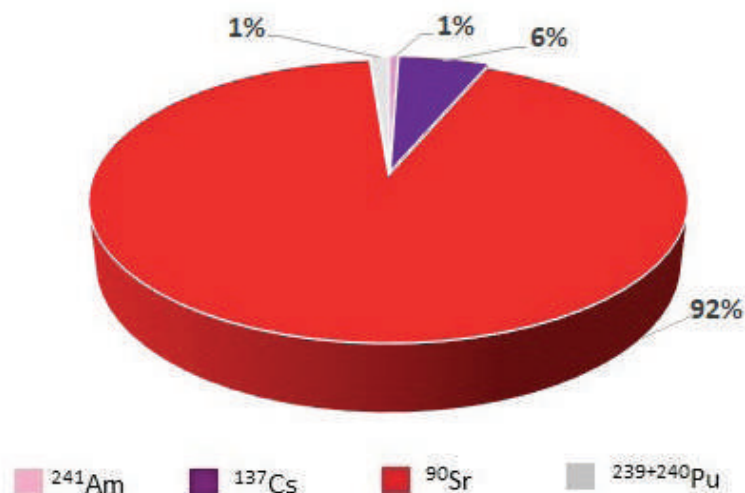


Figure 2.49. Contribution by artificial radionuclides to the committed annual effective dose of internal exposure on consumption of foodstuffs

Surface water sources are found in the STS territory – lakes, creeks and rivers both far from testing sites and close to their boundaries (Section 2.6 Radiological state of aquatic medium). Surface water bodies are unsuitable for drinking or watering animals due to chemical parameters (mineralization, hardness degree, the content of chlorides) [124]. However, as part of the conservative approach, internal exposure doses at intake of radionuclides with water from surface water bodies were calculated.

Concentration levels of ^3H , ^{90}Sr , ^{137}Cs , ^{241}Am and $^{239+240}\text{Pu}$ at a distance from testing sites are below values of the minimum detectable activity and do not exceed the intervention level as per the health standards (Section 2.6 Radiological state of aquatic medium) [48]. The internal exposure dose at intake of ^3H , ^{90}Sr , ^{137}Cs , ^{241}Am and $^{239+240}\text{Pu}$ from these sources may be 0.09 mSv. However, there are areas of elevated concentrations of ^3H and ^{90}Sr in surface water bodies that are close to testing sites (Section 2.6 Radiological state of aquatic medium). Such objects include Uzynbulak, Karabulak, Baitles, Toktakushyk and Aktybai creeks that are in the vicinity of the ‘Degelen’ site, Lake Kishkensor and the Shagan river that are in the vicinity of the ‘Balapan’ site.

Results of the conservative estimate of the internal exposure dose at intake of water with elevated values of concentrations of artificial radionuclides are depicted in the figure (Figure 2.50).

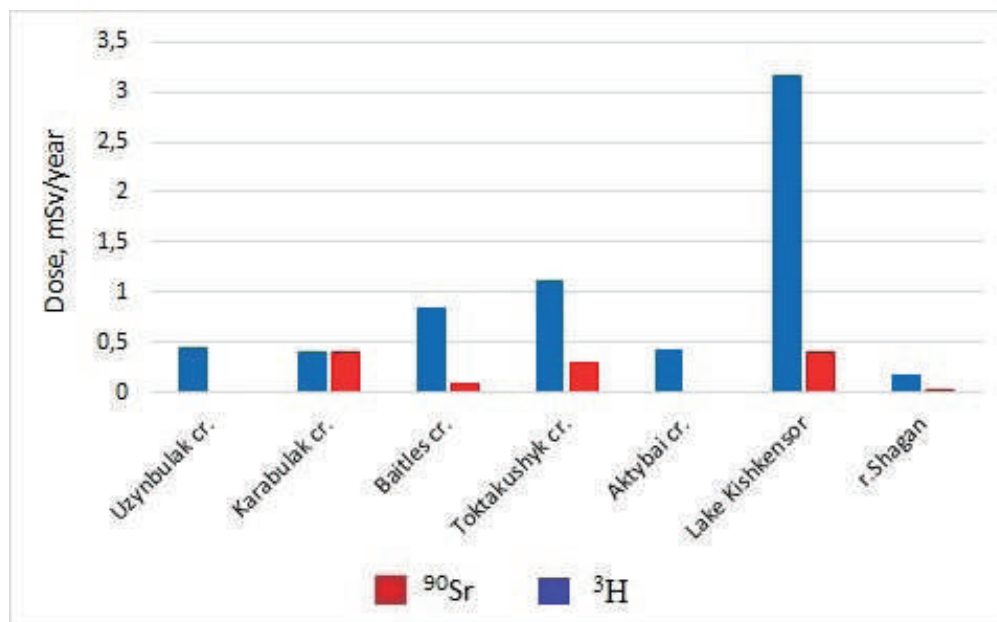


Figure 2.50. Committed annual effective dose of internal exposure on consumption of water with elevated content of artificial ^3H and ^{90}Sr

The committed annual effective dose of internal exposure at intake of ^3H and ^{90}Sr with water from surface water bodies that are near testing sites of the STS territory ranges from 0.2 to 3.5 mSv. Findings show that ^3H (~ 90 %) makes the main contribution to the total internal exposure dose on consumption of water from Baitles and Toktakushyk creeks, Lake Kishkensor and the Shagan river. It should be noted once again that water from surface water bodies that are close to testing sites is unsuitable for drinking or watering animals [125]. Therefore, the contribution by this pathway for man when living in the STS territory is ignored in the total committed annual effective dose.

Conclusions:

Values of the committed annual effective dose to man for the entire test site area range from 0.02 to 8.4 mSv. Maxima of doses

were reported near testing sites and for fallout plumes. The internal exposure dose at intake of radionuclides with foodstuffs, in which ^{90}Sr (92 %) is the major dose-forming radionuclide and its content in crop products, make the main contribution to the total radiation exposure to man. Values of the internal exposure dose at intake of radionuclides with water from surface water bodies that are in the vicinity of testing sites, range from 0.2 to 3.5 mSv, which exceeds the intervention level according to RK's standards [48]. Surface water bodies in the STS territory are unsuitable for drinking or watering animals [126]. Internal exposure doses at intake of radionuclides with water from these water bodies were calculated as part of the conservative approach. However, taking into account potentially elevated exposure when consuming this water, the public access and access for livestock to surface water bodies with increased radiation parameters must be restricted.

Values of the committed annual effective dose beyond testing site and fallout plumes do not exceed the intervention level being equal to 0.3 mSv or the main public dose limit being equal to 1 mSv as regulated by health standards 'Sanitary and Epidemiological Requirements for Radiation Safety Assurance' [48].

Based on the above and from assessments of the committed annual effective dose to man, the STS territory can be conventionally divided into 2 zones – the area of elevated radiation exposure values (higher than 0.3 mSv) and the area of dose values less than 0.3 mSv. The zone of elevated radiation exposure values includes the area near testing sites and fallout plumes (all surface water bodies with elevated values of radiation parameters are in this area). These areas are unusable for economic activities or living. The rest of the territory, for which values of the committed annual effective dose are lower than 0.3 mSv, can potentially be released to economic turnover and used for living.

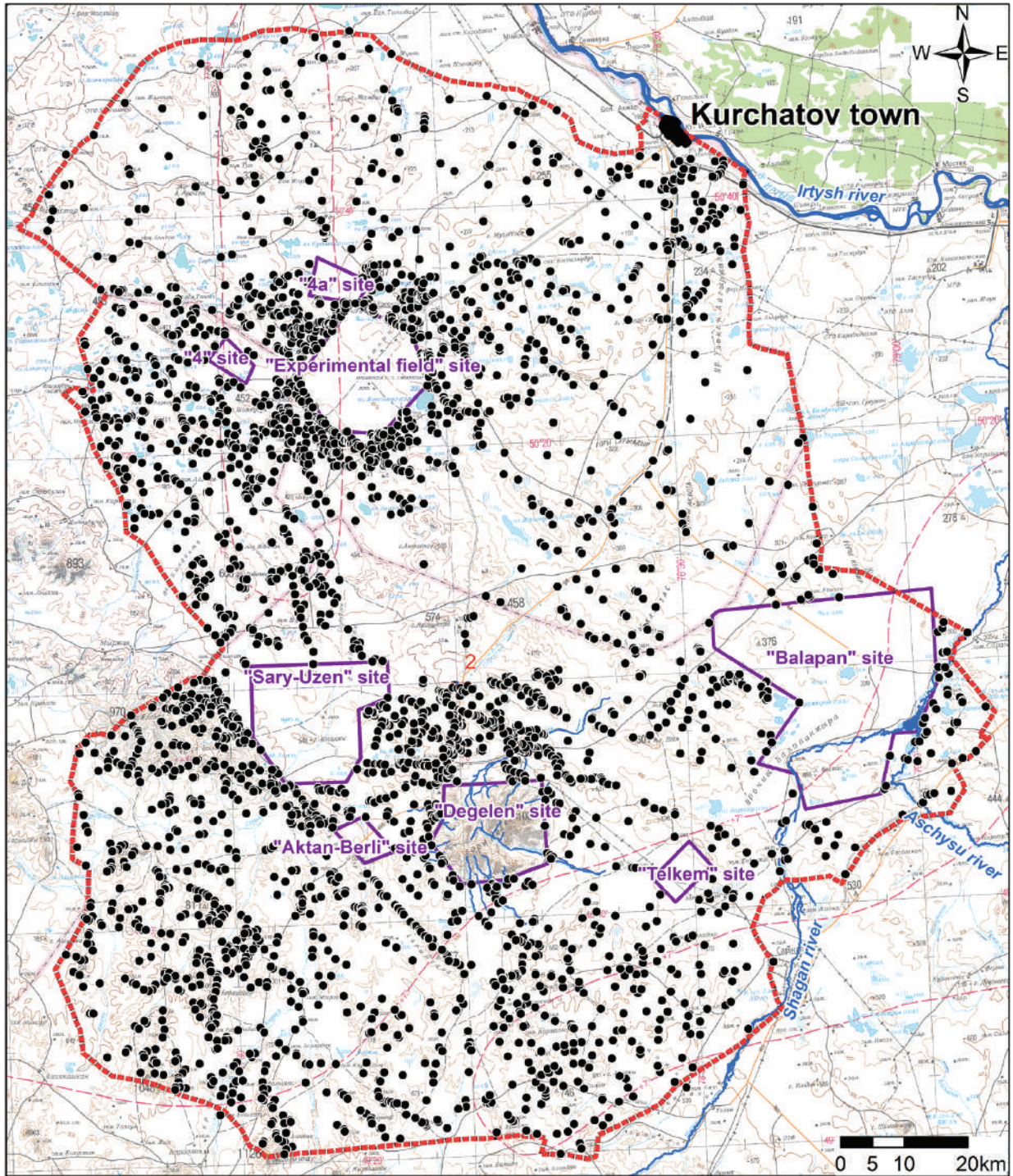
2.12 Follow-up research

During the comprehensive radioecological survey of the STS territory, a 1×1 km uniform sampling grid for topsoil was applied. This allowed identification of large spots of radioactive contamination. However, at such spacing, small locally contaminated spots could have probably been skipped. Generally, such contamination spots are associated with man-made objects (boreholes, burial sites, adits and others). In order to study the terrain in detail and identify potential radiation-hazardous objects of man-made origin that have remained since nuclear testing as well as the ones that resulted from unauthorized activities after the test site was shut down, the work on interpretation of satellite images was performed. Interpretation of satellite images overlaps possible 'gaps' in the sampling grid, which in turn significantly enhances capabilities of the comprehensive ecological survey of the STS territory in general.

Small-size man-made objects, given the large study area, cannot be identified by direct search afield. To identify potential radioactively contaminated man-made objects, a specifically developed methodology was applied that involved 2 main stages:

- office studies – identification of man-made origin through high-resolution satellite image interpretation;
- field work – visual examination of a man-made object state and measurement of its parameters.

The technology of a visual interpretation technique is based upon comparison of the available information (map documents and archival materials) on key areas (reference areas) with relevant fragments of satellite images. Relying on the information from these sources and based upon interpretation signs, man-made objects were visually interpreted followed by being plotted onto the STS overview map.



Legend



 STS boundary  boundaries of testing sites • interpretation objects

Figure 2.51. Results of office interpretation

Satellite images with the highest possible resolution available collected from different map services (Bing Maps, Google Maps and Yandex Maps) were source materials for interpretation. To increase the

efficiency of the work in progress, all collected satellite images were grouped by nomenclature for maps of the relevant scale (1:25 000, 1:50 000 etc.).

Based upon outputs, about 4,000 objects of man-made origin were revealed in the STS territory. A detailed catalogue of identified objects was compiled stating: schematic locations of identified objects in the satellite image and their descriptions, ordinal numbers and geographical coordinates.

A visual examination of man-made objects during the field work consisted in comparing satellite images with the terrain. This method ensured completeness, quality and reliability of object interpretation results.

Field interpretation of objects included the following stages:

- on- site visits based upon results of office interpretation;
- visual examination and description of an object (size, origin (man-made or natural), distinguishing features as well as qualitative and/or quantitative characteristics);
- refinement of geographical coordinates;
- object photography;
- radiation parameter measurements – exposure dose rate (EDR) and beta-particle fluence;
- catalogue information update.

When visually examining interpretation objects, potentially radioactively contaminated objects include such objects that resulted from anthropogenic activity, for example:

- pits in the form of craters;
- lengthy earth excavations (trenches);
- objects at which items similar to chemical, physical or biological equipment, containers, laboratory materials, glassware or their fragments were discovered.

The other objects that resulted from economic activities in the test site area are not radioactively contaminated.

During the survey of the STS territory, accompanied by a simultaneous analysis of satellite images, in some cases, spots of heavy machinery tracks beyond testing sites were discovered. At the same time, the radiation background did not fit in the general picture of ground contamination. Visually, such spots were typically longitudinal strips of relocated soil, parallel lines of buried trenches, backfill traces in pits with clean soil or merely earth excavations.

Based upon findings, several objects were discovered. One of them is in the northern part of STS. This burial site located at a distance of about 15 km from Kurchatov town, represents a site with subsurface industrial waste disposal. The disposal site of radioactive materials across the perimeter is fenced with a barbed wire and on the outer side – with a ditch. Currently, the ditch is virtually destroyed. When surveying the site, 4 artificial embankments and 3 excavation spots were discovered. These had aluminum lids to unknown containers, replaceable gas mask filters, metal nets, bones of cattle and small animals nearby [127].



Figure 2.52. Burial site in the northern STS part

A metal container was found at a short distance from all excavations with no locking lid, being partially destroyed. Presumably, it was designed for storing radioactive materials. At about 40 cm from the neck, radioactive contamination with the following parameters was detected: EDR value – 160 $\mu\text{Sv/h}$, beta-particle fluence – about 10,000 parts/($\text{cm}^2 \times \text{min}$) [128].

In the northeastern part of the ‘Experimental Field’ testing site, a mortuary named as ‘M3’ was discovered. It represented a rectangular site of trench-type burial. Radioactively contaminated materials were found beneath the layer of backfilled soil at a depth of 10 cm and deeper [128]. This object is fenced with the artificial protective barrier of a barbed wire and a ditch across the perimeter.



Figure 2.53. ‘M-3’ burial site

When surveying the southeastern STS part, 5 km away from the eastern boundary of the ‘Degelen’ testing site, a burial site with disposal traces of man-made items was discovered. Like other objects of this type, a mortuary discovered was also fenced with a barbed wire having a warning sign. There are 40 rectangular pits (cells) with concrete walls up to 50 cm thick placed in 2 rows of 20 cells each. Cells had different man-made items (metal containers, fragments of plastic boxes etc.). Initially, cells were covered with concrete slabs

and backfilled with soil. However, during interpretation, it was found that some of cells were open up. When measuring radiation parameters of the object, no excess of EDR values or beta-particle fluence was revealed [129].

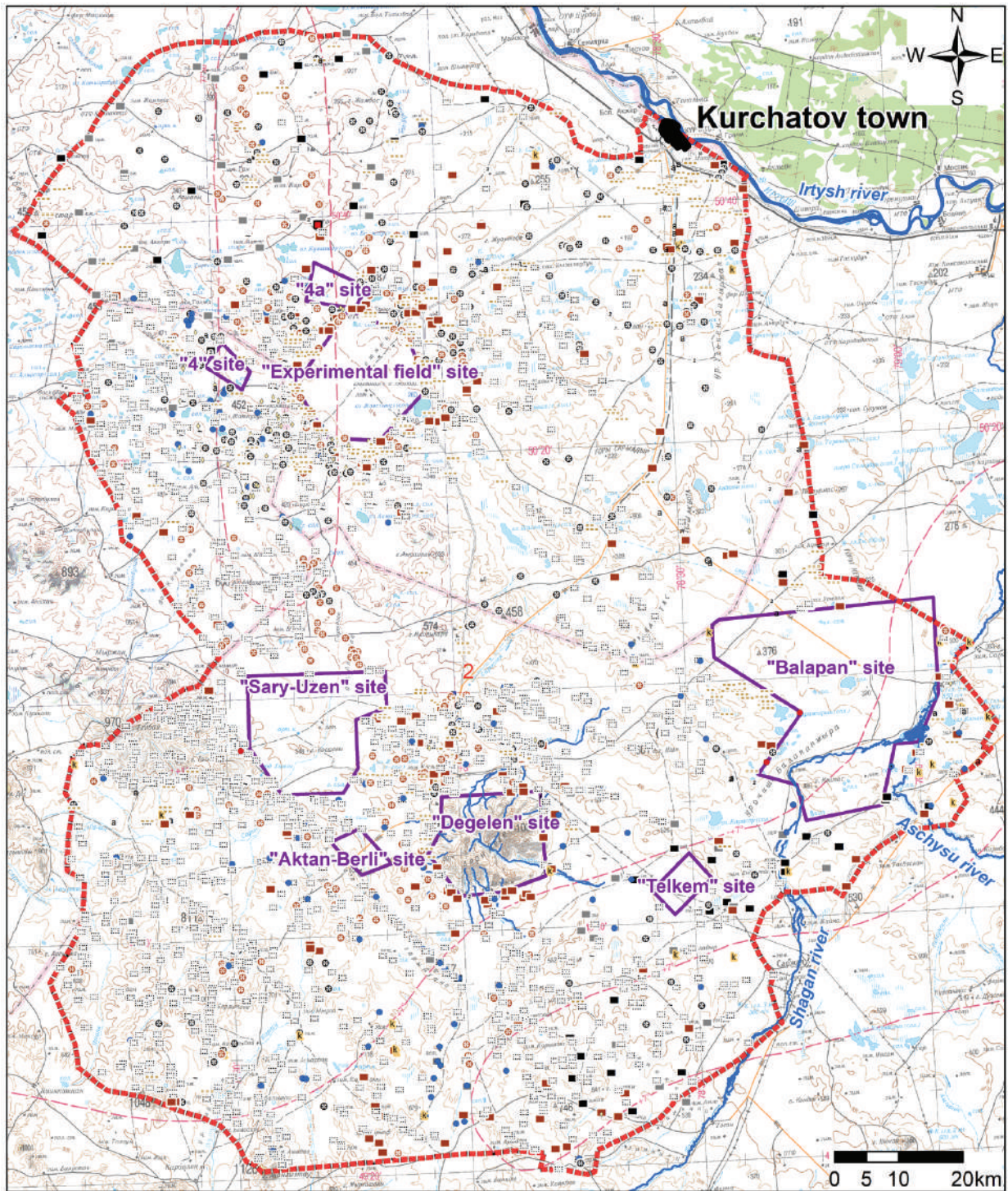


Figure 2.54. Burial site in the southeastern STS part

At a distance of about 100 m from the eastern boundary of the ‘Degelen’ site, a similar mortuary with buried man-made items was discovered. At the time of interpretation, this object was not fenced.

Following interpretation, objects were grouped by the main most common characteristics: ruins, trenches, pits in the form of craters, winter huts, objects of water use, open pits, concrete structures, saline soils and water monitoring sites to construct their location map for the STS territory. Objects of unidentified purpose were marked as ‘others’.

Based upon the above, one can conclude that there are objects beyond testing sites that pose a radiological hazard, which were interpreted and catalogued as radioactively contaminated in the STS territory.



Legend

STS boundary	interpretation objects	landfill cell	warfare borehole
boundaries of testing sites	open pit	water objects	saline soil
winterings	other objects	ruins	trenches
inhabited	concrete structure	agricultural land	adit
not inhabited	rocks outcrop	borehole	pit
			funnel pit

Figure 2.55. Interpretation results of the STS territory

CHAPTER 3. RADIOACTIVE CONTAMINATION OF TESTING SITES

3.1 Survey methodology

Immediately after the test site shut-down, gathering information on radiation parameters at individual, the largest and knowingly radioactively contaminated objects began. Subsequently, the survey was then carried out all over testing sites.

The first large-scale operations were associated with the survey of the ‘Degelen’ site in the late 90s. Exactly this site was of special interest because of free access to a great many of nuclear charge materials, which posed a serious threat from the perspective of radiation safety. Based upon the work on the radiation survey of the ‘Degelen’ site, rather a large amount of data and source information on the radiological situation at the site at that point in time were collected.

2000 through 2007, a variety of research was undertaken into STS testing sites. Research gave the first insight into the radiological situation in testing site areas but information was oftentimes inconsistent because there was no unified research system, and in some cases, information was not exhaustive. Taking into account this fact as well as the need for assessing a possible carry-away of radioactive material beyond boundaries of testing sites, the issue of a thorough and systematized survey of testing sites including land cover, aquatic medium, air basin and fauna arose. If jointly researched, this would allow a more accurate assessment of the existing radiological situation and a predictive estimate of its progression.

The first site to which this approach was applied, was the ‘Experimental Field’ that is most contaminated at the surface. The survey itself was carried out in a few stages. At the first stage, the general assessment of areal distribution of radioactive contamination

was given. To this end, ground was interpreted to identify all existing man-made and natural objects, a radiometric survey was applied and topsoil was sampled over a 500×500 m grid. This approach allowed the nature of topsoil contamination to be defined, areas of elevated values of the major artificial radionuclides and the existing water bodies to be identified.

In the course of the survey and while information was being gathered on the radiological situation at objects with different formation mechanisms of radioactive contamination, it became necessary to develop new survey techniques. In 2012, a pedestrian gamma-spectrometric survey was carried out for the first time to improve detailing of radioactive contamination maps.

The main point of the technique consisted in carrying out a continuous pedestrian gamma-spectrometric survey over the preset grid while recording geographical coordinates.

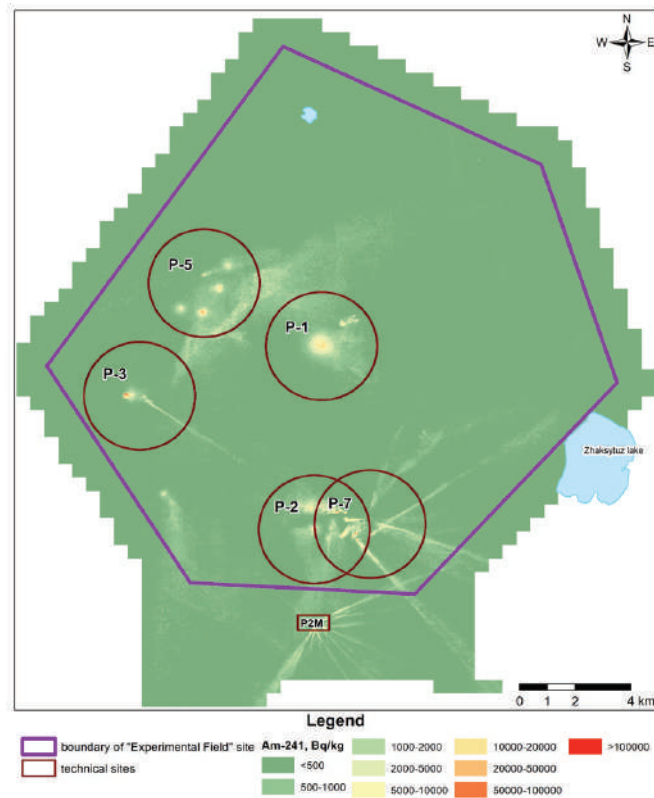
Previously, the entire study area was split into 500×500 m sectors with profile grids along which the ‘operator’ was moving. The distance between profiles was 20 m. The distance between profiles ensured detection of fallout plumes as well as relatively small-size (20×20 m) radioactively contaminated areas, which met the purpose of this survey type. The ‘operator’ who carried out a gamma-survey was moving along the profile route at a continuous speed of 1-2 km/h using a satellite navigator. The detector was attached to the ‘operator’ 0.5 m above the daylight surface. While moving along profiles, the ‘operator’ was continuously accumulating gamma-spectra. The accumulation time for one gamma-spectrum was 10 s. Spectrometric data was gridded and recorded automatically being saving in a portable PC (laptop). Thereafter, accumulated gamma-spectra were processed resulting in construction of radioactive contamination maps of the study area. The feature of this areal survey

technique was that the accumulated gamma-spectrum defined a spot between coordinate recording points rather than a ‘point’ at which coordinates were recorded, i.e. a spectrum was accumulated for 10 s while moving from point to point.

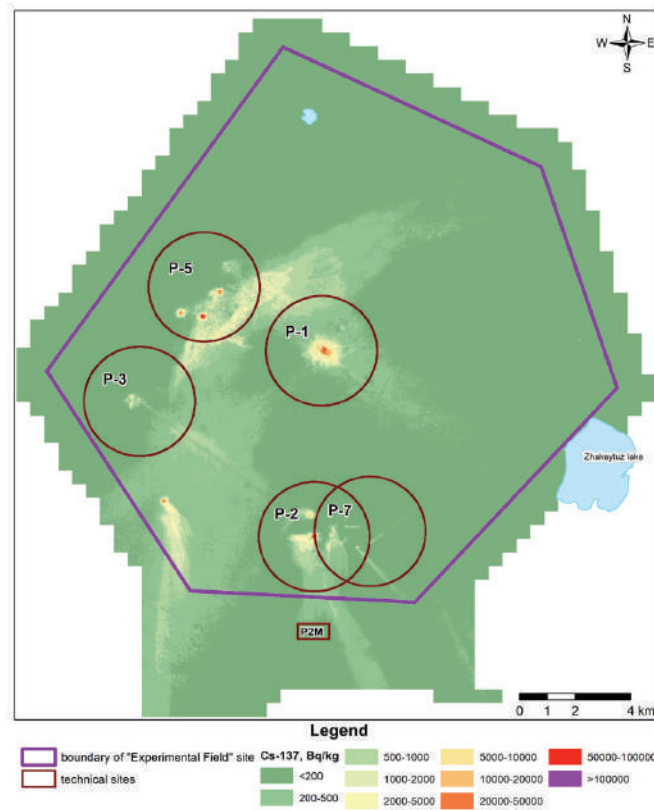
At the second stage, plant cover, air and aquatic media, fauna as well as the nature of vertical radioactive contamination in the soil profile were studied. These studies allowed determination of potential human radiation exposure. The work at the ‘Experimental Field’ site resulted in developing the main approach to the survey of STS sites. Certainly, when surveying other sites, the research methodology subsequently underwent changes depending on the terrain and testing conditions. In particular, ground water survey at the ‘Balapan’ and ‘Sary-Uzen’ sites used for underground nuclear tests in boreholes became one important aspect.

3.2 Description of findings

As a result of the work, a huge dataset was obtained and analyzed. In the course of the STS survey, it was established that not every testing site is radioactively contaminated on the daylight surface. Thus, no surface radioactive contamination was detected at the ‘Aktan-Berli’ site. The nature of radioactive contamination depending on the type of tests and the location of a site itself is site-specific. In some cases, the area of elevated content of man-made radionuclides is represented by a local spot of several square meters and in certain cases – by a large fallout plume extending for dozens of kilometers. To have a comprehensive picture of the current radioecological situation at STS testing sites, these have to be addressed separately. At the same time, a number of sites were addressed together because of similarity of tests conducted and radioactive contamination (‘4’ and ‘4A’ sites).



a)



b)

Figure 3.1. Distribution maps for the 'Experimental Field' site:

a) ^{241}Am ; b) ^{137}Cs

‘Experimental Field’ site

It is more logical to begin with the first STS testing site, at which atmospheric (aboveground and air) nuclear tests were conducted between 1949 and 1962. Significant events include 3 aboveground tests conducted on August 29, 1949 (22 kt), September 24, 1951 (38 kt), August 12, 1953 (400 kt), which resulted in fallout plumes that went not only beyond the ‘Experimental Field’ site but also beyond the test site.

Research findings showed that radioactive contamination of the ground at the site is not ubiquitous and is directly associated with test places – ground zeroes and epicentral areas as well as with fallout plumes of tests conducted.

All test places can be conventionally divided into three groups:

1) places of nuclear tests with a high energy release characterized by presence of significant quantities of fission products (^{137}Cs , ^{90}Sr);

2) places of nuclear experiments with a low or no nuclear energy release. The distinctive feature is a high concentration of a material in the charge. ($^{239+240}\text{Pu}$, ^{241}Am);

3) test places with a high (intense) neutron flux, which are characterized by presence of significant quantities of neutron activation products (^{60}Co , isotopes Eu , ^3H and others).

Technological sites of ‘Experimental Field’ (P-1, P-2, P-3, P-5) as well as P-2M, which is in close proximity to and associated with ‘Experimental Field’, were used to conduct different atmospheric tests, and, accordingly, the nature of radioactive contamination formed by these tests may differ.

Technological site P-1 is a place of the very first nuclear tests, which produced 3 large fallout plumes going beyond the test site territory. This notwithstanding, the bulk of radioisotopes is concentrated exactly in the epicentral area. Values of ^{241}Am activity concentrations in soil ranged from <1.8 to 7.9×10^4 Bq/kg, ^{137}Cs – <2 to 1.2×10^5 Bq/kg, ^{90}Sr – <2 to 1.6×10^5 Bq/kg, $^{239+240}\text{Pu}$ – 28 to 1.8×10^5 Bq/kg.

Technological sites P-2, P-7 and P-2M were used to conduct

aboveground nuclear tests as well as simulated non-nuclear and explosive experiments. When conducted, these ensure explosive compression of nuclear fissile material with a chemical explosive coat to such an extent that a nuclear charge material loses its mechanical strength and begins to behave like a liquid. During these experiments, a nuclear charge material (uranium or plutonium) was dispersed (sprayed). Evidently, such tests in a comparatively small territory were supposed to contaminate soil cover significantly. Based upon laboratory data on soil samples collected from sites under survey, $^{241}\text{Am}/^{137}\text{Cs}$ ratios, the quantity of which in some cases reached 1,700, were determined. This in turn points to tests of nuclear devices with low coefficients of nuclear reaction or to non-nuclear and explosive experiments. ^{241}Am activity concentrations in soil ranged from <1.0 to 7.9×10^6 Bq/kg, ^{137}Cs – <1.0 to 2.1×10^5 Bq/kg, ^{90}Sr – <2 to 4.3×10^6 Bq/kg, $^{239+240}\text{Pu}$ – <1.0 to 1.5×10^8 Bq/kg.

Technological sites P-3 and P-5 were used to conduct air and aboveground nuclear tests of different yield (P-3 – air tests of low- and medium-yield nuclear bombs, P-5 – aboveground tests of low-yield bombs and air tests of medium- and high-yield nuclear bombs). Such experiments resulted in heavy radioactive contamination of technological sites with both nuclear charge materials and fission products. Places of aboveground tests have craters with soil dumps and fragments of fritted soil containing nuclear debris. ^{241}Am activity concentration in soil ranged from <1.0 to 7.9×10^7 Bq/kg, ^{137}Cs – <1.0 to 3.4×10^5 Bq/kg, ^{90}Sr – <2 to 2.8×10^5 Bq/kg, $^{239+240}\text{Pu}$ – <1.0 to 2.1×10^6 Bq/kg.

When addressing plant cover, one can note that areas of all testing sites are characterized by a relatively high content of both transuranic radionuclides $^{239+240}\text{Pu}$ and ^{241}Am and fission products ^{137}Cs and ^{90}Sr . ^{241}Am activity concentration ranged from <0.3 to 5.3×10^2 Bq/kg, ^{137}Cs – 2.1 to 1.0×10^2 Bq/kg, ^{90}Sr – 11 to 2.0×10^3 Bq/kg, $^{239+240}\text{Pu}$ – <1.8 to 9.5×10^3 Bq/kg.

In air environment of the ‘Experimental Field’ site, maxima of $^{239+240}\text{Pu}$ are registered in ground zeroes reaching 1.1×10^{-2} and 1.6×10^{-2} Bq/m³, which exceeds the PVA_{pop} level by 3 times as specified by health standards ‘Sanitary and Epidemiological Requirements for Radiation Safety Assurance’ [48]. Concentrations of artificial radionuclides ^{241}Am , ^{137}Cs and ^{90}Sr in air environment are below the detection limit of the methodological instrumentation in use.

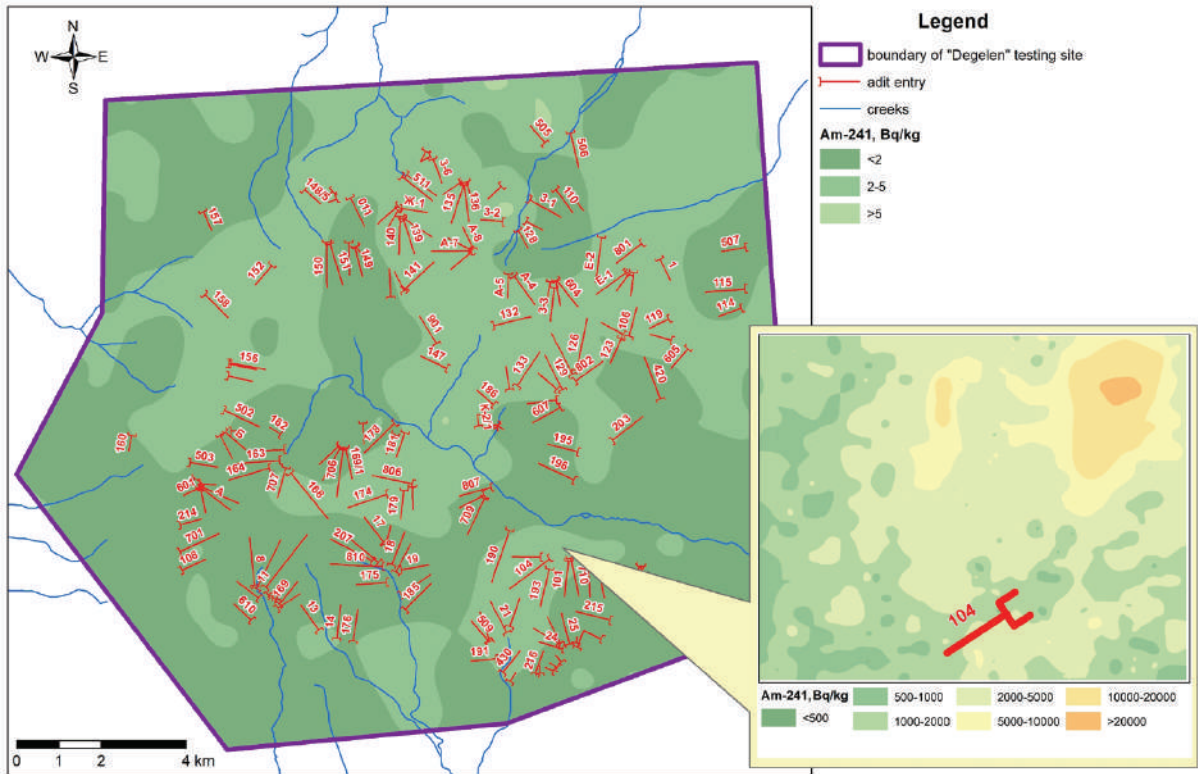
‘Degelen’ site

As mentioned above, 1949 through 1962, atmospheric tests at the ‘Experimental Field’ were mainly conducted until the Partial Test Ban Treaty entered into force [31]. As a result of the acceptance of the treaty and imposition of a moratorium on atmospheric nuclear explosions, testing began underground. The ‘Degelen’ site became the first USSR site, at which an underground nuclear test was conducted. The test took place in adit V-1 on October 11, 1961 (1 kt).

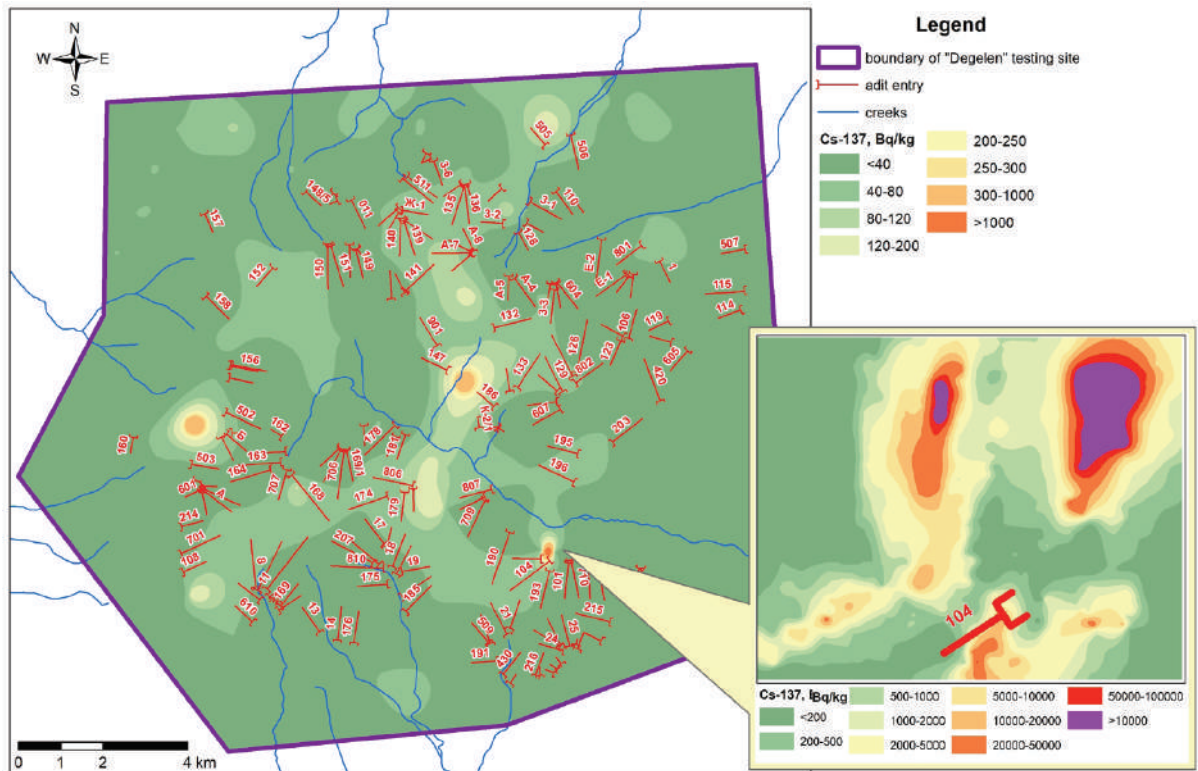
The radioecological survey of the ‘Degelen’ site showed that most of its territory was not contaminated because the bulk (over 90 %) of radioactivity produced during nuclear testing was concentrated in adit cavities. However, there are areas of elevated concentrations of radionuclides in environmental compartments (soil, water, vegetation). Such areas were mostly formed in three ways:

- 1) abnormal situations in nuclear testing;
- 2) opening up adits after testing;
- 3) radioactivity carry-away from adit cavities by water.

Radioactive contamination typically reaches maxima near adit entries, close to water stream outlets onto the daylight surface. With increasing distance from the near-entrance site, contamination of the ground decreases. ^{241}Am activity concentrations in soil ranged from <0.3 to 5.4×10^6 Bq/kg, ^{137}Cs – <0.1 to 3.1×10^6 Bq/kg, ^{90}Sr – <0.2 to 3.7×10^6 Bq/kg, $^{239+240}\text{Pu}$ – <1.0 to 4.8×10^5 Bq/kg.



a)



b)

Figure 3.2. Distribution maps for the 'Degelen' site area:

a) ^{241}Am ; b) ^{137}Cs

Underground nuclear testing in adits resulted in a significant deformation of rock mass forming a lot of crushing zones, sinkholes and gaping fissures. This resulted in a significantly increased permeability of rocks, which strengthened a descending filtration and partially directed surface water streams to underground ones. Thus, after nuclear explosions, an new type of ground water appeared at the Degelen mountain range that joined flows of fracture-vein and fracture waters, hereinafter referred to as adit waters, of the precipitation percolation zone [130].

Due to the entry of precipitation and inflow of fracture-vein waters into zones of irreversible deformations and directly into the pit cavity, radionuclide composition of adit waters is formed. Moving through fissure and adit cavity systems, waters contaminated with radionuclides replenish the basin of ground waters or come out into the surface in the vicinity of entries contaminating associated ecosystem components. The analysis of available information on maxima of activity concentrations of radionuclides in water streams from different adits showed that they reached: for ^{137}Cs – 820 Bq/kg (adit No. 504), for ^{90}Sr – 2,100 Bq/kg (tunnel No. 177), for $^{239+240}\text{Pu}$ – 6.4 Bq/kg (adit No. 503), for ^{241}Am – 2.6 Bq/kg (adit No. 177) and for ^3H – 9.9×10^5 Bq/kg (adit No. 160).

The highest values of activity concentrations of radionuclides in vegetation are generally noted for banks of water streams from adits. For ^{137}Cs , this value may reach in the order of 1×10^4 Bq/kg, ^{90}Sr – 1×10^4 Bq/kg, $^{239+240}\text{Pu}$ – 1×10^1 Bq/kg. ^{241}Am activity concentration in plants was registered at the level of detection limits – 2-4 Bq/kg. ^3H is included in the hydrodynamic system of the Degelen mountain range, therefore its presence in vegetation is attributed not only to the presence of a permanent surface water stream but also to the occurrence depth of ground waters. In valleys of creeks and depressions amidst bald peaks, the occurrence level of ground waters is shallow. Therefore,

^3H is present in vegetation that grows in ecosystems of plains and depressions amidst bald peaks within the ‘Degelen’ site.

No numerical values of ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$, ^{241}Am were determined in air of the ‘Degelen’ site except for ^3H , the content of which in some cases may reach $1,000\text{ Bq/m}^3$. This value shares the same order of magnitude as the limit of the average annual permissible volumetric activity in air to the public, PVA_{pop} , being $1,900\text{ Bq/m}^3$ and as specified by health standards ‘Sanitary and Epidemiological Requirements or Radiation Safety Assurance’ [48]. At the same time, it was found that ^3H concentration in ambient air is directly proportional to the one in a water source, soil air, plants as well as it may depend on productivity of plant cover when ^3H concentrations in plants are significant. Maximum ^3H concentrations in air are observed close to open water bodies (water stream, backwater, springs) contaminated with ^3H .

‘Balapan’ site

The Balapan’ site was used for underground nuclear explosions in boreholes. As opposed to atmospheric tests, radioactive contamination of the ground due to underground nuclear explosions in boreholes is negligible. The bulk of radioactive products remains ‘buried’ in the geological rock mass. In underground nuclear explosions in boreholes with a standard radiological situation, most of produced radioactivity remains at the ground zero underground. A relatively small part of it comes out into the surface.

Radioactive contamination at the testing site was caused by the 2 major factors. The first factor is the fallout of radioisotopes out of the atmosphere owing to nuclear tests at the ‘Experimental Field’ site. Fallout plumes extended from the northwestern part of the site to its center. The extent of plumes is $\sim 30\text{ km}$, the contamination area – $\sim 250\text{ km}^2$. ^{241}Am activity concentration in soil reaches up to 30 Bq/kg , that of ^{137}Cs – up to 80 Bq/kg . Another factor is the fallout of radioisotopes

due to underground nuclear testing with a radioactive release. Most of contamination was produced by fallout plumes of a test in borehole No. 1004. The fallout plume extends for roughly 15 km. Concentrations of artificial radio-nuclides reach: for ^{137}Cs – $n \times 10^3$ Bq/kg and ^{241}Am – $n \times 10^3$ Bq/kg.

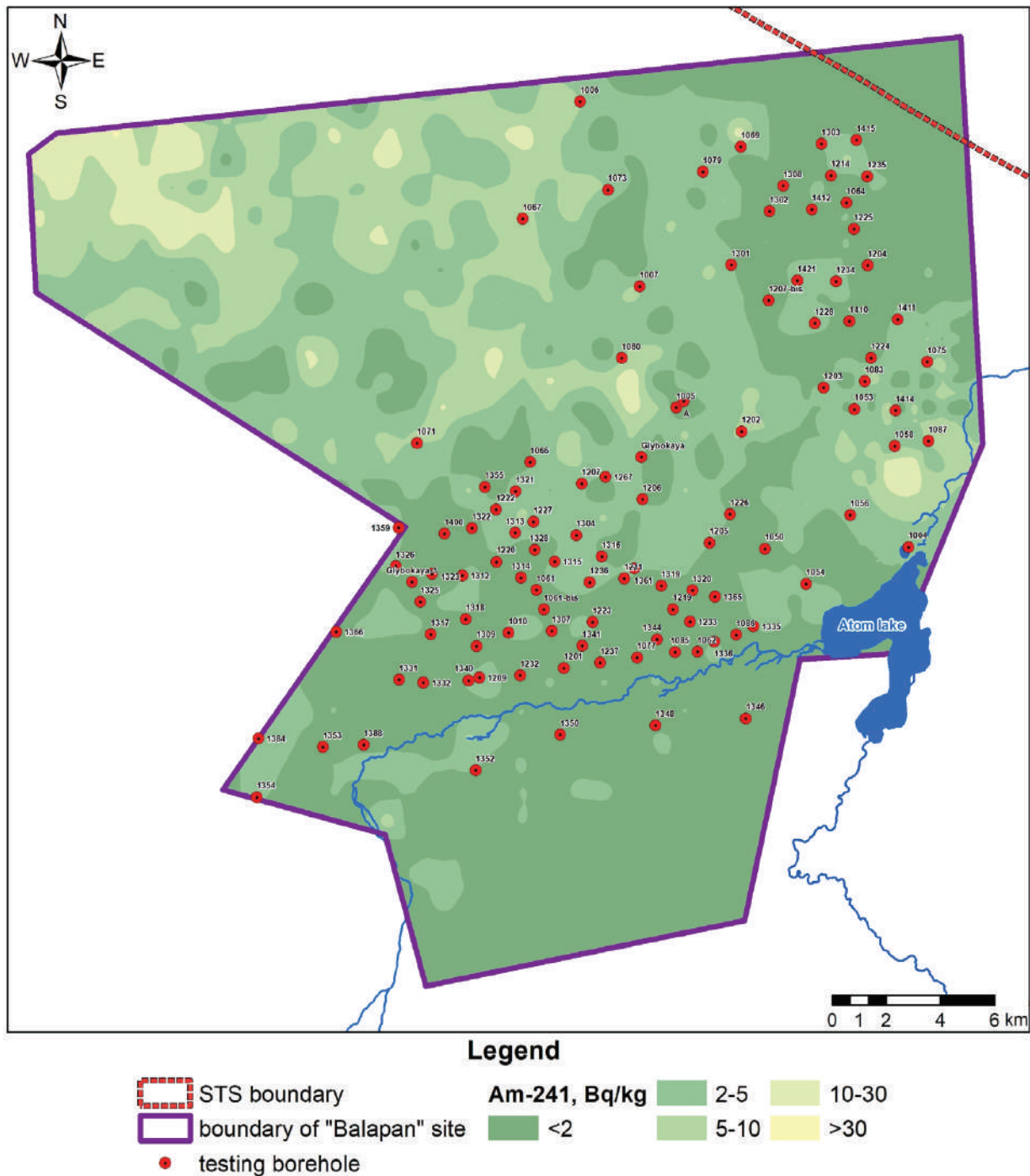


Figure 3.3. ^{241}Am distribution map of the ‘Balapan’ site area

When addressing the nature of radioactive contamination in near-mouth areas of boreholes in detail, it was found that the maximum radioactive contamination is associated either with the soil ejection explosion or tests in the abnormal radiological situation. Values ^{241}Am activity concentration ranged from <0.3 to 6.0×10^5 Bq/kg, for ^{137}Cs – <0.1 to 1.9×10^6 Bq/kg, for ^{90}Sr – <2 to 2.4×10^5 Bq/kg, for $^{239+240}\text{Pu}$ – <0.1 to 6.9×10^6 Bq/kg.

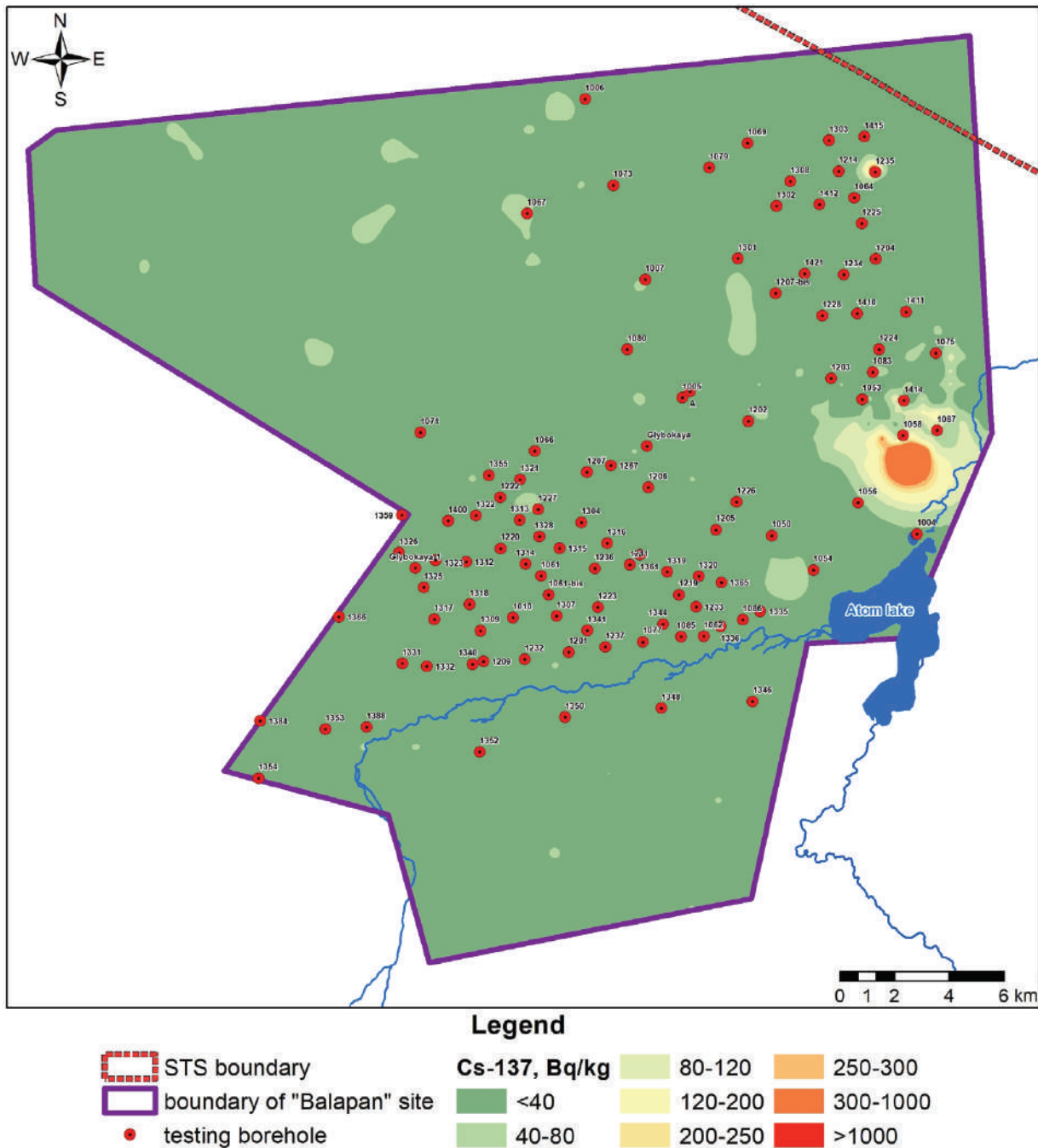


Figure 3.4. ^{137}Cs distribution map of the 'Balapan' site area

A high content of both transuranic radionuclides $^{239+240}\text{Pu}$ and ^{241}Am and fission products ^{137}Cs and ^{90}Sr are characteristic of plant cover in near-mouth areas of boreholes. ^{241}Am activity concentration varies from <0.1 to 9.4×10^4 Bq/kg, ^{137}Cs – <0.1 to 2.9×10^5 Bq/kg, ^{90}Sr – <0.3 to 8.3×10^4 Bq/kg, $^{239+240}\text{Pu}$ – <0.1 to 3.9×10^4 Bq/kg.

One peaceful test that entailed the formation of a vast radioactive contamination was named as ‘Chagan’. A nuclear device was planted in borehole No. 1004 at the confluence of the Shagan and Aschysu rivers. This test resulted in water and riverside contamination of the Shagan river itself.

Based upon survey findings on the Shagan river, the content of all major artificial radionuclides was found to be the highest in the dam outlet from the ‘Atomic lake’, which is undoubtedly attributed to an excavation explosion in borehole No. 1004. The exception is ^3H , the concentration of which is at the peak in areas from 5 to 14 km and reaches 370,000 Bq/kg.

When addressing air environment, maxima are also noted for the ‘Atomic Lake’. Maximum concentration of $^{239+240}\text{Pu}$ in air was detected in the dump zone reaching 6.0×10^{-3} Bq/m³, that of ^{241}Am – 7.4×10^{-4} to 1.3×10^{-3} Bq/m³. At some distance from the dump zone sideward, concentrations of radionuclides in air decrease.

‘Sary-Uzen’ site

‘Sary-Uzen’ site like the ‘Balapan’ site, was used to conduct underground nuclear explosions in boreholes. The difference is in the planting depth of a nuclear charge (‘Balapan’ – up to 600 m, ‘Sary-Uzen’ – up to 300 m [131] and that non-nuclear-explosive experiments were conducted here at this site.

Radioactive contamination at the testing site was also caused by the 2 main factors. The first is surface contamination attributed to fallout

after the aboveground nuclear test conducted on September 24, 1951 at the ‘Experimental Field ‘site. The fallout plume extended from the northwestern part of the ‘Sary-Uzen’ site to its southern boundary. The plume extent within this site is about 22 km, the contamination area – about 56 km². Values of ²⁴¹Am activity concentration vary from <0.3 to 390 Bq/kg, with a mean of 5 Bq/kg, for ¹³⁷Cs - <1.1 to 330 Bq/kg, with a mean of 55 Bq/kg.

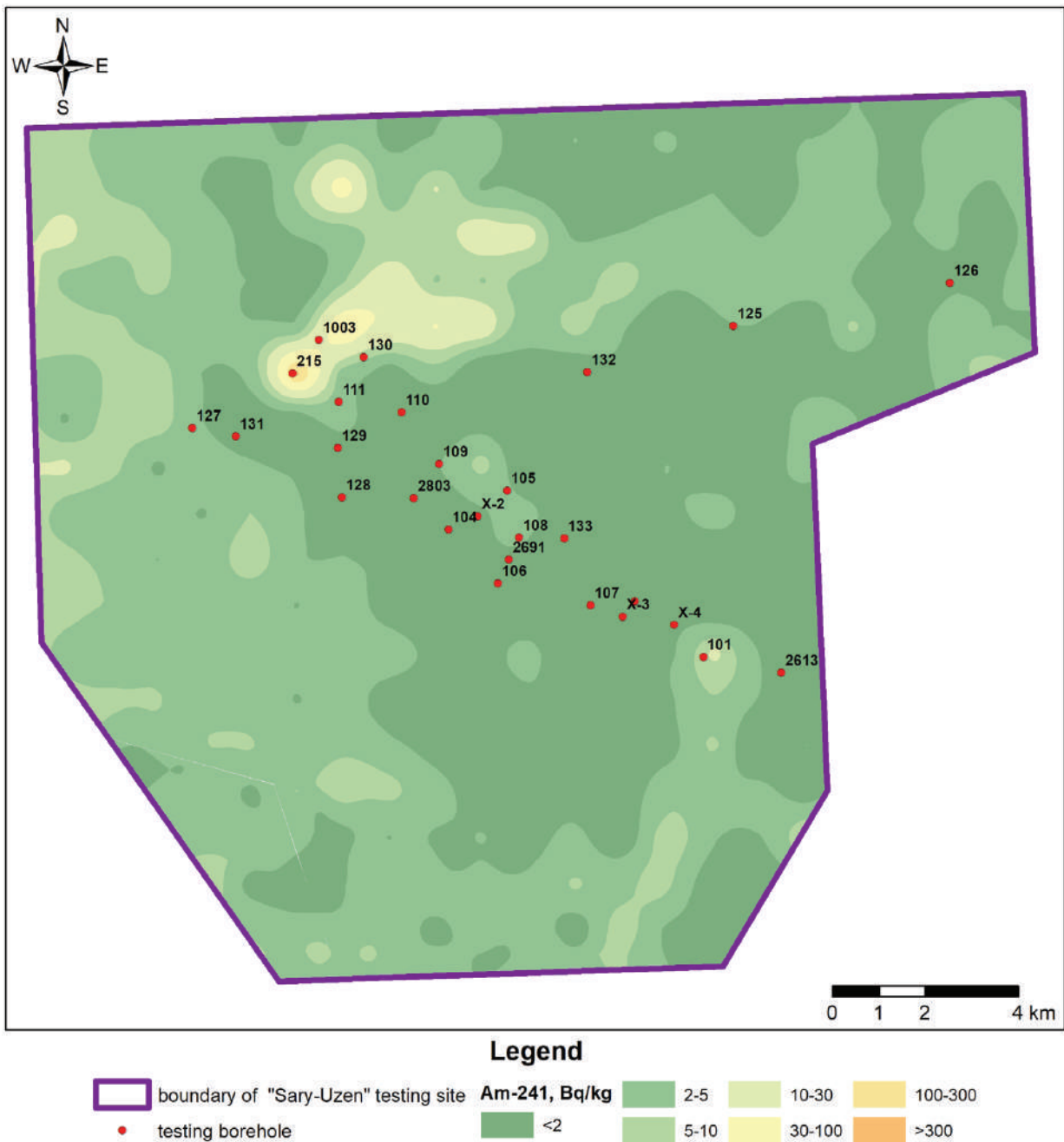


Figure 3.5. ²⁴¹Am distribution map of the ‘Sary-Uzen’ site area

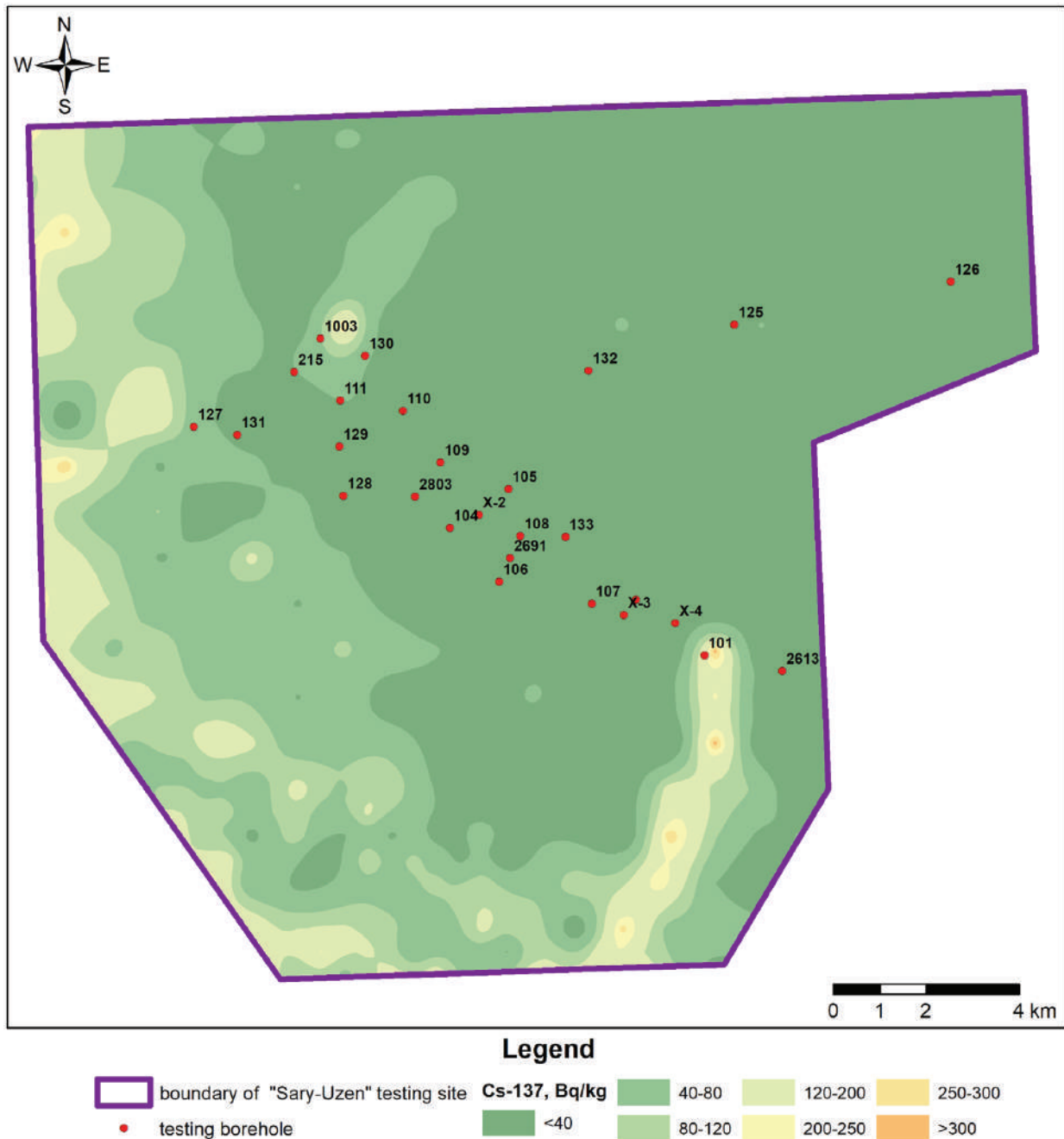


Figure 3.6. ¹³⁷Cs distribution map of the ‘Sary-Uzen’ site area

Another factor is contamination related to underground nuclear testing in boreholes No. 101, 125, 215 and 1003. The fallout plume of a nuclear test conducted in borehole No. 101 is the largest contamination area. This plume extends for about 8 km going beyond the testing site. In these areas, maximum concentrations of artificial radionuclides are: for ¹³⁷Cs – 1.1×10^4 Bq/kg and for ²⁴¹Am – 9.2×10^4 Bq/kg.

The survey of radioactive contamination of near-mouth areas of boreholes like at the 'Balapan' site, showed that maximum radioactive contamination is associated with either the soil ejection explosion or tests with the abnormal radiological situation. Values of ^{241}Am activity concentration ranged from <0.3 to 1.6×10^5 Bq/kg, for ^{137}Cs – <0.1 to 4.8×10^5 Bq/kg, for ^{90}Sr – <2 to 2.4×10^5 Bq/kg, for $^{239+240}\text{Pu}$ – <0.1 to 6.9×10^6 Bq/kg.

When addressing plant cover, one can note that near-mouth areas of boreholes are characterized by a high content of such radionuclides as $^{239+240}\text{Pu}$, ^{241}Am , ^{90}Sr and, to a lesser extent, is contaminated with ^{137}Cs . ^{241}Am activity concentration ranged from <0.1 to 6.0×10^3 Bq/kg, that of ^{137}Cs – <0.1 to 2.4×10^2 Bq/kg, for ^{90}Sr – <0.9 to 7.2×10^3 Bq/kg, for $^{239+240}\text{Pu}$ – <0.1 to 1.5×10^3 Bq/kg.

The content of ^{241}Am and ^{137}Cs in air is below the detection limit. Numerical values of radionuclides in air were only determined for $^{239+240}\text{Pu}$ – 0.5×10^{-6} to 13×10^{-6} Bq/m³, which indicated that the content of $^{239+240}\text{Pu}$ in air is 2–4 orders of magnitude lower than PVA_{pop} levels as specified by health standards 'Sanitary and Epidemiological Requirements for Radiation Safety Assurance' [48].

'4' and '4A' sites

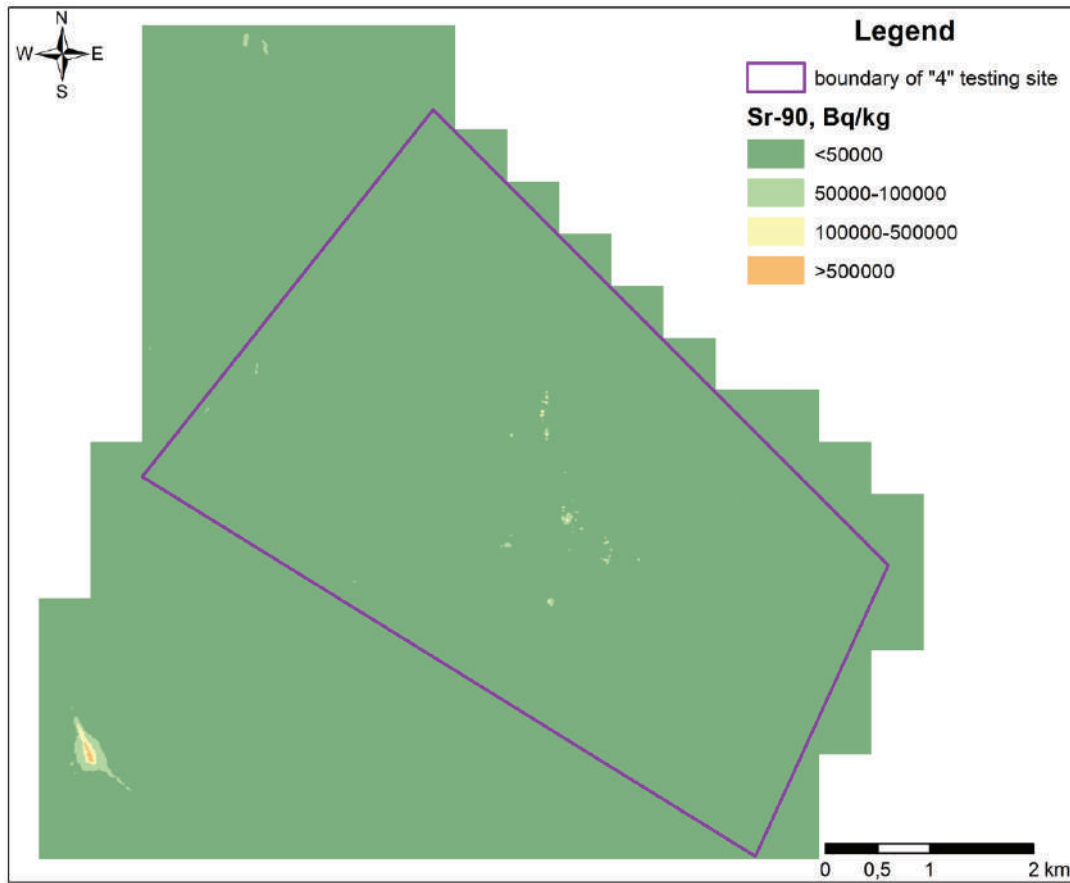
Nuclear explosions are known not to be the only type of tests conducted in the STS territory. '4' and '4A' are testing sites, at which radiological warfare agent test programs were implemented. Radioactive formulations containing fission products of the average and long half-lives were used in experiments. In most cases, ^{90}Sr posing the highest radiological hazard was used. Soluble ^{90}Sr forms are well absorbed by a mammal's gastro-intestinal tract. Besides, radioactive ^{90}Y having a 64-hour half-life is its decay product. Soon it emits one more β -electron and becomes stable ^{90}Zr . High ^{90}Sr doses cause acute radiation sickness in man. The lasting effect of small doses results in progression of its chronic form [132].

As mentioned above, the main work was exactly aimed at identifying ^{90}Sr while surveying areas of these testing sites. As a result of research, individual fragments of metal ware that were used during RWA tests were discovered as well as over 40 locally contaminated spots were revealed.

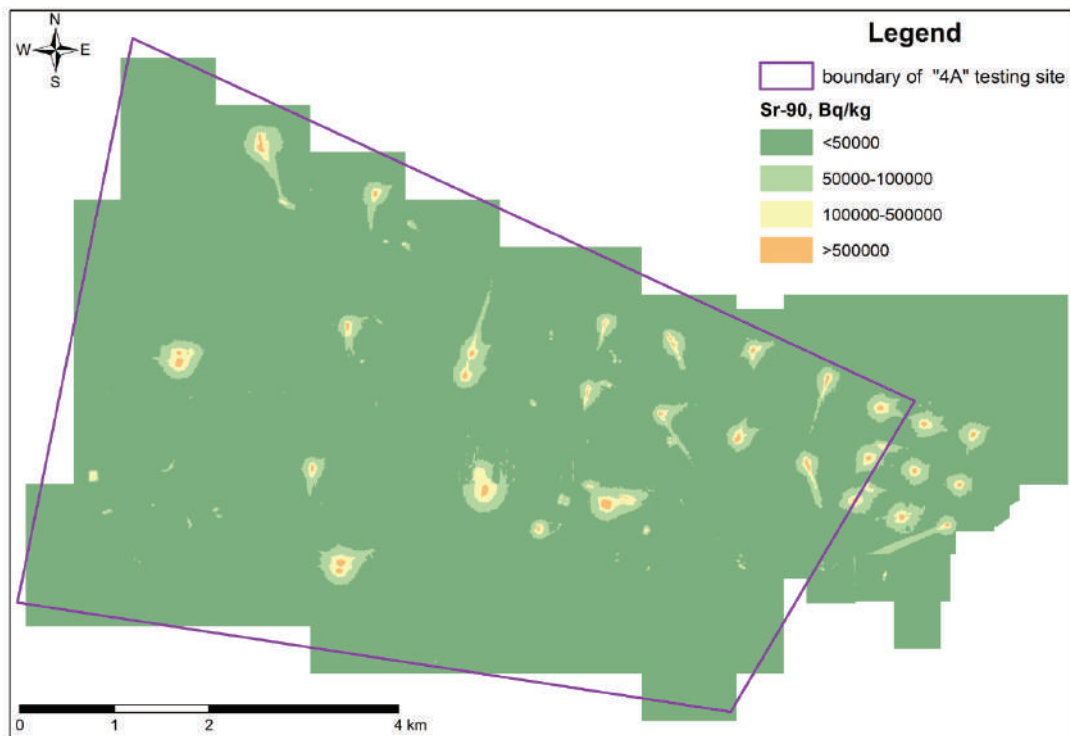
As expected, ^{90}Sr is the major contaminant of '4' and '4A' testing sites. Its concentration in soil varies between <1 and 5.9×10^8 Bq/kg. Research also showed that site areas have places with elevated values of other artificial radionuclides: ^{137}Cs - <0.2 to 3.8×10^5 Bq/kg, ^{241}Am - <0.3 to 3.0×10^4 Bq/kg, $^{239+240}\text{Pu}$ - <1 to 7.9×10^5 Bq/kg. One also has to note that not all of radioactive contamination is within historical boundaries of testing sites. The '4' site has a large radioactively contaminated area 3 km southwest of the site boundary. The '4A' site also has a number of locally contaminated spots that go beyond site boundaries eastward. Most likely, this is attributed to possible deviations from a designated position during testing (dropping a warhead from the airplane) as well as to relatively conventional boundaries. These areas are associated with those of '4' and '4A' sites.

^{90}Sr is the main contaminant of both plant cover and soil cover. Its concentration varies between <1 and 8.3×10^8 Bq/kg, which is comparable with the one in soil, and in some cases it even exceeds it. High values of activity concentration in plants are also characteristic of other radionuclides: for ^{241}Am - <0.1 to 9.2×10^2 Bq/kg, for ^{137}Cs - <0.2 to 1.0×10^3 Bq/kg, for $^{239+240}\text{Pu}$ - <2 to 2.4×10^3 Bq/kg.

Within sites under survey, volumetric activities of artificial radionuclides in air were: for ^{241}Am - $<8.0 \times 10^{-5}$ Bq/m³, for ^{137}Cs - $<3.5 \times 10^{-5}$ Bq/m³, ^{90}Sr - $<4.3 \times 10^{-5}$ to 1.4×10^{-2} Bq/m³, $^{239+240}\text{Pu}$ - $<4.2 \times 10^{-7}$ to 4.7×10^{-6} Bq/m³, which is 3-5 orders of magnitude below PVA_{pop} levels as specified by health standards 'Sanitary and Epidemiological Requirements for Radiation Safety Assurance' [48].



a)



b)

Figure 3.7. ^{90}Sr distribution maps of site areas: a) '4'; b) '4A'

‘Telkem’ site

The ‘Telkem’ site represents two large craters formed by two industrial excavation explosions (Telkem-1, Telkem-2) conducted in Autumn of 1968. Industrial nuclear explosions were among the first lines of the Program on industrial utilization of underground nuclear explosions with soil ejection to make artificial water reservoirs.

Areal studies showed that radionuclides are localized around craters (so-called ‘lakes’) produced during nuclear testing and filled up with ground waters

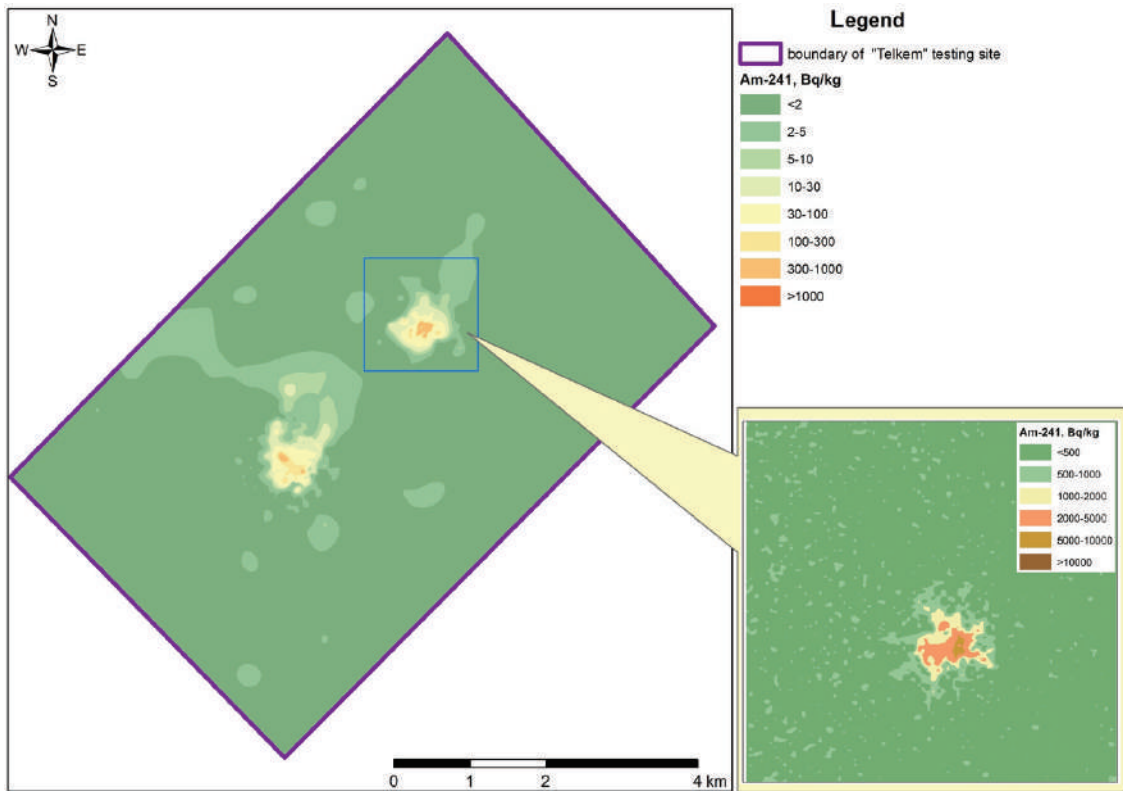
Based upon research into aquatic medium, surface waters that fill up craters at the ‘Telkem’ site were found to contain ^{90}Sr and ^3H in quantities not exceeding the intervention level [48]. No presence of ^{137}Cs , ^{241}Am or $^{239+240}\text{Pu}$ in water was noted.

Significant concentrations of $^{239+240}\text{Pu}$ activity concentrations (from 5.1 to 1.6×10^4 Bq/kg) are noted in plants. ^{241}Am activity concentration ranged from <0.1 to 1.3×10^3 Bq/kg, ^{137}Cs – <0.2 to 1.6×10^3 Bq/kg, ^{90}Sr – 68 to 5.4×10^3 Bq/kg.

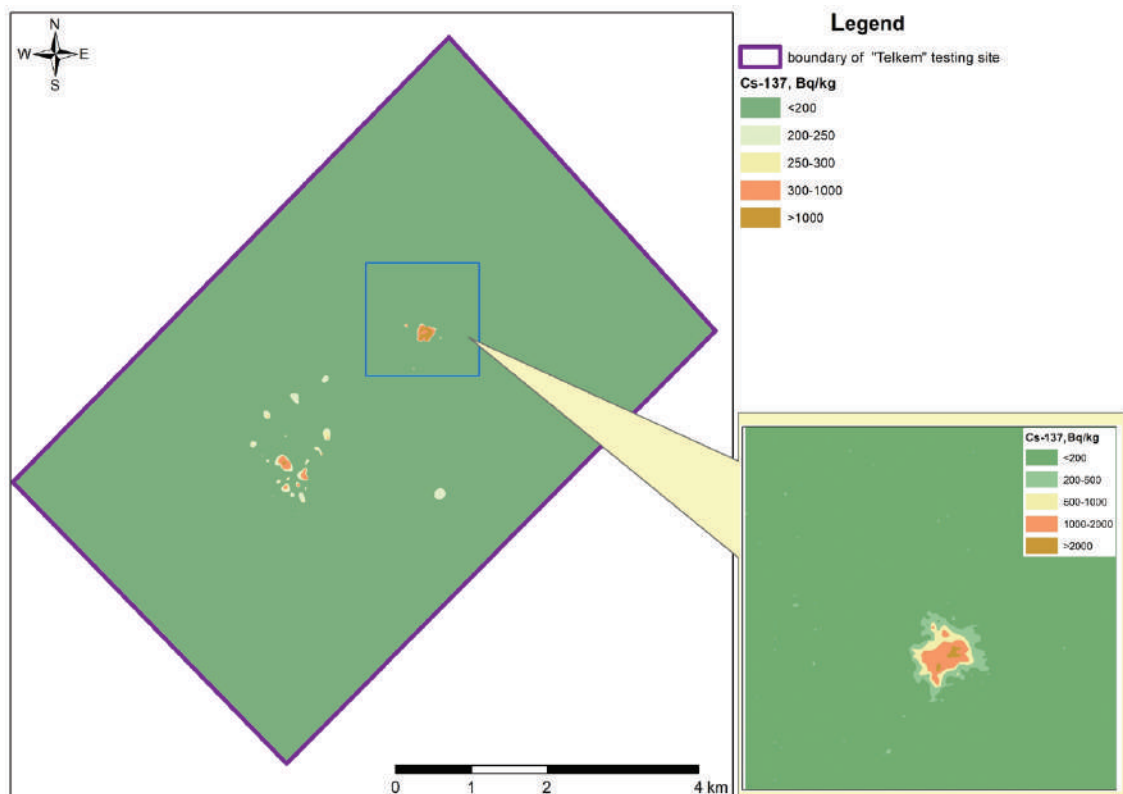
Contamination of the air basin is attributed to a secondary transfer of radioactive dust particles containing long-lived ^{137}Cs , ^{241}Am , ^{90}Sr and $^{239+240}\text{Pu}$. Numerical values of concentrations were only reported for $^{239+240}\text{Pu}$ and reached 1×10^{-3} Bq/kg.

Conclusions

Based upon data obtained from the long-term survey of testing sites and the analysis of areal distribution maps of artificial radionuclides, radioactively contaminated areas, in which areal activity values of radionuclides in soil cover exceeded the ones as specified by the Criteria for the assessment of ecological situation around areas, were revealed [51]. For example, 25 radioactively contaminated areas were revealed at the ‘Experimental Field’ site totaling 4.2×10^7 m², at the ‘Degelen’ site – 16 areas totaling 7.6×10^5 m², at the ‘Balapan’ site – 13 areas totaling 8.0×10^6 m², at the ‘Sary-Uzen’ site – 7 areas totaling 9.4×10^5 m², at the ‘4’ site – 6 areas totaling 1.6×10^5 m², at the ‘4A’ – 36 areas totaling 2.7×10^6 m², at the ‘Telkem’ site – 2 areas totaling 1.6×10^5 m².



a)



b)

Figure 3.8. Distribution maps for the 'Telkem' site area:

a) ^{241}Am ; b) ^{137}Cs

CHAPTER 4. PROSPECTS FOR TEST SITE DEVELOPMENT

4.1 Radiological situation in adjacent areas

STS activity of many years have caused radioactive contamination of areas beyond the test site. The main contribution to radioactive contamination of areas has been made by atmospheric nuclear tests conducted between 1949 and 1962. First of all, this is due to weather conditions at the time of nuclear testing. These conditions resulted in radioactive clouds going beyond the test site and fell onto the earth's surface in the form of radioactive fallout. Despite a great many atmospheric nuclear tests conducted at STS (116 tests [3, 133]), only a few formed radioactive contamination beyond the test site whereas most tests were conducted under conditions of the heaviest deposition of nuclear debris directly in the test site territory. Late in 1956, military specialists of the test site and specialists of the Institute of Applied Geophysics of the USSR's Academy of Sciences conducted the first detailed dosimetric and radiometric STS survey as well as an airborne gamma survey of terrain at a distance of up to 500 km around the test site.

The survey showed that the first Soviet atmospheric nuclear test conducted on August 29, 1949 that produced a radioactive plume northeast of the 'Experimental Field' testing site, the atmospheric nuclear test conducted on September 24, 1951 resulting in a plume southward and the first test of the Soviet hydrogen bomb in the atmosphere conducted on August 12, 1953 that caused a plume to appear southeastward, are among tests that affected the radiological situation beyond STS.

There is little information on the arrangement of meteorological support of the first nuclear tests. Archival data concerning the first nuclear test conducted on August 29, 1949 only reports the speed

of mean wind being equal to 40-60 km/h in the atmospheric layer from 0 to 6 km [2]. According to witnesses, the weather was dry and hot in August of 1949. However, on the night of August 28 through 29, the wind velocity sharply increased, and a thunderstorm began in the morning. Experiment supervisors were concerned about unauthorized detonation of a nuclear charge planted on a 37.5-meter metal tower in case of a lightning strike. At the same time, the first Soviet experimental test of the nuclear charge was an important military and political event on the world stage. Work managers made a decision to bring forward the nuclear test from 8 a.m. to 7 a.m. Thus, lack of meteorological information during the test caused extensive radioactive contamination beyond the test site where the external gamma dose afield could exceed 1 R before radioactive substances completely decayed.

The first experimental test of the nuclear charge was an important military and political event that caused meteorological conditions to be disregarded and the device to be detonated in rainy weather with sharp wind gusts. The result of the decision made – extensive radioactive contamination of the territory beyond the test site, at which the external gamma dose afield could reach 1 R before radioactive substances completely decayed. Contamination stretched as a gradually broadening strip as far as roughly 300 km from the boundary of the restricted area with a plume as wide as 40–50 km [134]. The zone of a passing fallout plume after the 29.08.1949 nuclear test involved the Beskaragai and Novopokrovsky areas of the Semipalatinsk region as well as some areas of the Altai Territory. As a result of fallout after the nuclear test conducted on September 24, 1951, the Abai, Chubartau and Ayaguz areas of the Semipalatinsk region were exposed to radioactive contamination. After the most powerful aboveground test in the USSR conducted on August 12, 1953, the Abai, Georgiyevka and Ayaguz areas of the Semipalatinsk region with settlements Abai,

Kyzyltas, Zhurekodyr, Sarzhal (Telman collective farm) and others were contaminated with debris [3, 8].

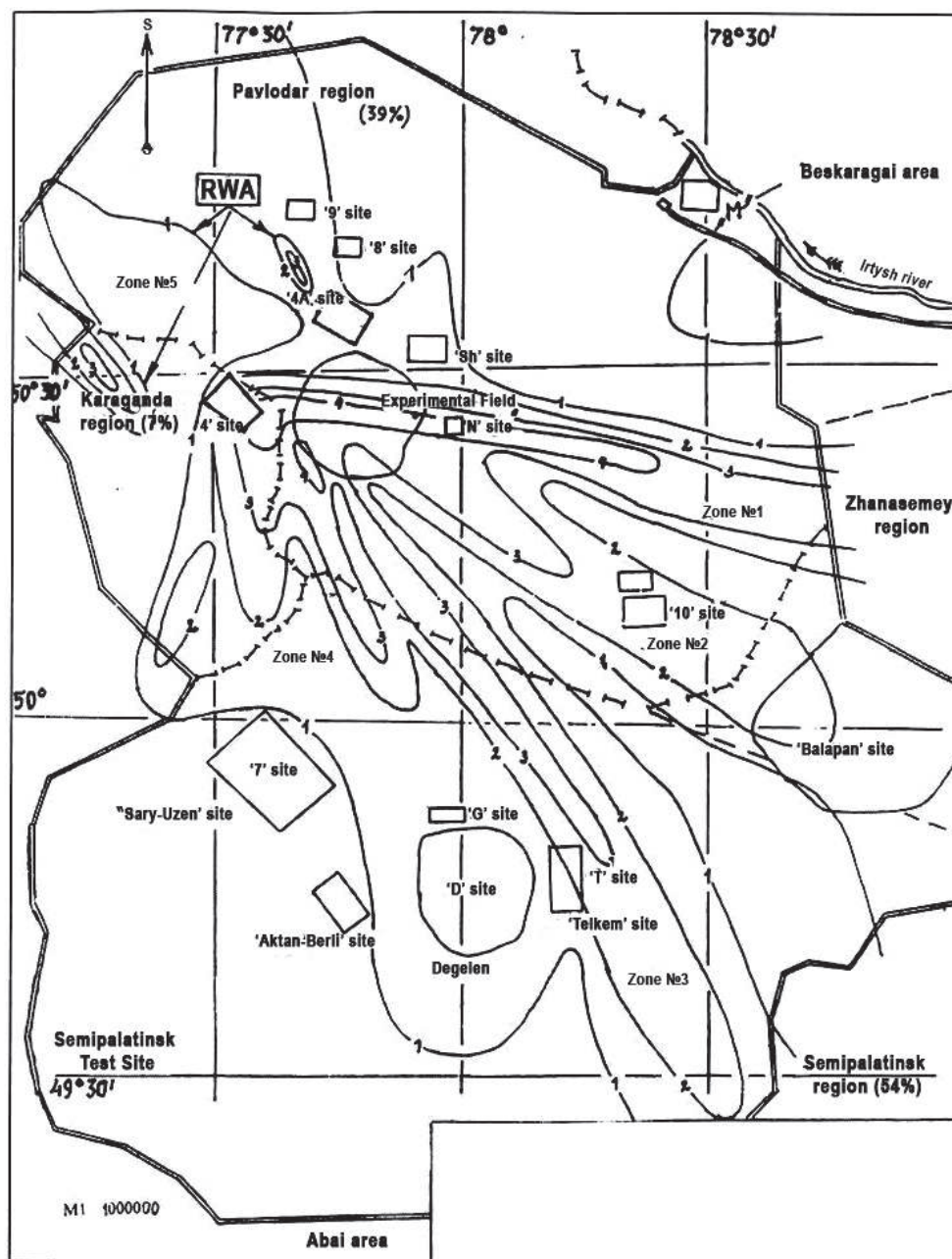


Figure 4.1. Scheme of radioactive contamination in the STS territory as of December 1956. Positions of gamma dose rate isolines, $\mu\text{R/h}$: 1) 12-40, 2) 40-100, 3) 100-1000, 4) >1000 [8]

1956 through 1989, 6 comprehensive medical scientific expeditions were arranged with 2 dedicated health centers that operated on a permanent basis. These were studying the radiological and sanitary-hygiene situation as well as examining the state

of people's health around settlements in some areas of the East Kazakhstan, Semipalatinsk, Pavlodar and Karaganda regions [3]. It has to be mentioned that no cases of acute or chronic radiation sickness were revealed in the state of people's health over the entire observation period [3].

The main goal of radiation control during nuclear tests was to define characteristics of each radioactive plume and, first of all, public external exposure doses close to the test site [3, 3]. For example, according to literature data, the average public dose varied between 0.03 and 0.50 R (0.26-4.40 mSv) in areas adjacent to STS that were in the zone of fallout plumes due to atmospheric tests [8].

Once nuclear tests ceased, the issue of defining the extent and levels of radioactive contamination of the environment in areas adjacent to the test site as well as severity of exposure of the public health to the test site activity arose. In order to define the radiological situation in areas adjacent to STS, Kazakhstani specialists carried out radioecological surveys under different projects jointly with colleagues from near- and far-abroad countries (Russia, the USA, Japan, Germany, Austria, France and others).

Based upon research, passports of 711 settlements were prepared stating external exposure doses after each specific test and total external exposure doses over the entire testing period. Such outstanding scientists from Kazakhstan as E. Batyrbekov, R. Aitmagambetov, T. Saibekov were passport development reviewers. All passports were submitted to the Ministry of Healthcare RK and to the Ministry of Ecological and Biological Resources RK [8].

Based upon these materials, the Law of the Republic of Kazakhstan dated December 18, 1992 No. 1787-XII 'On Social Protection of Citizens who suffered from nuclear tests at the Semipalatinsk Nuclear Test Site' was drafted and adopted classifying territories affected by nuclear tests (Figure 4.2).

According to the classification, the entire territory of the East Kazakhstan region and areas of the Pavlodar, Karaganda regions adjacent to the test site were declared ecological disaster zones. The zone of extreme radiation risk included areas of the Sarzhhal rural district of the Abai region, those of the Dolon rural district of the Beskaragai region, settlements Sarapan and Isa of the abolished Zhanasemei area of the East Kazakhstan region [136].

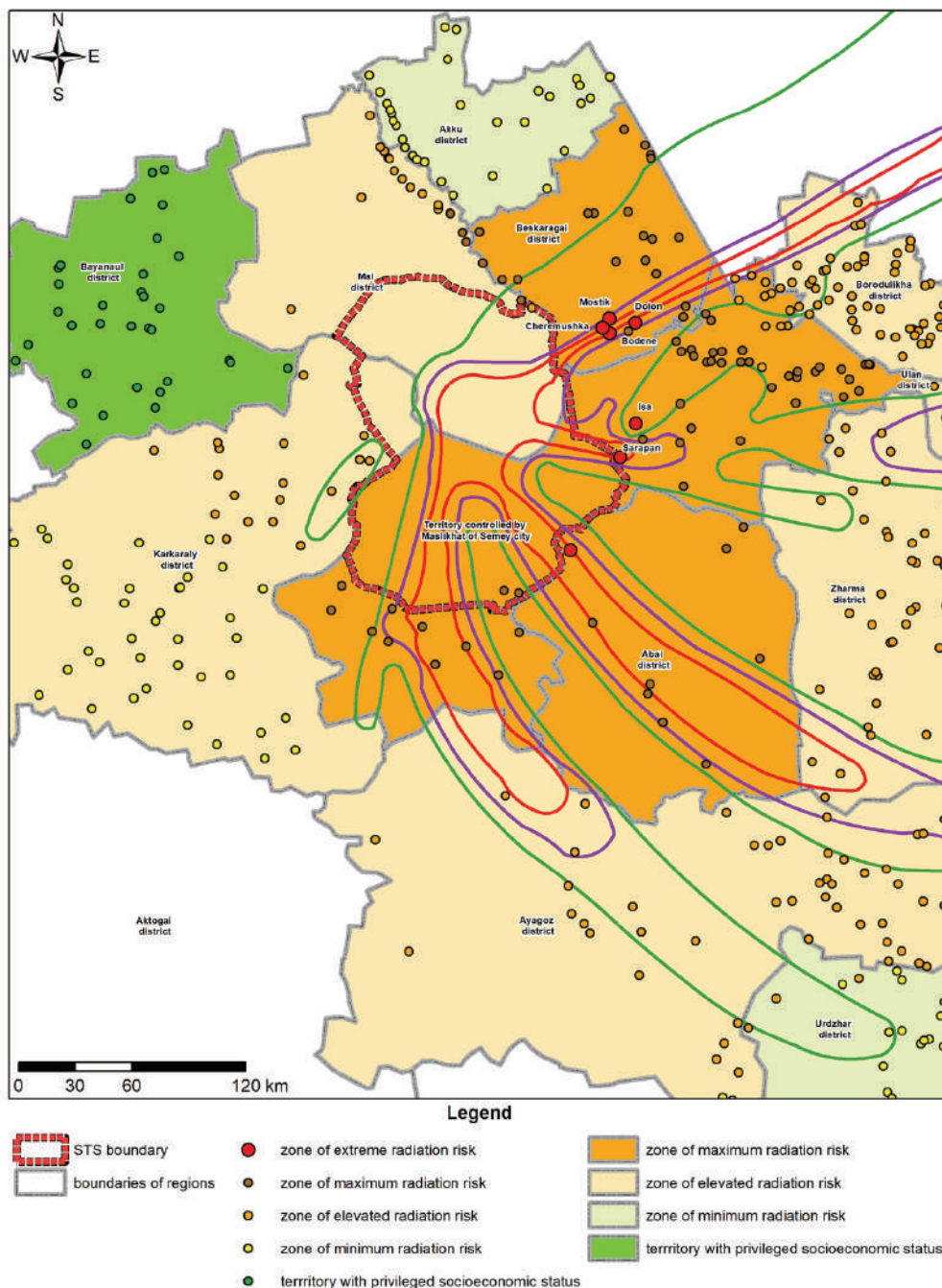


Figure 4.2. Classification of territories affected by fallout during nuclear tests

Preliminary research undertaken in 2004-2005 in ribbon forests of the Near-Irtysh area (Beskaragai region) and in the territory of the Abai region (between settlements Sarzhal and Karaul) revealed contamination of soil cover with artificial ^{137}Cs at the level of hundreds of Becquerels per kilogram [137]. Further research into ribbon forests undertaken in 2006-2010 under the state-funded program 'Forest Preservation and Increase in Area under Forest of the Republic', showed that contamination of soil cover with artificial radionuclides ^{137}Cs , ^{90}Sr and $^{239+240}\text{Pu}$ along fallout plumes is at the level of hundreds of Becquerels per kilograms, which exceeds the content of radionuclides detected in soils of the northern and western STS parts [138, 139].

In different periods, specialists of the National Nuclear Center RK conducted radioecological surveys of a portion of the Maisk area of the Pavlodar region, the Abraly and Beskaragai areas of the East Kazakhstan region [140, 141].

Based upon the comprehensive radioecological survey of the STS territory that the National Nuclear Center RK conducted, radioactive contamination of the environment with artificial radionuclides was registered on the STS boundary. This proves the fact that some of lands beyond the test site were also exposed to radioactive contamination due to nuclear weapon tests. For example, between 2011 and 2014, under the work according to the republican state-funded program, a comprehensive ecological survey of the southeastern STS part was conducted. It was found from the survey that radioactive contamination of the environment with artificial radionuclides is registered on the southeastern STS boundary [141]. The zone width reached 40 km on the test site boundary and 55-60 km at a distance of 140 to 150 km from ground zero.

Under the work according to the republican state-funded program for 2014-2016, comprehensive radioecological surveys of the Beskaragai, formerly named as the Zhanasemei area, and a number of

settlements that referred to zones of extreme and maximum risk were planned [141]. In 2014, the survey of the Beskaragai area, 340 km² and settlements Beskaragai and Kanonerka began. A fallout plume after the 29.08.1949 nuclear test passed exactly through this territory (Figure 4.5) [142].

Under the 2015 work, follow-up research aimed at delineating radioactively contaminated areas, eliciting mechanisms and contributors to the formation and progression of the radiological situation was undertaken.

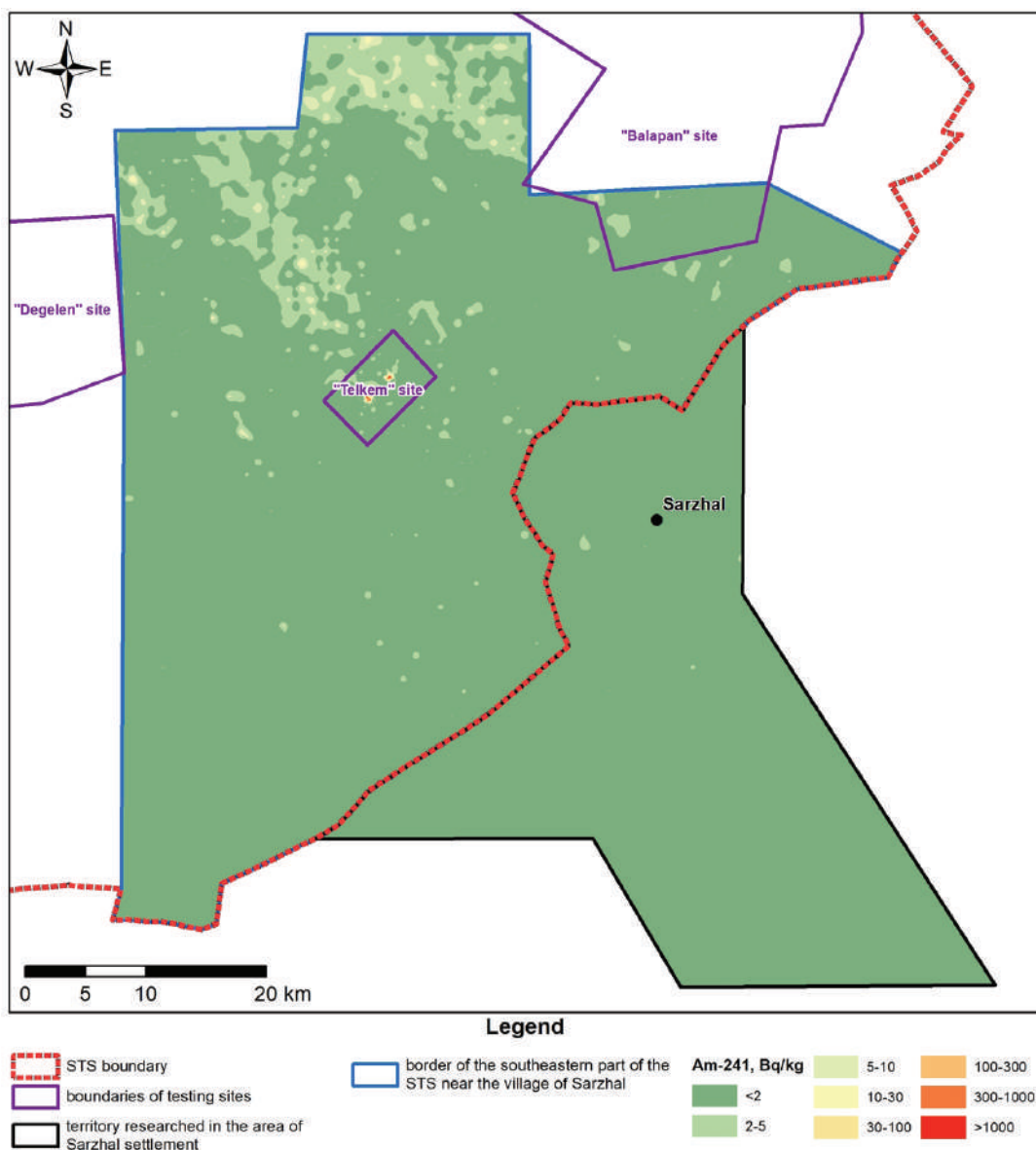


Figure 4.3. Radioactive contamination with ²⁴¹Am in the southeastern part within and outside the STS boundary

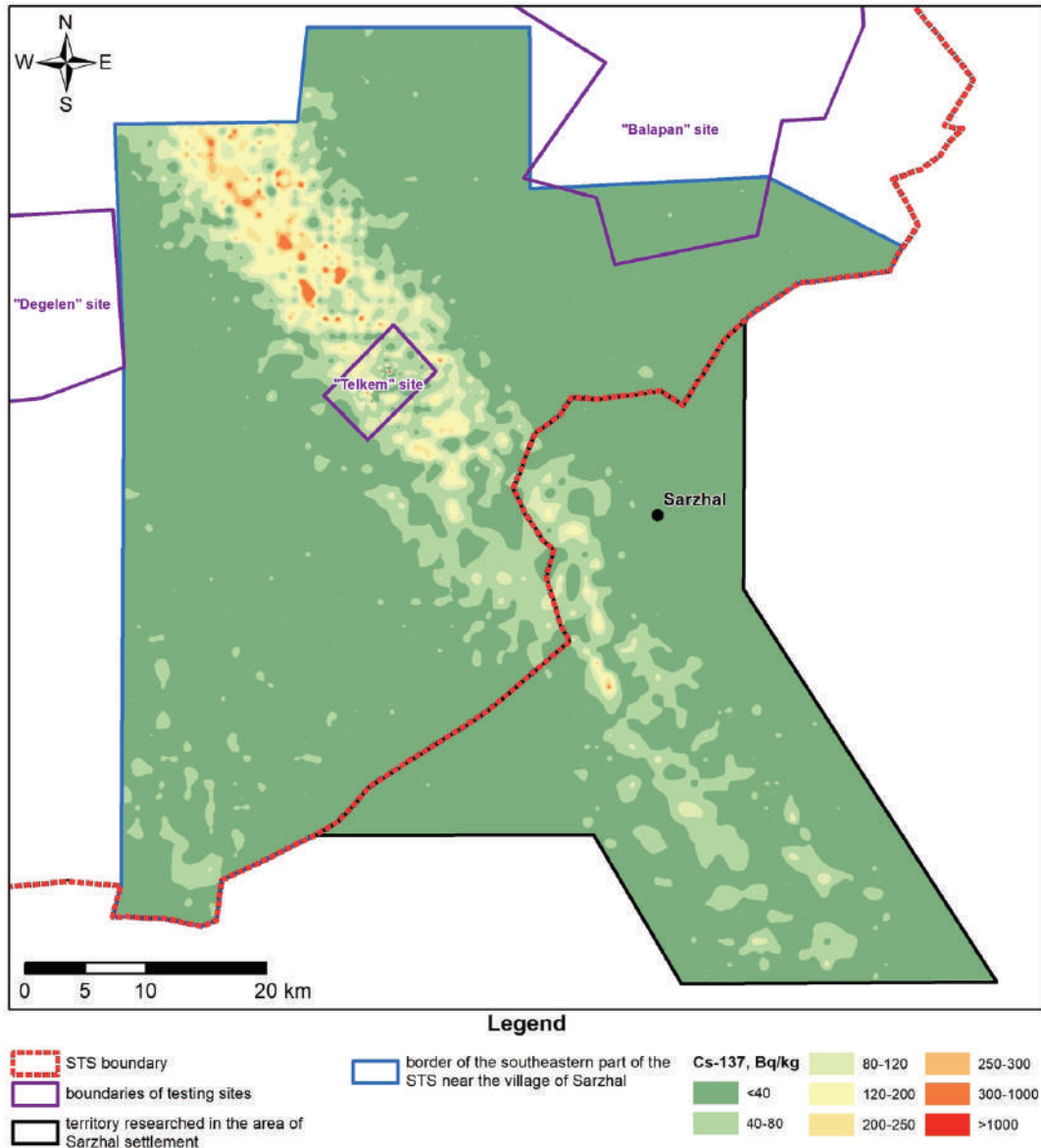


Figure 4.4. Radioactive contamination with ¹³⁷Cs in the southeastern part within and outside the STS boundary

The analysis of findings showed that average concentrations of artificial radionuclides in soil of settlements surveyed did not exceed regulatory values [48, 143]. It was also found that outskirts of some settlements have regions of elevated values. Penetration of artificial radionuclides due to economic activities might have caused their concentrations to be low in the central part of settlements.

In addition to contamination of areas adjacent to STS during tests, the problem of the carry-away of artificial radionuclides beyond the

STS territory after tests were terminated remains. For example, the low water Shagan river flowing from west to east along the southern boundary of the ‘Balapan’ testing site is a left-bank tributary to the Irtysh river.

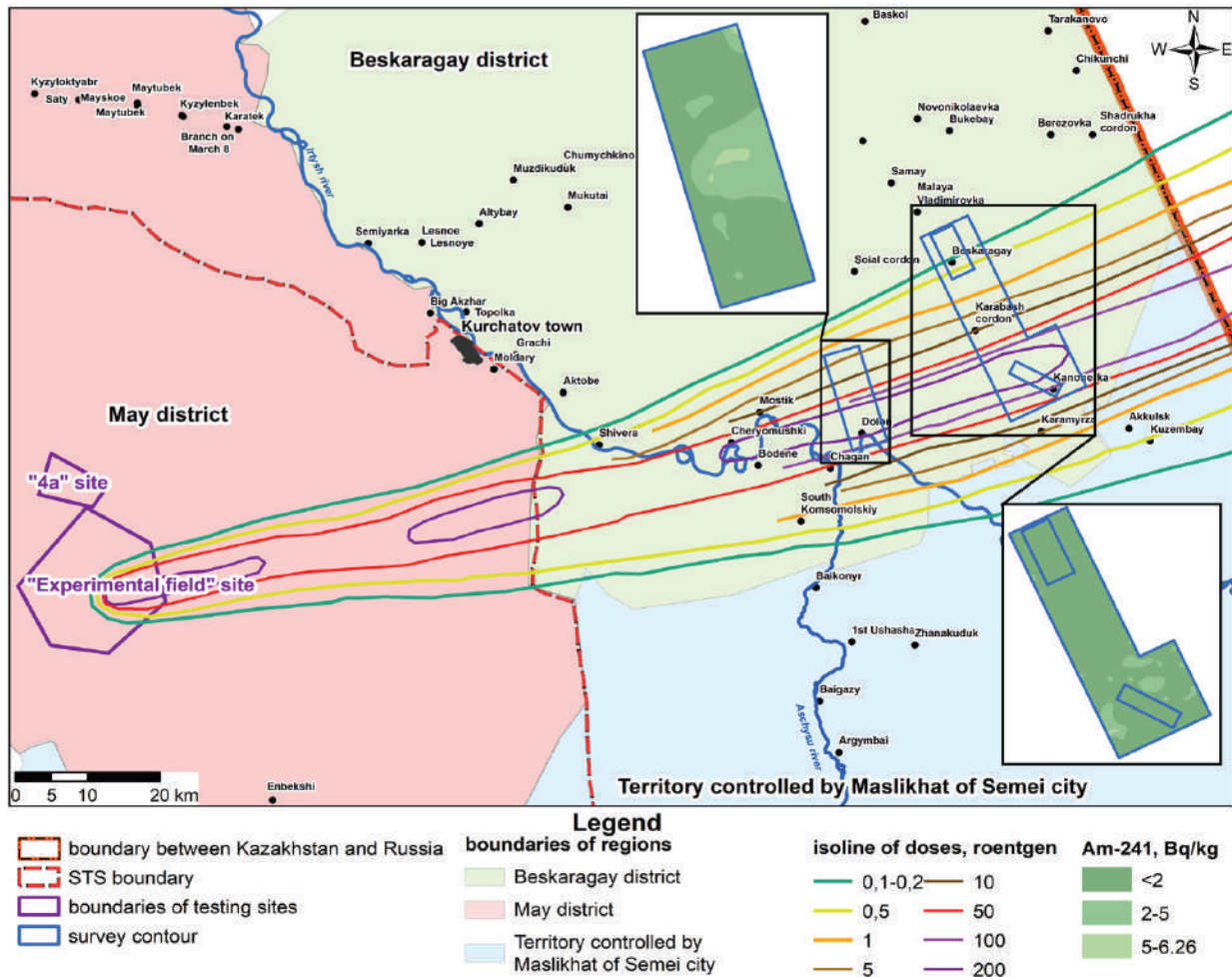


Figure 4.5. Scheme of radioactive contamination produced by fallout after the 29.08.1949 nuclear test in areas adjacent to STS

Being affected by nuclear tests that were conducted in the STS territory, the Shagan river and its riverside area were repeatedly exposed to radiation. Radioactive contamination of the river’s ecosystem components is concentrated near borehole No. 1004 in which, on January 15, 1965, an excavation fusion explosion was conducted at a depth of 178 meters in order to make a water reservoir [141]. In addition, radioactive contamination of the Shagan river is attributed to

ground waters that enter surface waters of the river from the ‘Balapan’ site, at which underground nuclear tests were conducted in boreholes [144, 145, 146].

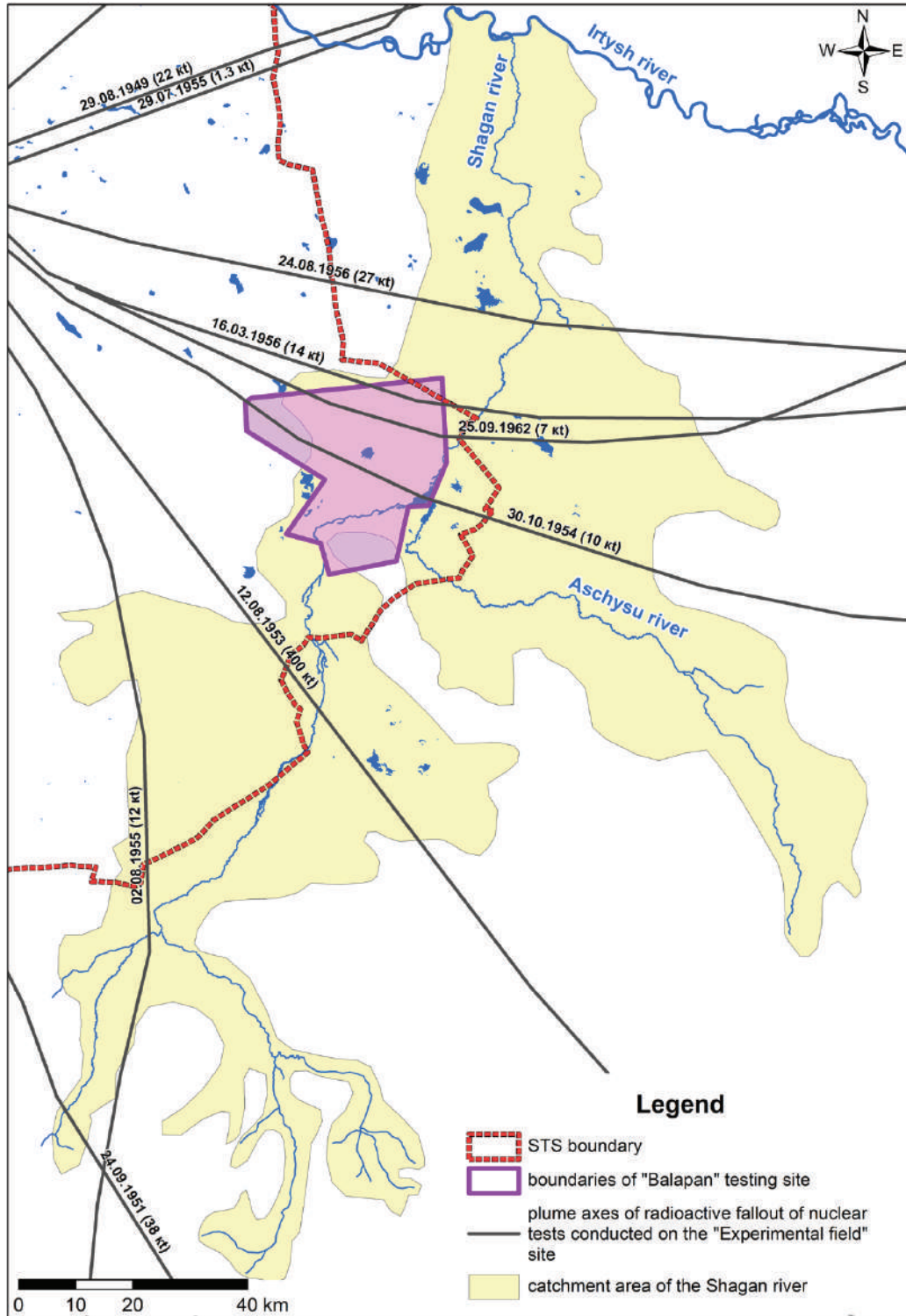


Figure 4.6. Catchment area of the Shagan river’s basin and plumes of local fallout after aboveground explosions at the ‘Experimental Field’ site

Research of many years has revealed and proved many times that ^3H is the major contaminant of the Shagan river. Radioactive contamination of river water is characterized by a highly nonuniform distribution of ^3H . For example, based upon research findings, several radioactively contaminated areas were revealed at the section of the Shagan river from the 'Atomic Lake' to the inflow into the Irtysh river with different tritium concentrations in surface waters. Maximum registered ^3H concentration is 5 km downstream the Shagan river from the 'Atomic Lake' and reaches 350,000 Bq/kg, which exceeds the regulatory value for the public by almost 50 times. Such considerable radioactive river water contamination is comparable with the level of liquid radioactive waste. As far as 10 km beyond the test site, the content of ^3H in river water varies between 10,000 and 40,000 Bq/kg, which exceeds the regulatory value for the public by 1.3 to 5.2 times [147, 148, 149, 150, 151].

As a result of the ecological chain, a secondary contamination of ecosystem components that include plants, animals and air with ^3H occurs. Currently, the impact zone of the Shagan river has residential winter and summer huts, around which agricultural activities are being actively carried out: livestock breeding and grazing, haymaking, commercial activities (fishing out, hunting for aquatic birds etc.). However, no comprehensive ecological survey of the Shagan river section was carried out from the STS boundary to the inflow into the Irtysh river.

Thus, one can note that research into the radioecological situation, the impact of nuclear tests on the environment and human health beyond the test site has been undertaken since tests began, although being irregular. A number of factors such as lack of unified research tasks, utilization of various procedures, inconsistency of research findings resulted in fragmentary information. Ongoing research at that point in time did not fully cover areas of the Beskaragai rural

district. One should also mention that the territory of the Sarzhal rural district was only surveyed along the expected axis of the fallout plume after the 12.08.1953 test. In addition, a complete survey of the rural district territory was not conducted. Findings do not reflect the existing radiological situation.

Clause 16 of the RK's Law 'On Social Protection of Citizens who suffered from nuclear tests at the Semipalatinsk Test Site' says that a range of measures have to be taken to enhance the environment in areas affected by STS nuclear tests, in particular, environmental scientific research has to be undertaken, environmental compartments and locally produced foodstuffs have to be continuously monitored. The environmental survey of areas that refer to the zone of extreme radiation risk and the section of the Shagan river, from the STS boundary to the inflow into the Irtysh river will allow obtainment of relevant data on concentrations of radionuclides in environmental compartments and assessment of the radiological hazard to the environment and the public.

The National Nuclear Center of the Republic of Kazakhstan is currently working on the inclusion of the comprehensive ecological survey of the main environmental components in these areas in republican programs. Findings will allow assessment of public radiation exposure for those who are living there at this point in time, which will eventually make it possible to reduce social tension related to negative attitude towards living conditions close to the test site.

4.2 Radiation monitoring

Currently, the main mechanisms of radionuclide migration in the STS territory from places of nuclear tests are by air and water. Migration of radionuclides with air currents may occur owing to natural or man-made raise and transport of dust-like fractions of radioactively contaminated soil into the atmosphere. Natural dust raise depends on wind velocity, and man-made raise may depend on a

number of factors, for example, movement of people, animals, vehicles in the test site area [152, 153]. Migration of radionuclides in aquatic medium is attributed to the carry-away of artificial radionuclides with surface and ground waters through natural hydrographic paths of the test site (creeks, catchment basins, faults) [154, 155].

Taking into account the possibility of the transport of man-made radionuclides, one of crucial tasks at this point in time is to study air and water quality. To this end, active preparation of monitoring sites in the test site area and adjacent areas is in progress for regular observations of the radiological state of air and aquatic media.

Thus, in order to develop radiation monitoring and for its further implementation, source data obtainment, definition of controlled parameters and decision-making on monitoring frequency, specification of the number and locations of monitoring sites are in progress.

Radiation monitoring

For air monitoring, around-the-clock monitoring sites were arranged in the STS territory and adjacent areas. Air environment is monitored in the vicinity of STS testing sites ('Experimental Field', 'Balapan' and 'Degelen') as well as in settlements being adjacent to the STS territory (Kurchatov, Dolon and Sarzhal).

Air aerosols were sampled with different fixed-site and portable air samplers, filters are replaced once per month. The average volume of pumped air is 520,000 m³. Air aerosol sampling in progress is depicted in figures (Figure 4.7).

Air monitoring data showed that maximum concentrations of artificial radionuclides ²³⁹⁺²⁴⁰Pu, ²⁴¹Am and ¹³⁷Cs in air are directly registered in the place of man-made impact on soil cover. ²³⁹⁺²⁴⁰Pu concentration in air in this case may exceed the PVA_{pop} by more than 10 times being 2.5×10⁻³ Bq/m³. However, 300 m away from the radioactively contaminated area, the average concentration of artificial radionuclides in air decreases by 2-3 orders of magnitude.



Figure 4.7. Air aerosol sampling at monitoring sites:
a) air aerosol sampling at RRF IGR;
b) air aerosol sampling in Kurchatov t.

To assess the extent of spreading artificial radionuclides by air beyond testing sites, special experimental research was undertaken at different distances from ground zeroes. For instance, at the ‘Balapan’ site, maximum $^{239+240}\text{Pu}$ concentrations in air are observed in the zone of a contaminated dump at the ‘Atomic Lake’ reaching $6.5 \times 10^{-3} \text{ Bq/m}^3$. At a distance of 5 to 10 km from the ‘Atomic Lake’, $^{239+240}\text{Pu}$ concentration in air is at the level of $1.0 \times 10^{-6} \text{ Bq/m}^3$, which is 3 orders of magnitude lower than the PVA_{pop} level.

As a whole, no ^{241}Am , ^{137}Cs or ^{90}Sr beyond ground zeroes were detected. Numerical values for air environment are registered for $^{239+240}\text{Pu}$. As observed, the volumetric activity of $^{239+240}\text{Pu}$ registered in air of all STS areas and settlements (Kurchatov t., Dolon vil. and Sarzhal vil.) varies from 10^{-9} to 10^{-7} Bq/m^3 . These values are 3-5 orders of magnitude lower than the permissible volumetric activity for the population category (PVA_{pop}) as specified by health standards and pose no threat to health [48].

For monitoring of aquatic medium, monitoring sites of surface and ground waters on migration paths of artificial radionuclides related to ground zeroes were arranged, i.e. the ‘Degelen’, ‘Balapan’ and ‘Sary-Uzen’ sites (Section 2.6 Radiological state of aquatic medium). Water at monitoring sites is sampled using special sampling devices and vehicles (Figure 4.8).

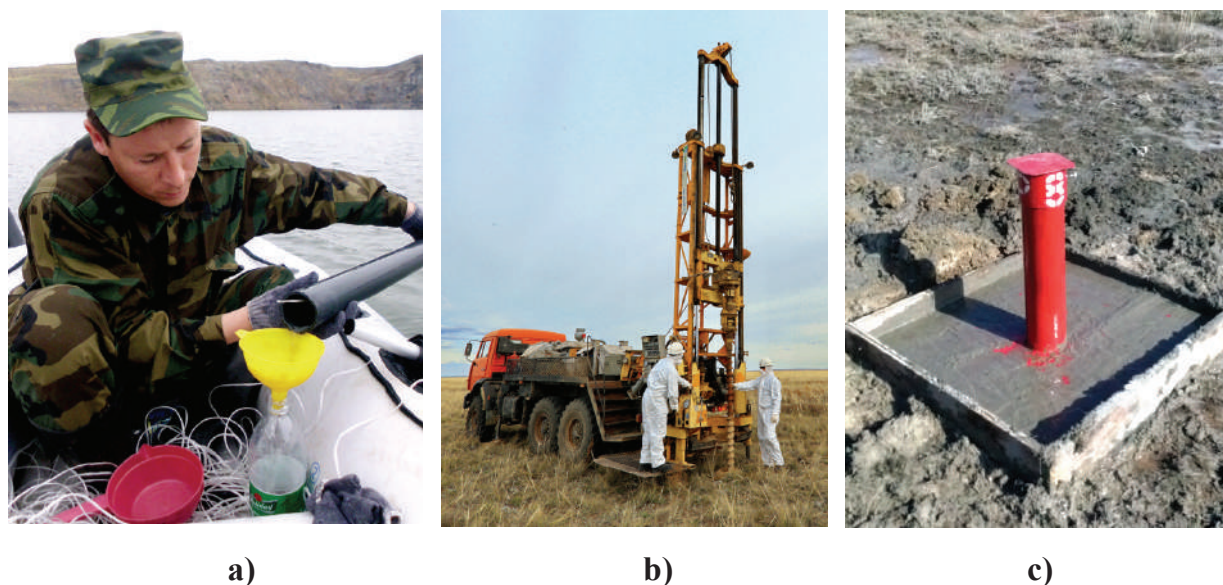


Figure 4.8. Surface and ground water monitoring: a) surface water sampling; b) ground water sampling; c) observation point of ground water

The ongoing monitoring showed that the major radionuclide travelling beyond contaminated areas with ground and surface waters is ^3H . Migration of ^{137}Cs , ^{90}Sr , $^{239+240}\text{Pu}$ is mostly localized within testing sites ‘Degelen’, ‘Balapan’ and ‘Sary-Uzen’.

The comparative analysis of monitoring data showed that the content of ^3H in water at most monitoring sites of surface and ground waters significantly exceeds the intervention level (7,600 Bq/kg) varying between 20 and 400,000 Bq/kg. ^3H activity concentration is observed to both increase and decrease. In this regard, it was decided to sample water in different seasons at certain monitoring sites: in spring, summer and autumn. This allowed a more detailed description of variation in the radiological situation.

For instance, in the bed of the Shagan river, based upon findings, 3 monitoring sites were arranged at different distances from the ‘Atomic Lake’ downstream the river: in the section of maximum ^3H concentration in water (‘5 km’), in the vicinity of the Shagan river flowing beyond the STS boundary (‘14 km’) and in the section the Shagan river flows into the Irtysh river (‘110 km’). Monitoring sites are depicted in the figure (Figure 4.9).

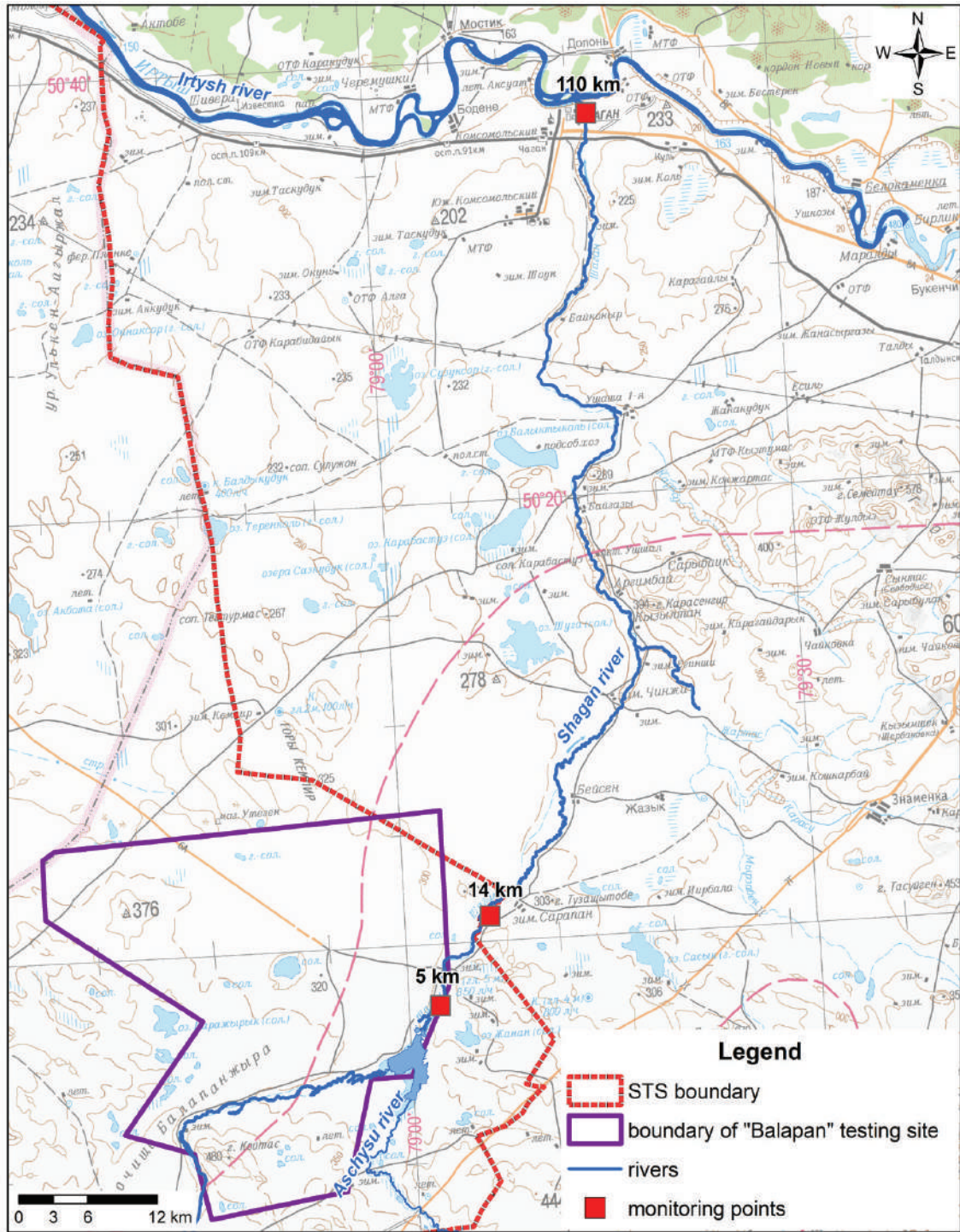


Figure 4.9. Water monitoring sites at the Shagan river

Surface waters were seasonally sampled at each of the three monitoring sites: in spring, summer and autumn. Monitoring data is presented in the figure (Figure 4.10).

Monitoring data showed that April through September, ^3H activity concentration may vary significantly. The most pronounced

fluctuations are noted at the ‘5 km’ observation point, which is characterized as the area most contaminated with ^3H . The smallest fluctuations are registered at the ‘110 km observation point at the confluence of the Shagan and Irtysh rivers. One also has to mention that ^3H numerical values are traced at all monitoring sites irrespective of an observation season. This points to ^3H migration beyond the STS boundary.

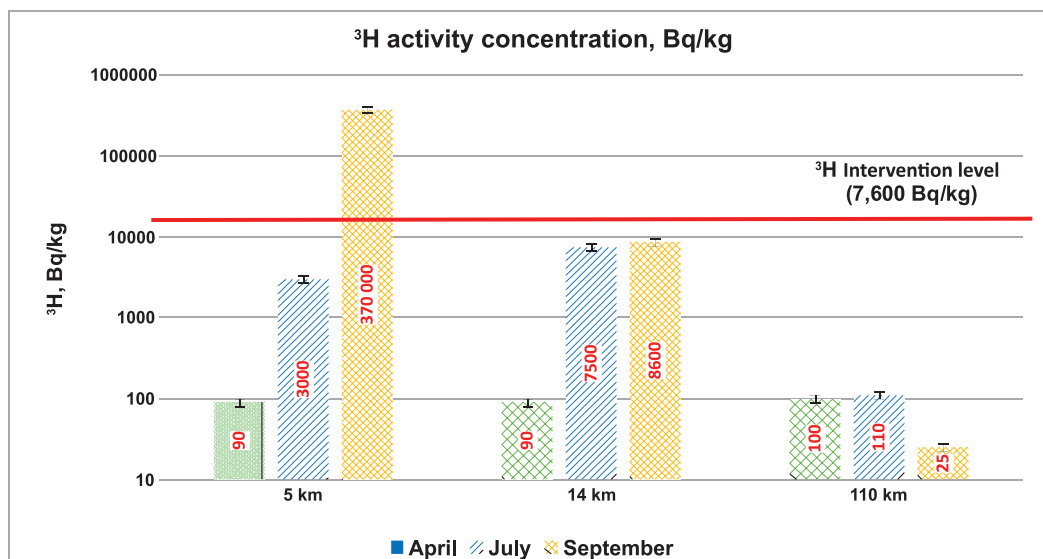


Figure 4.10. Water monitoring of the Shagan river

However, values exceeding the permissible intervention level of ^3H being equal to 7,600 Bq/kg, are noted at monitoring sites ‘5 km’ and ‘14 km’. At the confluence of the Shagan and Irtysh rivers, ^3H concentration in water varied from 25 to 110 Bq/kg, which was well below the intervention level.

Further development of radiation monitoring

Additionally, in order to enhance control of the radioecological state of air environment in the future, creation of route points near radioactively contaminated areas is expected. For a long-term prediction of further changes in the ecological situation, all fixed-site air monitoring sites will be equipped with meteorological stations as well as with EDR monitors.

Development of aquatic medium monitoring requires the observation system, regime network, design of observation points etc. to improve continuously. Therefore, as of today, equipping observation points with automated devices for water and temperature level measurements is a prospective focus area, which will allow obtainment of reliable hydrological source data.

At the same time, if air and water monitoring provides actual information on radioactive contamination at the time of sampling, soil and plant monitoring would be a more comprehensive source of information on the radiological state of the territory. Plants, for example, can reflect the possibility of the transfer of artificial radionuclides by wind including by dust storms. Due to their accumulative capacity, plants can also be more representative to characterize water and air contamination over a long period. For example, individual groups of plants are able to characterize ground water contamination, in particular, with ^3H , others – to concentrate ^3H from air. In this regard, for further development of radiation monitoring, soil and plants will also be included as objects under control.

Conclusions

The current radiological state of air environment at STS and in the adjacent territory, is stable without posing any public hazard. The exception are radioactively contaminated spots of testing sites, at which nuclear tests were conducted.

By the state of aquatic medium, one can note that all critical areas with unstable concentrations of artificial radionuclides in ground and surface waters have been identified. The main controlled parameters of aquatic medium have also been defined.

Data on the radiological state of the main environmental components from the comprehensive survey of the Semipalatinsk Test Site enables to revise administrative boundaries that will be closer to testing sites.

In this regard, implementation of the state policy in radiation safety assurance requires radiation monitoring of supposed boundaries of the Semipalatinsk Test Site. This monitoring would allow control of the radiological situation in areas of nuclear tests, obtainment of relevant and objective information on the current radiological situation, timely identification of adverse changes in progression of the radiological situation as well as making available information on the radiological situation to offices of state and the public.

4.3 Predicted progression of the radiological situation in study areas

Prediction of the ground water radiological state in the STS territory

The ground water radiological state in the STS territory was predicted in order to reveal routes of entry of ground waters contaminated with radionuclides from places of nuclear tests beyond testing sites and STS boundaries into ground waters of adjacent areas.

Under this section, features of radioactive contamination of ground waters at different testing sites were addressed, the analysis to identify potential sources and routes of entry of contaminated ground waters from places of STS nuclear tests into ground waters of adjacent areas was carried out based upon earlier outputs.

The main sources of contamination of ground waters are rocks containing nuclear debris from tests conducted at STS testing sites: the 'Experimental Field', the 'Degelen', the 'Balapan', the 'Sary-Uzen', the 'Aktan-Berli', the 'Telkem'.

Proceeding from features of the geological structure and hydrogeological conditions, the following possible movement paths of contaminated flows from places of STS nuclear tests can be mentioned:

- flows of underground fracture waters incorporated in the regional basin of ground waters that go beyond testing sites;

– flows of underground fracture-vein waters associated with zones of regional tectonic faults: Chinrau, Kalba-Chingiz, West Arkalyk, the Main Chingiz. Routes of these faults pass through STS testing sites or in close proximity to their boundaries.

Pore waters of recent deluvial-proluvial and alluvial-proluvial deposits do not commonly occur. Hence, they do not matter much during migration of UNE debris beyond STS and are not addressed in this section.

Within areas of STS testing sites, the main radioactive contaminants of ground waters are currently long-lived artificial radionuclides: $^{239+240}\text{Pu}$, ^{90}Sr , ^{137}Cs and ^3H .

When ground waters move from UNE places, $^{239+240}\text{Pu}$, ^{90}Sr , ^{137}Cs are sorbed on fracture planes of host rocks. This results in a complete purification of ground waters from these radionuclides. Thus, the main radioactive contaminant of ground waters that flow beyond testing sites is tritium.

Prediction of a possible entry of ground waters contaminated with radionuclides from the ‘Experimental Field’ testing site

Radioactive products resulted from far and near fallout after atmospheric nuclear tests may be the main source of radioactive contamination of ground waters. Research into a possible migration of fallout after atmospheric nuclear explosions to the ground water level was undertaken as part of the survey of ‘northern’ areas [156]. Outputs showed that fallout is firmly fixed in topsoil down to 20 cm and hardly migrate vertically. Findings were proved by drilling and sampling results from water wells at the ‘Experimental Field’ testing site. Thus, no entry of contaminated ground waters from places of atmospheric nuclear tests or tests of radiological warfare agents into ground waters of the study area is expected.

Prediction of migration of artificial radionuclides with ground waters from the ‘Degelen’ site

Slabs of rocks enclosing central zones of underground nuclear explosions that were conducted in horizontal mine working – adits, are the main contamination source of ground waters at the Degelen mountain range. Ground waters become contaminated due to percolation of precipitation through man-made fissures to zones of irreversible deformations and directly to pit cavities of underground nuclear explosions. Water currents transport radionuclides and, moving through fracture-fault systems and adit cavities, recharge the ground water basin or come out into the daylight surface in the vicinity of adit entries.

Fracture ground waters

Ground waters of a fracture type at the Degelen mountain range are associated with zones of exogenous weathering of Paleozoic rocks, traced along slopes of coinciding with gradients of gullies and creek valleys.

Tritium migration with fracture ground waters beyond the ‘Degelen’ site is limited by boundaries of local catchment basins. Flows of fracture waters with different tritium contamination level travel to different sides from the Degelen mountains in accordance with their belonging to local catchment basins in which the recharge, transit and discharge occur within basins stretching for up to 20 km. The absence of tritium in ground waters beyond catchment basins was detected by drilling and sampling from water wells.

Prediction of ground water contamination with tritium is complicated by lack of data on its quantities that remained after fusion charges and produced during fusion explosions in rocks. At the same time, results of a long-term water monitoring at the Degelen mountain range can be used for an approximate prediction. These results showed that, in general, processes of the carry-away of artificial radionuclides

beyond central UNE zones and their entry into ground waters of the regional basin have currently become stabilized.

Values of tritium concentrations in currents of ground waters flowing beyond the Degelen mountains are not the same in different directions. Tritium maxima up to 260 kBq/kg were determined in ground waters southeastward that are common in the valley of the Baitles creek. At a distance from the mountains, tritium concentration gradually decreases to the safe level [157, 158, 159].

To predict ground water contamination with ^3H at the outlet beyond the Degelen mountain range, calculations were made for 1, 5, 10, 50 and 100 years. Data on ^3H concentrations was used based upon sampling from water wells in 2010 (Table 4.1).

Table 4.1. Results of predictive estimates of tritium concentrations in ground waters in the vicinity of creeks on the boundary of the Degelen mountain range

Study area	Estimated data on ^3H as of 2019, Bq/kg	Prediction period, years/Bq/kg				
		1	5	10	50	100
Uzynbulak creek, No. 1	63 250	61482	49092	37054	3904	234
Karabulak creek, No. 2	29 325	28505	22761	17180	1810	109
Toktakushyk creek, No. 3	149 502	145321	116036	87583	9227	554
Baitles creek, No. 4	97 751	95018	75870	57266	6033	362

As shown by tabulated data, values of ^3H concentrations in ground waters far exceed the intervention level, and in sections of the Baitles and Toktakushyk creeks – exceed the level of liquid radioactive waste (76,000 Bq/kg) [48]. Calculation results showed that in 100 years, ^3H concentration will decrease to the safe level in each direction.

Fracture –vein ground waters

The main possible channel for fracture-vein ground waters contaminated with radionuclides to move from the ‘Degelen’ site

is the impact zone of the West Arkalyk regional fault. Its route passes in close proximity to the Degelen mountains and crosses the valley of the Karabulak creek, with which fracture and underflow ground waters contaminated with radionuclides are associated. At the junction spot, concentrations of radionuclides in ground waters reach: ^3H – 30 kBq/kg and ^{90}Sr up to 8.0 Bq/kg [158]. To assess a possible entry of contaminated water, associated with the bed of the Karabulak creek, into fracture-vein waters of the West Arkalyk fault, two water wells were drilled and sampled from. One well (55P) was drilled where it intersects the bed of the Karabulak creek. Another one 1PU-20 was drilled on the fault route in the vicinity of the ‘Sary-Uzen’ site. Laboratory analyses showed that ^3H concentration in water samples from well 55P reaches 500 Bq/kg, which is well below the intervention level. In well 1PU-20, the content of ^3H is below values of the minimum detectable activity, which indicates no entry of contaminated waters through the fault zone northwestward.

Thus, no entry of contaminated ground waters from the Degelen mountain range beyond STS is expected.

Based upon research findings on the current state of ground waters as well as upon prediction of a possible variation in contamination with radionuclides, the territory in the vicinity of the ‘Degelen’ site was zoned by levels of ground water contamination with tritium (Figure 4.11).

As a whole, the area adjacent to the ‘Degelen’ site, based upon prediction of ground water contamination, should be divided into three zones:

Zone No. 1 (restricted zone). Within this zone, concentration levels of artificial radionuclides pose a radiological hazard to the public. In this regard, avoidance of whatever economic activities is recommended here.

Zone No. 2 (limited use). Within this zone, one is allowed to carry out economic activities if radiation support is provided. Mostly, this concerns mining operations.

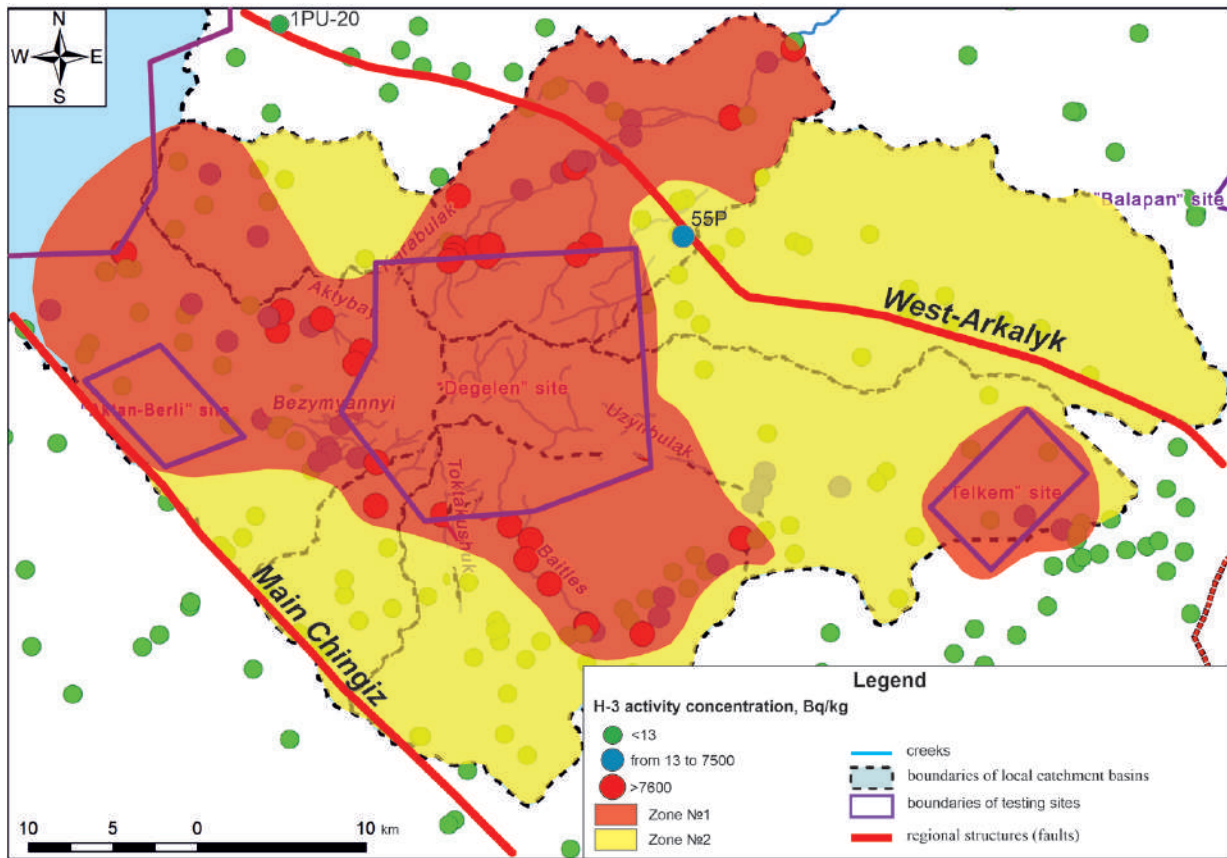


Figure 4.11. Degelen mountain range. Scheme of local catchment basins

When mine workings are driven with drainage waters removed, craters dewatering ground waters around open pits are formed. This may lead to a local change in travel direction of ground waters. Hence, contaminated waters from Zone No. 1 may enter ground waters of this territory. In this regard, planning the work in this area requires special radioecological research to be undertaken given stated types of activity.

Zone No. 3 (unlimited use). By levels of radioactive contamination of ground waters, Zone No. 3 can be used for whatever types of economic activity with no limitations.

Prediction of the radiological state of ground waters in the vicinity of the 'Balapan' site

The process of radioactive contamination of ground waters. Pit cavities of explosions that were conducted in boreholes are well below the level of ground water travel unlike UNE in adits. After UNE were

conducted, deformation zones consisting of voids and crushed rock are formed in rock mass. UNE debris are localized on surfaces of fractures and rock fragments. Fracture ground waters enter deformation zones through systems of man-made fractures. High temperature in the cavity persists for a long time due to the mass of overburden rock up to 500 m thick. High temperatures cause heat convection. In this case, the cavity of a nuclear explosion acts as a natural thermal spring. Having reached the cavity, waters warm up dissolving chemical elements and radionuclides and together with them return to the aquifer followed by migration.

Migration of artificial radionuclides with fracture waters

At the ‘Balapan’ site, fracture waters of the regional basin are concentrated in the zone of exogenous fracturing of Paleozoic rocks and occur at different depths from 4 to 70 m. Ground waters mainly move northeastward with a gradient of up to 0.002. Ground waters move around the site with sufficiently low values of hydraulic gradient and low percolation rates. Flow rates of ground waters in most of the site area are less than 1 m³/day. Maxima of flow rates – up to 2 m³/day – are only observed in the southern part of the site, in which the region of ground water recharge is localized [160].

The structure of a seepage flow within the site is nonhomogeneous – three relatively separate current lines with numbers 1-3 assigned are noted on the regional background in plan (Figure 4.12).

The entry of ground waters contaminated with tritium beyond the ‘Balapan’ site is directly related to the feature of flow movement in the structure of current lines.

In the northwestern part of the site (current line No. 1), the seepage flow is formed at high levels of Paleozoic basement with the thinnest covering deposits. The structure of the flow is complicated by a local depression linked to water removal from the operating coal open pit at the Karazhyra deposit. This site has only one ‘warfare’ borehole 1071. A contaminated flow from this borehole enters the impact zone of the dewatering depression crater. In this regard, no outflow beyond the ‘Balapan’ site is expected.

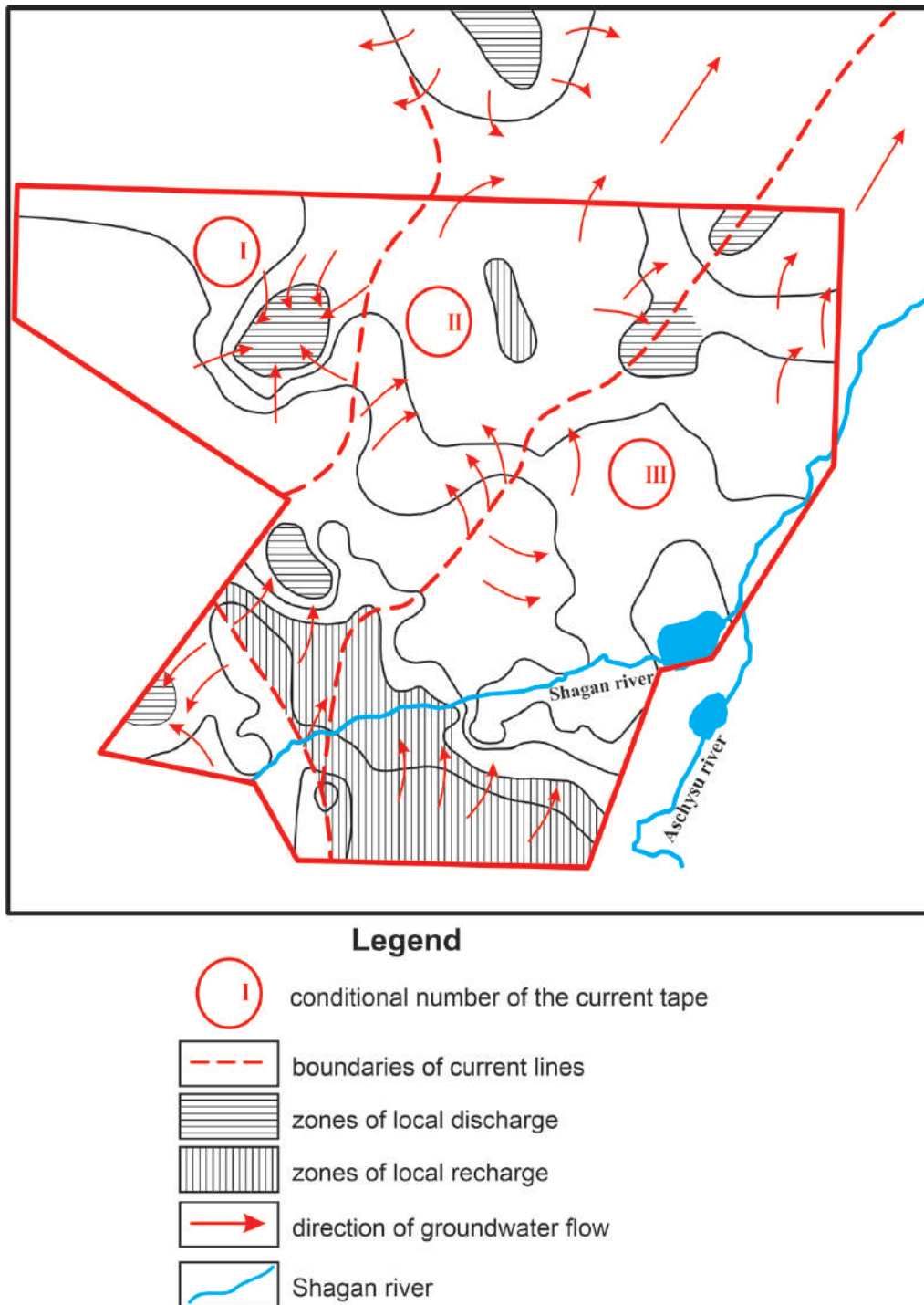


Figure 4.12. Structure of the seepage flow of ground waters

The central part of the experimental site has current line No. 2. The occurrence depth of the basement is at the level of mean values. Beyond the northern site boundary, reference relief marks of the aquifer elevate. In this regard, the flow changes its direction towards current line No. 3. Within this line, there are more than 50 ‘warfare’

boreholes. Tritium concentration in fracture waters of the northeastern part of the site reached 4,800 kBq/kg [161]. Predicted variations in tritium concentration in ground waters in the next one hundred years are listed in the table (Table 4.2).

Table 4.2. Results of predictive calculations of tritium concentrations in ground waters in the northeastern part of the ‘Balapan’ site

Study area	Estimated data on ^3H as of 2019, Bq/kg	Prediction period, years/Bq/kg				
		1	5	10	50	100
Balapan, current line No. 2	4800000	4537399	3623014	2734631	288090	17290

Ground waters of this current line are most contaminated with tritium, but even in 100 years, they will not pose any hazard given that, in addition to the radioactive isotope decay, they will be diluted with recent ground waters.

Current line No. 3 is noted along the southeastern section contour, in the direction that coincides with the bed flow of the Shagan river. Its position is structurally associated with the lowest levels of Paleozoic basement and with the thickest covering deposits. A portion of ground waters of current line No. 3 is discharged into surface waters of the Shagan river. A discharge section begins farther than the river outlet from the ‘Atomic Lake’ and persists 8 km downstream. According to outputs [161], pronounced local intervals with drops and growth of ^3H activity and sections of stably high and low values alternate on the left bank. The interval of maximum ^3H values (4.7-7.8 km) with the activity concentration within 44,000 Bq/kg is registered.

Table 4.3. Results of predictive calculations of tritium concentrations in ground waters at the section of discharge into surface waters of the Shagan river

Study area	Estimated data on ^3H as of 2019, Bq/kg	Prediction period, years/Bq/kg				
		1	5	10	50	100
Shagan river	44000	41592	33211	25067	2641	158

Migration of artificial radionuclides with fracture-vein waters

The ‘Balapan’ site is a pit of about 20 km diameter rimmed by the hummocks. In most of the territory, fracture waters are artesian with a head of up to 80 meters. In this regard, a portion of fracture waters is discharged into surface water bodies through fracture-vein channels associated with tectonic faults, of which, at the ‘Balapan’ site, are: Zhanan, Sosnovyi, Chinrau, Kalba-Chingiz and others (Figure 4.13).

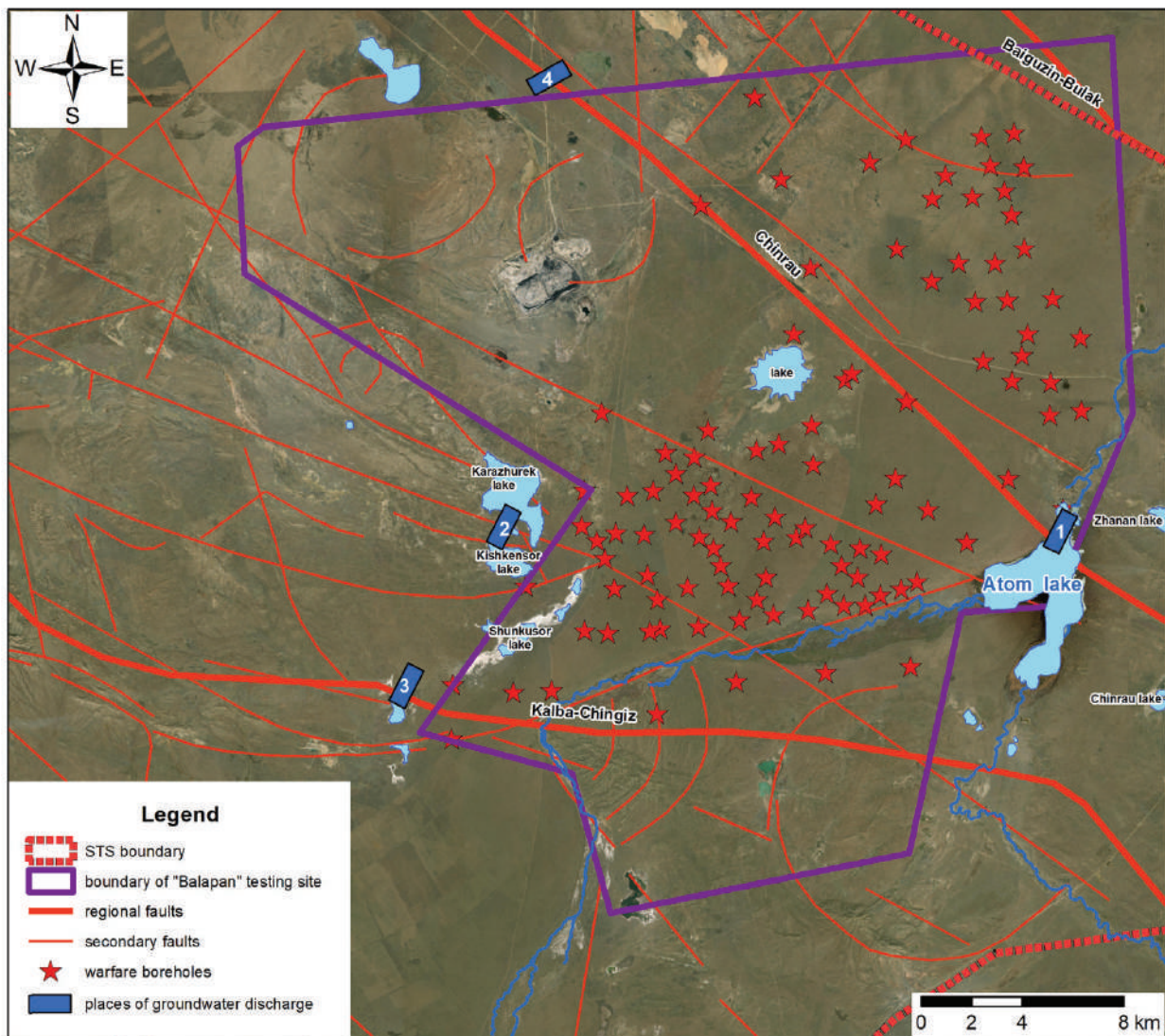


Figure 4.13. Scheme of tectonic faults at the ‘Balapan’ site

Zhanan fault of the northwestern strike passes along the northeastern part of the ‘Balapan’ site, at which maximum tritium concentrations varying from 1,200 to 4,800 kBq/kg were detected in epicentral areas of ‘warfare’ boreholes. This fault crosses the bed of

the Shagan river 4 km from the ‘Atomic Lake’. At the junction from 4.7 to 7.8 km, fracture-vein waters are discharged into surface waters of the river in the fault impact zone. In 2019, tritium concentration was up to 350 kBq/kg [162].

Predicted variations in tritium concentration in ground waters in the next one hundred years are listed in the table (Table 4.4).

Table 4.4. Variations in maximum tritium concentrations in fracture-vein waters of the Zhanan fault

Study area	Estimated data on ³ H as of 2020, Bq/kg	Prediction period, years/Bq/kg				
		1	5	10	50	100
Zhanan fault	350000	333000	265900	200700	21100	1300

As you can see from the table, ³H concentration in water of this lake will be above the intervention level even in 50 years [48].

The Sosnovyi fault passes through the ‘Balapan’ site from southwest to northeast. A lot of concomitant and branch smaller tectonic faults are associated with the route of this fault. Surface waters of Lakes Karazhurek, Kishkensor and Shunkursor, which are within the western boundary of the ‘Balapan’ site, are recharged in the impact zone of these faults. Maximum contamination of surface waters was detected in the Kishkensor with ³H activity reaching 350 kBq/kg [2]. Predicted variations in tritium concentration are listed in the table (Table 4.5).

Table 4.5. Variations in maximum tritium concentration in waters of the Kishkensor

Study area	Estimated data on ³ H as of 2020, Bq/kg	Prediction period, years/Bq/kg				
		1	5	10	50	100
Lake Kishkensor	260000	249730	199400	150510	15860	950

As you can see from the table, ^3H concentration in water of this lake will exceed the level of liquid radioactive waste twice even in 50 years.

The Chinrau fault of the northwestern strike passes through the central part of the 'Balapan' site'. 5 UNE were conducted in 'warfare' boreholes in the impact zone of this fault. Tritium concentration in ground waters of the fault in the site area reaches 160 kBq/kg. To assess a possible migration of contaminated ground waters in the fault zone, research was undertaken including geophysical and drilling operations at the fault outlet beyond site boundaries. Sampling results on the borehole showed that tritium concentration in this section is 0.750 kBq/kg, which is well below the intervention level [161].

The Kalba-Chingiz fault of the northwestern strike passes through the southern part of the 'Balapan' site. 5 UNE were conducted in 'warfare' boreholes in the impact zone of this fault. Tritium concentration in ground waters of the fault in the site area reaches 560 kBq/kg [161].

As part of research into the state of ground waters in the fault zone, geophysical research was undertaken at the fault outlet beyond the southwestern boundaries of the 'Balapan' site. Based upon research findings, places to drill four water wells were chosen. Based upon laboratory analyses, activities of artificial radionuclides in water samples from wells are below values of the minimum detectable activity, except for wells 63P and 64P in which tritium concentration was 200 Bq/kg, which is well below the intervention level [164].

Zoning of the 'Balapan' site by the state of ground waters

Based upon research findings on the current state of ground waters as well as upon prediction of a possible variation in contamination with radionuclides, the territory in the vicinity of the 'Balapan' site was zoned by levels of radioactive contamination of ground waters with tritium (Figure 4.14).

Thus, contamination levels of ground waters at the ‘Balapan’ site make it possible to note the following zones:

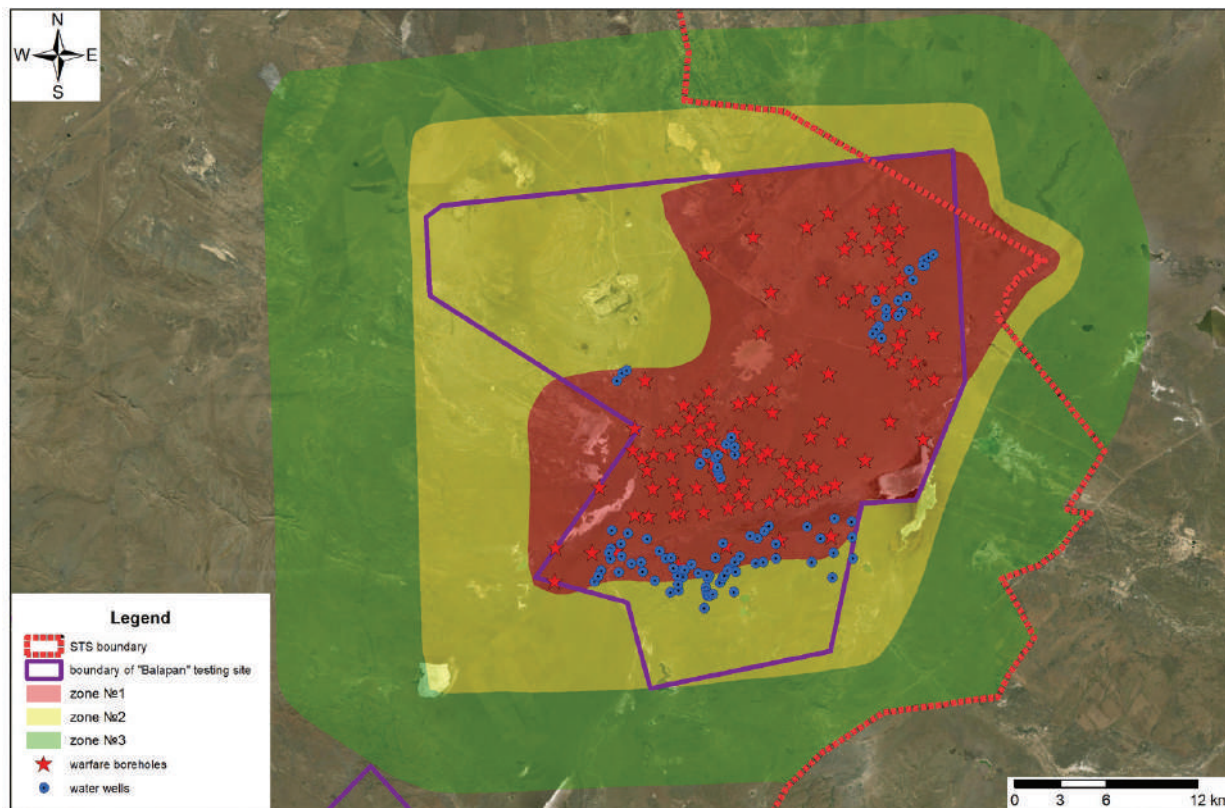


Figure 4.14. Territorial zoning at the ‘Balapan’ site

Zone No. 1 (restricted zone). Within this zone, concentration levels of artificial radionuclides pose a radiological hazard to the public. In this regard, avoidance of whatever economic activities is recommended here. At the ‘Balapan’ site, this zone covers locations of ‘warfare’ boreholes. Besides, areas with tritium concentrations exceeding the intervention level are included in zone No. 1. Those are the location of the Kishkensor and the section of the Shagan riverbed (downstream) 20 km from the ‘Atomic Lake’.

Zone No. 2 (limited use). Within this zone, one is allowed to carry out economic activities if radiation support is provided. This mostly concerns mining operations. When mine workings are driven with drainage water removed, the entry of contaminated ground waters from waters of Zone No. 1 into ground waters of this area is possible. In this regard, planning the work in this territory requires special

radioecological research to be undertaken given stated types of activity.

Zone No. 3 (with no limitations). By levels of radioactive contamination of ground waters, zone No. 3 can be used for whatever types of economic activity with no limitations.

Predicted migration of artificial radionuclides with ground waters from the ‘Sary-Uzen’ site

Migration of artificial radionuclides with fracture waters

By the hydrogeological conditions and the nature of ground water radioactive contamination, the ‘Sary-Uzen’ site is similar to the ‘Balapan’ site. Slabs of rocks enclosing central zones of underground nuclear explosions are a contamination source of ground waters. 24 underground nuclear explosions in ‘warfare’ boreholes were conducted at the testing site [8]. Fracture waters of Paleozoic rocks flowing beyond the site along the dry bed of the Sary-Uzyn creek northward are the main carrier of radioactive contamination (Figure 4.15).

Tritium is the main radioactive contaminant of ground waters. Maximum concentration within the site reaches 500 kBq/kg [165]. Beyond the site until 2020, according to sampling data on wells 1Z, 2Z, 3Z, 4Z, SUZ-1/19, values of tritium concentrations in ground waters did not exceed those of the minimum detectable activity. In 2020, tritium content was 200 Bq/kg in water of observation well SUZ-1/19, which points to the fact that the front of contaminated ground waters approached the northern site boundary. To obtain data on prediction of tritium migration in this direction, it is necessary to continue observations of tritium content in well SUZ-1/19. 3 additional observation wells will be drilled to refine the nature of tritium distribution in the flow of ground waters associated with the riverbed.

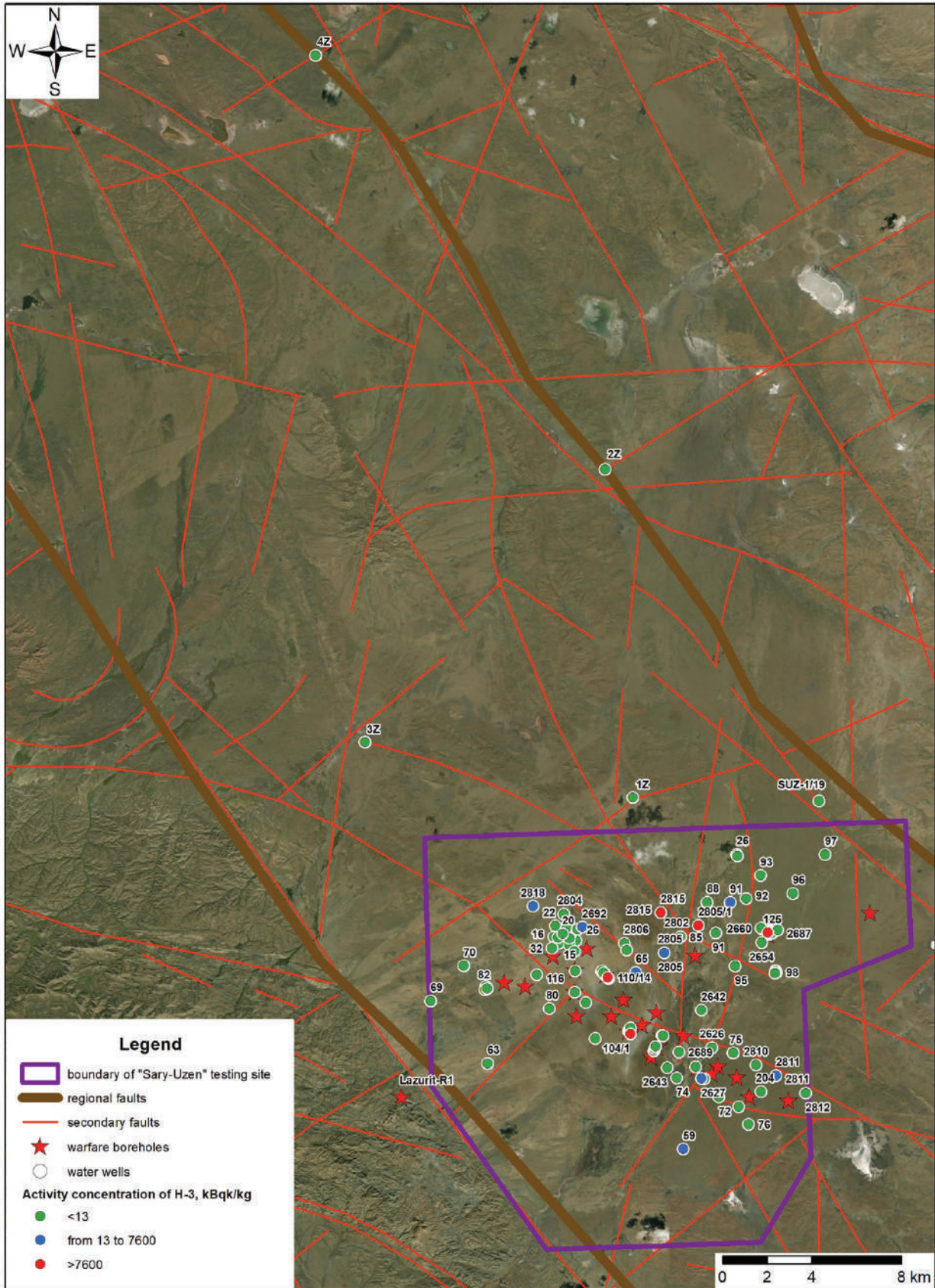


Figure 4.15. Scheme of the travelling front of contaminated ground waters at the 'Sary-Uzen' site

Migration of artificial radionuclides with fracture-vein waters

Impact zones of the West Arkalyk and the Main Chingiz regional tectonic faults can be the main possible pathways of contaminated waters beyond the ‘Sary-Uzen’ site. For the assessment of a possible entry of contaminated ground waters from the site into fault waters, well 1PU-20 in the zone of the West Arkalyk and well 1VK-PN-20 in the impact zone of the Main Chingiz fault were drilled. Tritium concentration in water of these wells does not exceed values of the minimum detectable activity, which indicates the absence of tritium migration through zones of these faults.

Conclusions

‘Degelen’ site

Currents of fracture ground waters flowing beyond the Degelen mountains diverge in separate directions according to their belonging to local catchment basins. Since catchment basins extend for up to 20 km and their structures are closed, tritium-contaminated fracture waters do not migrate farther than 20 km from the ‘Degelen’ site boundaries. Ground waters are discharged from catchment basins due to evaporation and transpiration by plants.

Thus, no entry of ground waters contaminated with artificial radionuclides is expected beyond STS from the ‘Degelen’ site.

‘Sary-Uzen’ site

In 2020, tritium content being 200 Bq/kg was detected in the vicinity of the northeastern site boundary in ground waters. This indicates that the front of contaminated ground waters approached the northern boundary of the ‘Sary-Uzen’ site. To obtain data on prediction of tritium migration in this direction, observations of its content in ground waters including by means of new observation wells will continue.

‘Balapan’ site

Two sections of contaminated ground waters carried away to the daylight surface were discovered at the ‘Balapan’ site. The first section is linked to ground water discharge in the impact zone of the Sosnovyi fault into surface waters of Lake Kishkensor, at which tritium concentration in water will be above the intervention level for over 50 years. According to preliminary data, contaminated flows come from rock slabs enclosing UNE central zones of the nearest ‘warfare’ boreholes. In this regard, the territory of the Kishkensor has to be included in STS lands.

Another section was discovered in the valley of the Shagan at the bed of 30 km long after the river outflows from the ‘Atomic Lake’. In this section, tritium-contaminated fracture waters from the ‘Balapan’ site are discharged into surface waters of the Shagan. The Shagan valley goes beyond the site and farther beyond STS.

Tritium is currently and in the near future will be the main radioactive contaminant of STS ground waters.

The valley of the Shagan bed is the only direction, in which tritium-contaminated ground waters are and will be flowing beyond the STS eastern boundary. In this regard, whatever economic activities must be avoided in the riverbed section 30 km from the ‘Atomic Lake’.

4.4 Land rehabilitation

In the course of the STS survey, virtually all significantly contaminated areas with values reaching radioactive waste levels (RAW) have been identified. Major efforts have been made to refine boundaries of spreading contamination with radionuclides at STS radiation-hazardous objects. Using up-to-date techniques of large-scale pedestrian gamma-spectrometry resulted in a sufficiently clear localization of areas that pose a hazard to the public and require measures to be taken to restrict their impact on the environment and

man. Those are such objects as the ‘Atomic Lake’, the ‘Sary-Uzen’, ‘Balapan’, ‘Telkem’, ‘Degelen’ and ‘Experimental Field’ testing sites, fallout plumes. Significantly contaminated areas pose a special hazard. Values of this radioactive contamination reach levels of medium-level RAW. All the above-mentioned areas containing radionuclides at the RAW level are in different parts of STS, which significantly complicates control. As sites are contaminated with long-lived radionuclides, it is necessary to control radiation safety for a long period (dozens, hundreds and in some cases thousands of years), which together with their territorial remoteness, makes this measure highly cost-ineffective, and rehabilitation measures may take several dozens of years. At the same time, the public access to many of such sites endangers human health. That is why the issue of STS rehabilitation is topical.

Radioactively contaminated STS lands can be rehabilitated in different ways, the choice of which, primarily, depends on natural conditions of a specific area and levels of contamination with radionuclides. The National Nuclear Center RK has already made major efforts on testing rehabilitation techniques for individual radiation hazardous areas in different ways.

Prospects of rehabilitation measures for the territory of the Semipalatinsk Test Site

Based upon survey findings on radioactively contaminated objects at STS sites, in general, one can note 2 main groups of objects: objects with and without anthropogenic disturbance. Each group can also be conventionally divided into local relatively small-size objects (trenches, embankments, concrete structures, small areas of surface radioactive contamination etc.) and large-size ones (craters, fallout plumes).

The task to remediate contaminated areas after nuclear tests is one of the most relevant challenges related to STS.

Objects without anthropogenic disturbance

At objects without anthropogenic disturbance, the bulk of radioactive material is concentrated in the subsurface layer. Taking this into account, one of the main criteria to make a decision on a rehabilitation technique is the extent of radioactive contamination.

In case contamination is local (for instance, radioactive contamination from RWA tests), the most effective action is to remove a contaminated layer followed by decision-making on how to dispose it. In the global practice, RAW is most often put into temporary storage.

Temporary storage implies the arrangement of a specialized facility (natural or man-made) to store RAW. While addressing the option of temporary storage, it is worth noting that: firstly, the amount of radioactive material to be removed is limited by the storage area. Secondly, this requires a radiation control. Thirdly, this technique defers a solution rather than solves the problem as such. Advantages of such remediation type is implementation simplicity and prompt coordinated actions.

A good example is the British experience 1953 through 1963, when nuclear weapon tests were conducted in the atmosphere in the vicinity of Maralinga – a distant area south of the Central Australia. Several nuclear explosions were conducted ('major tests'), from 1 to 27 kt, as well as many other low-yield tests ('minor tests'), which caused radioactive materials to spread. Tests produced about 22 kg of plutonium-239 and the same amount of uranium-235 in the area of roughly 130 km² around the region named as Taranaki. 1996 through 2000, a large-scale rehabilitation program was implemented. Most of this program deals with removal and burial of 260,000 m³ of heavily contaminated topsoil from Taranaki in deep soil. [166]. Disadvantages of such rehabilitation are complicated implementation (burial has to be at places that exclude a possible migration of radionuclides or by prior RAW vitrification). The advantage of this type of work is complete actions on RAW burial.

Going back to tests of radiological warfare agents, it should be mentioned that these tests resulted in contamination of the ground in more than 30 areas within the '4' and '4A' sites. Levels of radioactive contamination in certain areas are comparable with medium-level RAW. Species of radionuclides in soil, their migration abilities and high levels of radioactive contamination make these areas the most hazardous to the STS natural environment. Therefore, in the next years, it is at the '4' and '4A' sites that the largest scope of rehabilitation measures is planned. As a result, about 100,000 m³ of RAW will be removed and buried.

When addressing large objects (for instance, fallout plumes after aboveground nuclear tests at the 'Experimental Field' site), removal is unreasonable because RAW volumes are a few orders of magnitude larger than at local objects. In this regard, removal of the radioactive material on such scale (the areas over 500 km²) will require a great many storage places to be arranged.

In such case, the main task is RAW non-proliferation. Of techniques globally practiced, plowing and physical protection are possible. In the first case, (deep plowing by complete soil overturning) the radioactive layer existing on the surface (5-10 cm) moves underground (down to 50-70 cm). With such plowing, contaminated topsoil falls on the furrow bottom, and thus plant root systems will not reach it. The technique is among the cheapest and promptly implemented, but cannot completely solve the problem, although allows man, animals and plants to avoid a direct contact while not excluding migration of radionuclides.

Another option is to create physical protection in the form of barriers and ditches around radioactively contaminated objects. Basically, this type of work just like plowing is not exactly remediation, rather it is an action to restrict access to the public and animals so as to minimize individual and collective radiation exposure. The technique is cheaper, simple and prompt to implement than concrete cover operations but, at the same time, it is less efficient from the perspective of public radiation safety.

Of the two above-mentioned options, plowing operations or combination of these techniques will be more efficient for large objects without anthropogenic disturbance.

Objects with anthropogenic disturbance

As with objects without anthropogenic disturbance, the extent of radioactive contamination is one of the main criteria for decision-making on a rehabilitation technique.

Removal is applicable in case an object is relatively small as with objects without anthropogenic disturbance. However, in some cases due to a complicated technical design or RAW location at a depth, removal operations will be technically complicated to implement as well as this will cause personnel to be overexposed. In such case, operations on physical protection in the form of concrete containments would be much more effective. A good example are physical protection operations at the P-2M technological site. Hydronuclear and hydrodynamic experiments were conducted at this site. Owing to these experiments, soil became radioactively contaminated 1 to 4 meters deep. To restrict access to the public and animals, the National Nuclear Center of the Republic of Kazakhstan conducted operations on making special reinforced concrete structures that prevented a potential access to RAW.

In addition to locally contaminated spots, there are quite vast radioactively contaminated areas. The ‘Atomic Lake’, ‘Telkem’, craters that resulted from aboveground nuclear tests and containing a tremendous amount of RAW come under such objects. The situation with nuclear test remediation at such objects is more complicated than at object without anthropogenic disturbance. This is related to the fact that most of radioactive material is in the dump zone of craters at a depth down to several dozens of meters rather than in the subsurface soil. This complicates the removal process of radioactive soil a lot. The global practice has 2 main remediation types for such objects: removal of radioactive material followed by disposal and on-site burial of radioactive material followed by creating physical barriers.

The first option was discussed above. It should be particularly noted that as with ‘plumes’, the amount of RAW is one order and in other cases, even two or three orders of magnitude is larger than at local objects. In this regard, removal of radioactive material on such scale will also require creation of huge storage areas for temporary storage.

Another option does not provide for any removal of radioactive materials as such and represents its concentration in the crater pit including physical protection in the form of a concrete cap. A good example of such type of rehabilitation measures is decontamination operations on islands of the Enewetak atoll that is located in the Pacific, in which 1948 through 1958, the United States of America conducted approximately 43 nuclear weapon tests. On May 15, 1977, the American government sent its troops so as to decontaminate the islands. That was done by mixing 85,000 m³ of contaminated soil with material debris from different islands and by disposing in one of craters that was formed after the explosion on an islet on the eastern side of the atoll. The burial continued until the crater became an embankment 7.5 m high. Thereafter, the crater was covered with concrete 43 cm thick. [167]. Advantages of such solution is simplicity and a rather prompt implementation.

A method, as described before, can also be used for these objects – creation of physical barriers in the form of fences (or ditches) around objects without concentrating radioactive materials in the crater.

Following completion of all remediation measures, STS operations will consist in maintaining integrity of security systems (physical barriers) as well as in creating a water and air radiation monitoring system, which will make it possible to control the radiological situation in the STS territory.

4.5 Present-day land utilization

Since STS was shut down, its lands have come to be actively used by legal bodies and individual persons for industrial, mining, transportation and agricultural activities.

In order to carry out these activities, it is necessary to obtain a license according to the Law of the Republic of Kazakhstan ‘On Atomic Energy Use’ and the Law of the Republic of Kazakhstan ‘On Permits and Notifications’ [168, 169]. Along with this, as per para. 3 of cl. 143 of the Land Code of the Republic of Kazakhstan, the Government of the Republic of Kazakhstan can release land plots on which nuclear weapon tests were conducted into the ownership as soon as all remediation measures and the comprehensive ecological survey are complete, with a positive State Environmental Expert Evaluation [170].

In order to assure license requirements and radiation safety when carrying out economic activities at the test site, radiation control and monitoring are carried out. Depending on specificity of enterprise activities as well as given potential sources of radioactive contamination, a special radiation control and monitoring program is developed to define controlled parameters, the scope of field work, for laboratory analyses and monitoring frequency.

Authorized economic activities are currently carried out at the test site by different companies as per licenses issued by authorized bodies.

The industrial field covers activities of the metallurgical facility ‘Kazzinc’ Ltd that has an industrial waste repository (arsenic) in the ‘Balapan’ site area.

The mining industry is represented by two large deposits ‘Karazhyra’ and ‘Karadzhal’, at which JSC ‘Karazhyra’ and JSC ‘Ulba Ironworks’ (JSC ‘UMZ’) are mining coal and fluorite ore involving different contracting organizations.

The transport field involves carriage of mined products by railway and motor transport organizations.

A large coal deposit ‘Karazhyra’ is located in the STS territory within the ‘Balapan’ testing site, 130 km south-west of Semey city in the East Kazakhstan region. JSC ‘Karazhyra’ is engaged in developing the deposit, mining and selling coal.



Figure 4.16. Coal mining by JSC 'Karazhyra'

Different contracting organizations jointly with JSC ‘Karazhyra’ are operating on the premises of the coal open pit. They are engaged in stripping, drilling and blasting, loading operations, crushing and transporting ore as well as provide maintenance service for vehicles and special machines employed at the open pit.



Figure 4.17. Operations of contracting organizations at the ‘Karazhyra’ and ‘Karadzhal’ deposits in progress

The fluorite deposit ‘Karazhyra’ in the STS territory near the ‘Degelen’ testing site is located in the East Kazakhstan region, 170 km south-west of Semey city and 120 km south-west of Kurchatov city. JSC ‘UMZ’ is mining minerals.



Figure 4.18. Radiation control of the economic activity in the test site area provided by specialists of the branch ‘IRSE’ NNC RK

The STS territory is used not only for developing deposits and mining minerals but also for operations to exploit suitable areas of the test site for industrial purposes.

To store wastes, a special engineering structure was prepared – a landfill. All the infrastructure was prepared for test site operations. The project being implemented by ‘Kazzinc’ Ltd has been a success.

In addition to the ‘Balapan’ site, the STS territory has a number of places to bury various types of waste. Considering the experience gained by ‘Kazzinc’ Ltd in industrial waste disposal, a number of organizations are considering the issue of constructing a landfill in this territory.



Figure 4.19. Landfill of ‘Kazzinc’ Ltd

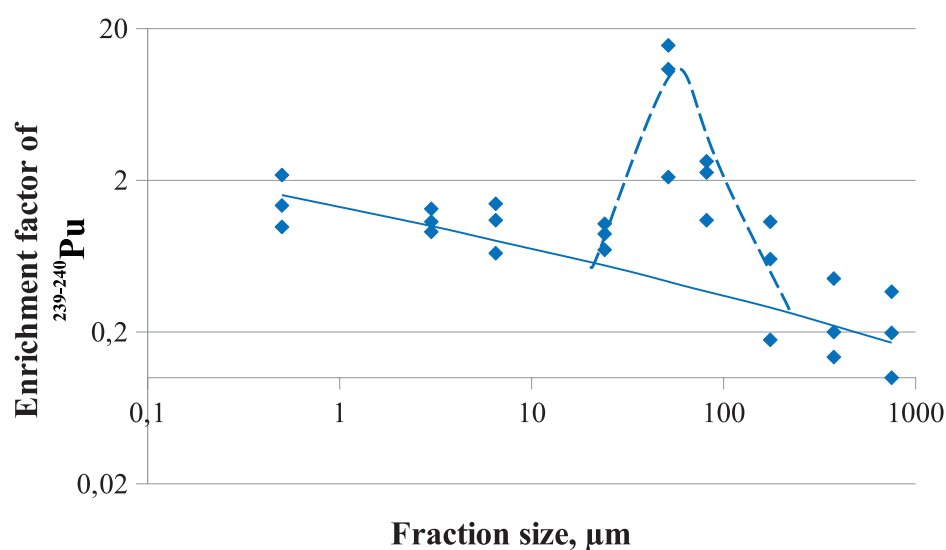
Besides the authorized industrial activity, cases of scrap metal collection, cattle grazing, haymaking by groups of individuals are registered at the test site, not only in conventionally ‘background’ but also in contaminated areas. Such activities at STS are regarded as unauthorized and, depending on a territory, they may or may not lead to public overexposure.

4.6 Scientific development prospects

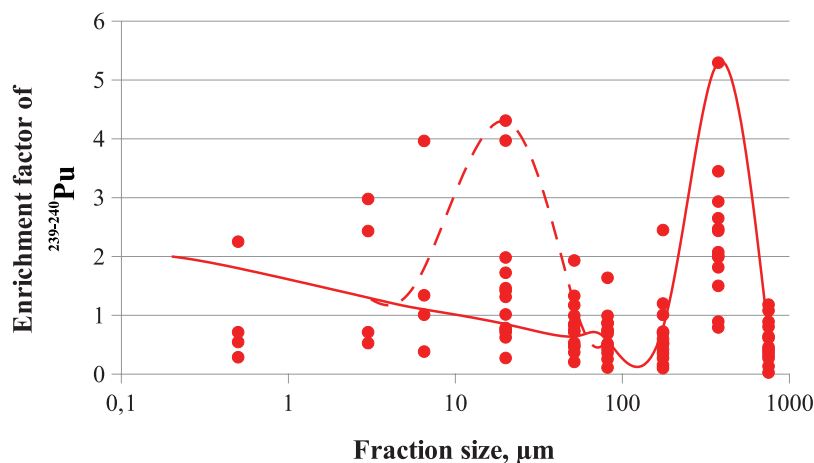
The STS territory is unique from the perspective of all kinds of research to be undertaken. A variety of landscapes of the test site and a various nature of contamination with radionuclides allow obtainment of unique data that characterizes features of redistribution of radionuclides amidst environmental components of different ecosystems. As

of today, a large set of parameters that describe redistribution of radionuclides in systems ‘water-plants’, ‘bottom sediments-plants’, ‘soil-plants’, ‘soil-animals’, ‘plants-air’ has been obtained.

The focus is on research into the behavior of radionuclides in soil cover as the initial link of radionuclide migration amidst environmental components. Unique data was obtained on the distribution nature of artificial radionuclides in different soil types at the former testing sites and unrelated areas as well as data characterizing mobility of radionuclides in soils (species of radionuclides, distribution in particle-size fractions, physical and chemical soil properties). According to research into species of artificial radionuclides in soils, a variation in the distribution of radionuclide species was revealed depending on the nature of radioactive contamination of STS soil cover. At the same time, results showed that the distribution of radionuclides in particle-size fractions is also the indicator of formation mechanism of radioactive soil contamination, and can be used as a diagnostic sign of radioactive contamination origin. In conditions of increased moistening, radionuclides are accumulated most by fine soil fractions (sorption-desorption redistribution) (Figure 4.20, a). A significant ‘enrichment’ of the relevant particle-size soil fraction points to the presence of nuclear fallout on the soil surface (Figure 4.20, b).



a)



b)

Figure 4.20. Distribution of radionuclides in particle-size soil fractions (a) in meadow soils in the vicinity of adit No. 176 (the ‘Degelen’ site), (b) in arid soils of the aboveground fusion explosion plume dated August 12, 1953

This data allows optimization of the survey of test site areas by reducing the number of radionuclide analyses and improvement of the assessment quality of human radiation exposure at intake of radionuclides through the respiratory apparatus and skin cover. The main outputs are set forth in publications [171, 172, 173, 174, 175, 176, 177, 178, 179].

The same focus is also on research into plant cover. Transfer parameters of radionuclides from soil to plants of natural ecosystems were defined for different test site areas. A holistic picture of transfer factors of radionuclides from soil to plants of natural ecosystems was obtained for the entire STS territory that is characterized by various types of radioactive contamination (Figure 4.21). Differences in transfer factors for ^{137}Cs reach 71 times, ^{90}Sr – 74 times, $^{239+240}\text{Pu}$ – 14 times, ^{241}Am – 11 times. Nevertheless, a descending series of radionuclides by their ability to be accumulated by plants appears as follows: $^{90}\text{Sr} > ^{137}\text{Cs} > ^{239+240}\text{Pu} > ^{241}\text{Am}$. Transfer factors of ^{90}Sr on average exceed those of ^{137}Cs by 8 times and $^{239+240}\text{Pu}$ by up to 16 times. Values of $^{239+240}\text{Pu}$ transfer factors are up to 3 times higher than those of ^{241}Am .

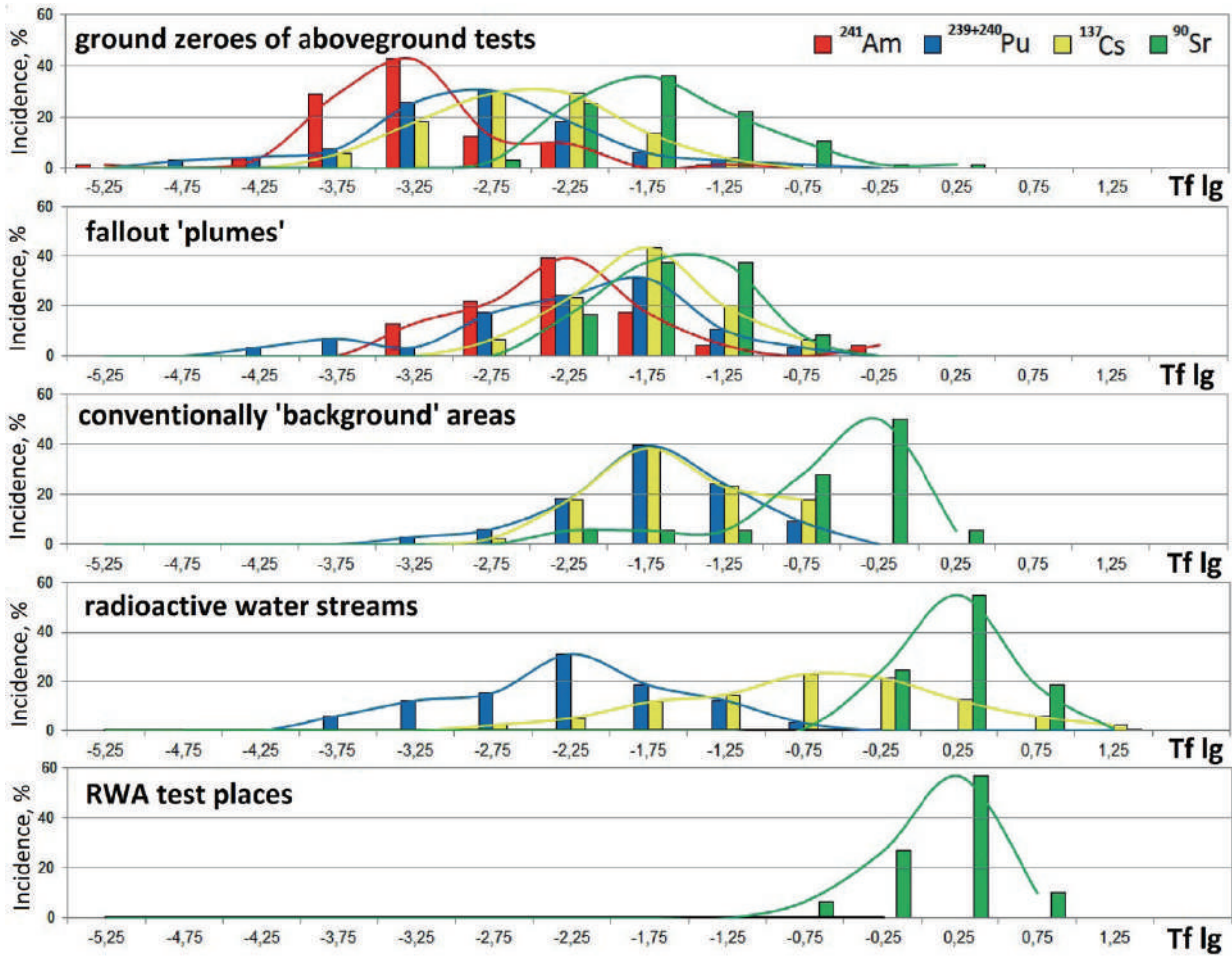


Figure 4.21. Distribution of Tf lg values for STS areas of interest

A possibility to use plants as indicators of tritium content in ground waters was proved (Figure 4.22). The main research findings in this focus area are provided in publications [180, 181, 182, 183, 184, 185, 186].

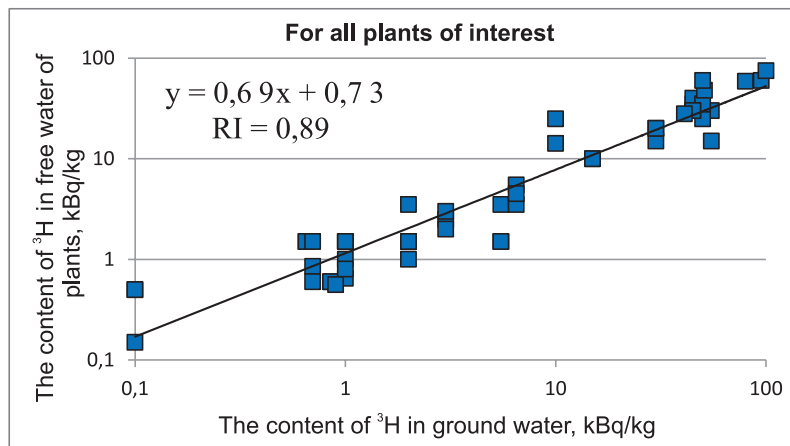


Figure 4.22. Dependence of ³H content in free water of plants on its content in ground waters

Besides, a radioecological description was given to fauna of the test site. Transfer parameters of radionuclides for individual species of STS wild animals were defined. As found by research, individual species of animals with a short radius of diurnal activity can be an essential factor of radionuclide redistribution in the environment. For example, in lizards inhabiting places of radiological warfare agent tests, ^{90}Sr content may reach several hundreds of thousands Bq/kg (Figure 4.23). Thus, one lizard is able to carry up to 5,000 Bq of this radionuclide. The main research findings are set forth in publications [187, 188, 189].

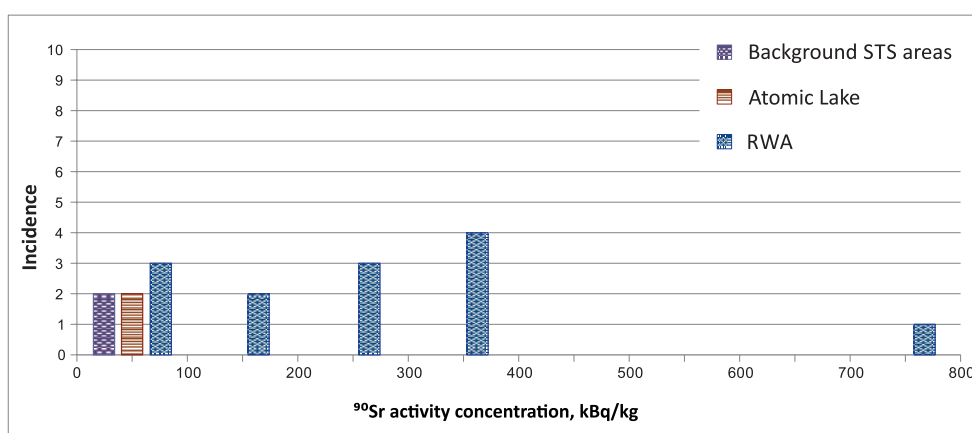


Figure 4.23. Incidence histogram of ^{90}Sr activity concentration in a sand lizard in STS areas

Research into aquatic medium of the test site is equally interesting, for example, determination of radionuclide species in water and their transformation depending on physical and chemical environmental parameters. Data on radionuclide species in water is the indicator of the migration ability of radionuclides in aquatic ecosystems and can be used to predict progression of the radiological situation at objects under study. As a result of such research, radionuclide species were determined in the most contaminated STS surface water streams. It was found that the dominant speciation of ^{90}Sr and ^{137}Cs in waters investigated is dissolved matter. Different species are characteristic of $^{239+240}\text{Pu}$ with dominating dissolved and suspended forms (Figure 4.24, a). The main speciation of ^{238}U is dissolved matter. The distribution in the form of a coarse suspension, suspended matter and colloids of different size are also observed (Figure 4.24, b).

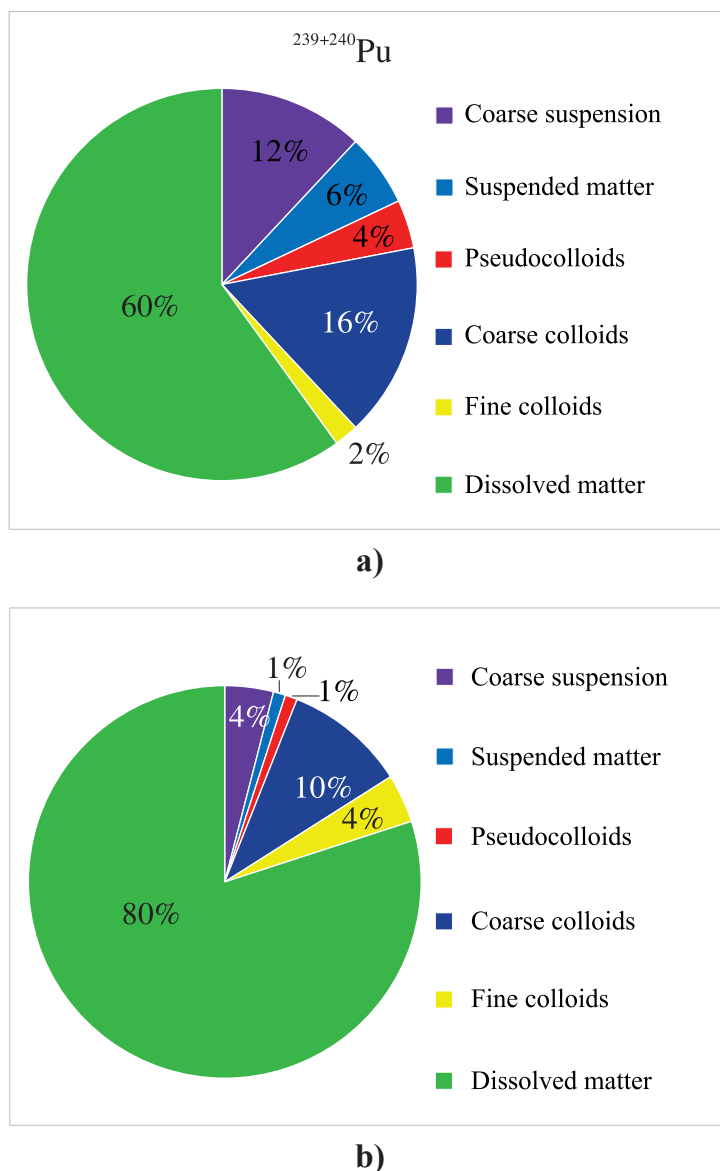


Figure 4.24. $^{239+240}\text{Pu}$ distribution by species in the water stream of adit 609 (a) and ^{238}U distribution in the water stream of adit 503 (b)

The study of the impact of physical and chemical parameters of aquatic medium on radionuclide species showed that with certain pH values and macrocomponent composition of water, radionuclide species are transformed and redistributed in different forms. The main research findings are set forth in publications [190, 191, 192].

One more line of ongoing scientific research in the test site territory is to determine tritium species. Owing to nuclear tests, a large amount of ^3H was produced, the activity of which in surface and ground waters, vegetation and soil as of today may reach hundreds

of thousands Bq (Figure 4.25). Research findings illustrate ^3H ability not only to be redistributed amidst various ecosystem compartments but also be accumulated by individual environmental components in different species (in the oxidized form or in tritiated water – HTO, in the organically bound form – OBT, in tritiated water vapour – HTO and gaseous compounds – $^3\text{H}_{\text{gas}}$). In soil of nuclear test places, ^3H can simultaneously be in several different forms: ^3H in surface-adsorbed water, ^3H in interlayer water, hydroxyl ^3H , organically bound ^3H and crystalline bound ^3H .

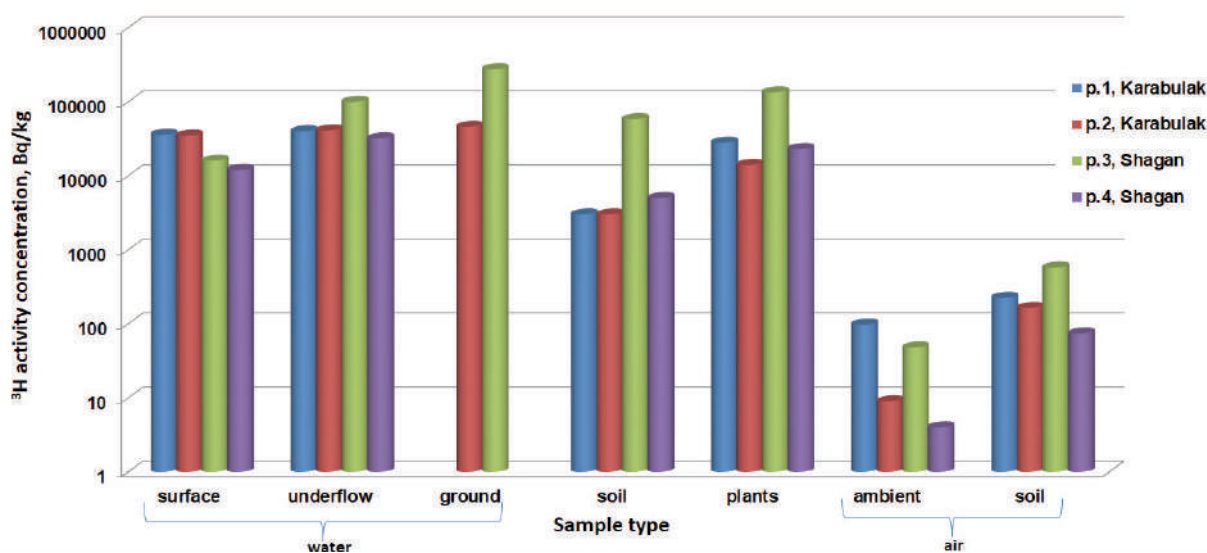


Figure 4.25. ^3H activity concentration in different environmental components of the ‘Degelen’ site (the Karabulak creek) and the Shagan area

Information on the level and species of ^3H suggests its migration mechanisms as well as allows the assessment of its biological availability. Tritium as a hydrogen isotope has a far higher migration ability than all the other artificial radionuclides. The main outputs obtained in this line are set forth in publications [193, 194, 195, 196, 197, 198, 199].

To reveal features of the transfer of radionuclides to farm products in the STS territory, a series of agricultural radioecological experiments was conducted. To do so, ‘experimental farm enterprises’ were set up in territories of the ‘Degelen’ and the ‘Experimental Field’ testing sites in different years.

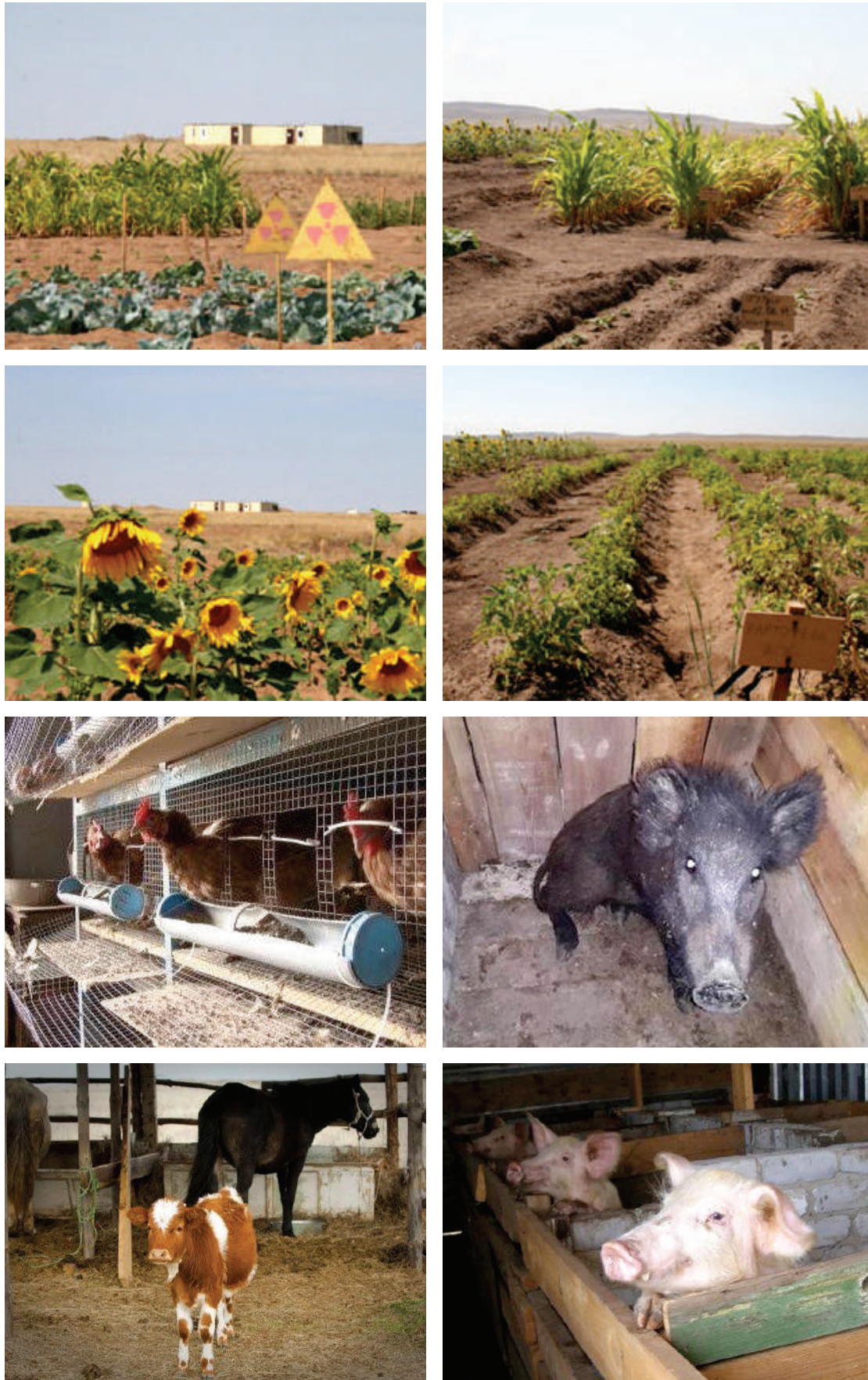


Figure 4.26. Agricultural plants and farm animals of interest

As a result of research, transfer parameters of artificial radionuclides from the diet (plants, soil, water, air) to the main animal products – mutton, beef, pork and game of wild boars, horse beef, chicken, cow and mare milk, chicken eggs were obtained. For the first time, the same data was obtained for different tritium forms (Figure 4.27). In the course of research, a possibility that radionuclides are determinable in tissues and organs of animals during their lifetime was proved by activity concentrations of radionuclides in animal wool.

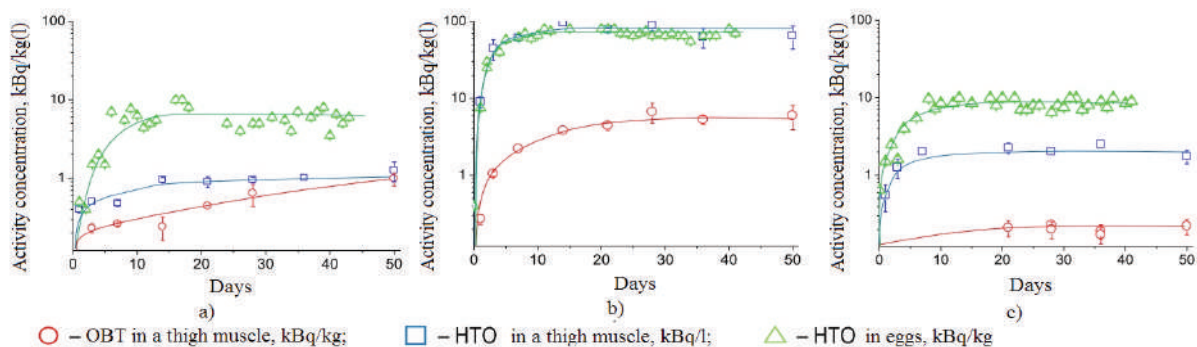


Figure 4.27. Dynamics of tritium transfer to muscular tissue and eggs of hens at a long-term intake with a) forage; b) water; c) air

Transfer parameters were also obtained for radionuclides of interest from soil to the main crop products raised in the region. The impact of different agrotechnical measures (control of moistening regime, application of different types of fertilizers) on the transfer of radionuclides to crop products was researched (Figure 4.28).

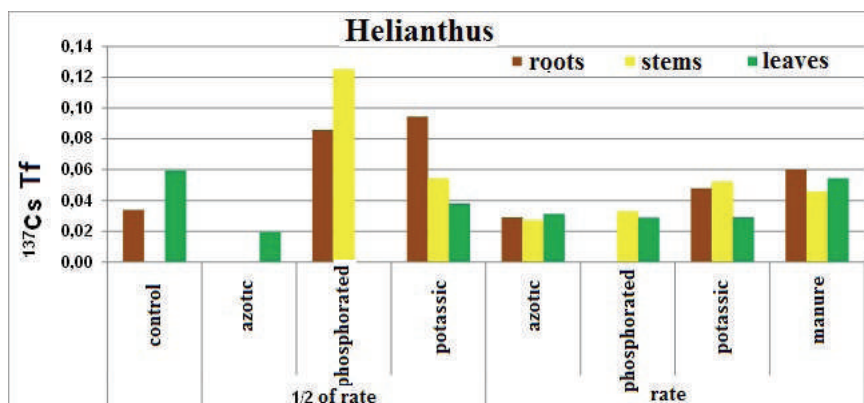


Figure 4.28. Features of ^{137}Cs transfer to sunflower with different doses of various fertilizer types applied

These parameters are necessary for different predictive models of the assessment of radionuclide migration in food chains, the assessment of radiation exposure and human risks. The main outputs obtained under this line of research are set forth in publications [200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210].

Living organisms and plants that inhabit and grow in areas with high concentrations of radionuclides in ecosystem components for a long time are also of interest from the perspective of studying the biological effect of ionizing radiation. Research was undertaken in different years to reveal a potential influence of low doses of ionizing radiation on living organisms and plants in contaminated test site areas. For instance, species and seasonal regularities were established in the formation of haematological indicators in field mice and voles. Study data on the fauna of rotifers and entomostracans is provided. Ichthyofauna data on beardie variability from the STS water body zone is compared with reference populations of fishes from the Ayaguz river. Fork-tailed tench population was discovered. More profound studies of chromosomes on the assessment of potential radiation effect on biota were conducted. For example, genetic effects in individual animal species induced by chronic exposure in low doses were studied. For the first time, natural populations of chironomids were researched in open water bodies of the Balapan stow and the Degelen mountain range. Species were cytotaxonomically identified, spectra and frequencies of inversion disc sequences were revealed in each chromosomal arm of various chironomid types. A possibility to use chironomids as an indication criterion in lake classification was proved. The abundance and existence of individual species were found to be able to act as an index to assess the ecological state of water bodies.

Besides, data on the influence of toxic elements on anatomic indicators of some plants was obtained as well as a linear growth nature of aberrant cells versus the absorbed dose rate in plants growing in test places of radiological warfare agents was discovered (Figure 4.30).

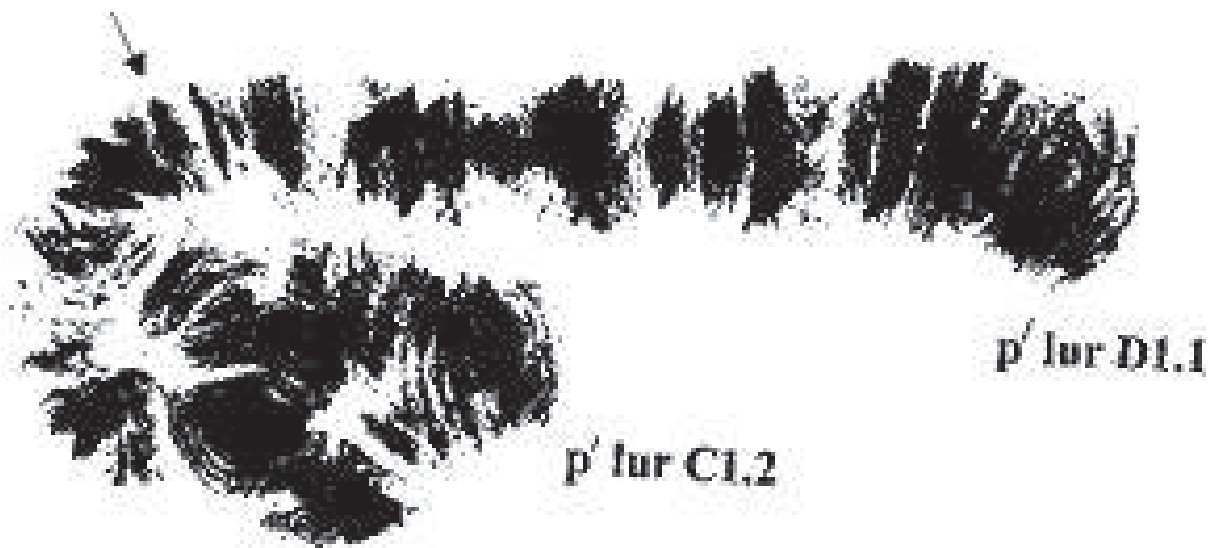


Figure 4.29. Chromosome polymorphism of *Chironomus luridus*, heterozygous inversion p/lur C.1.2

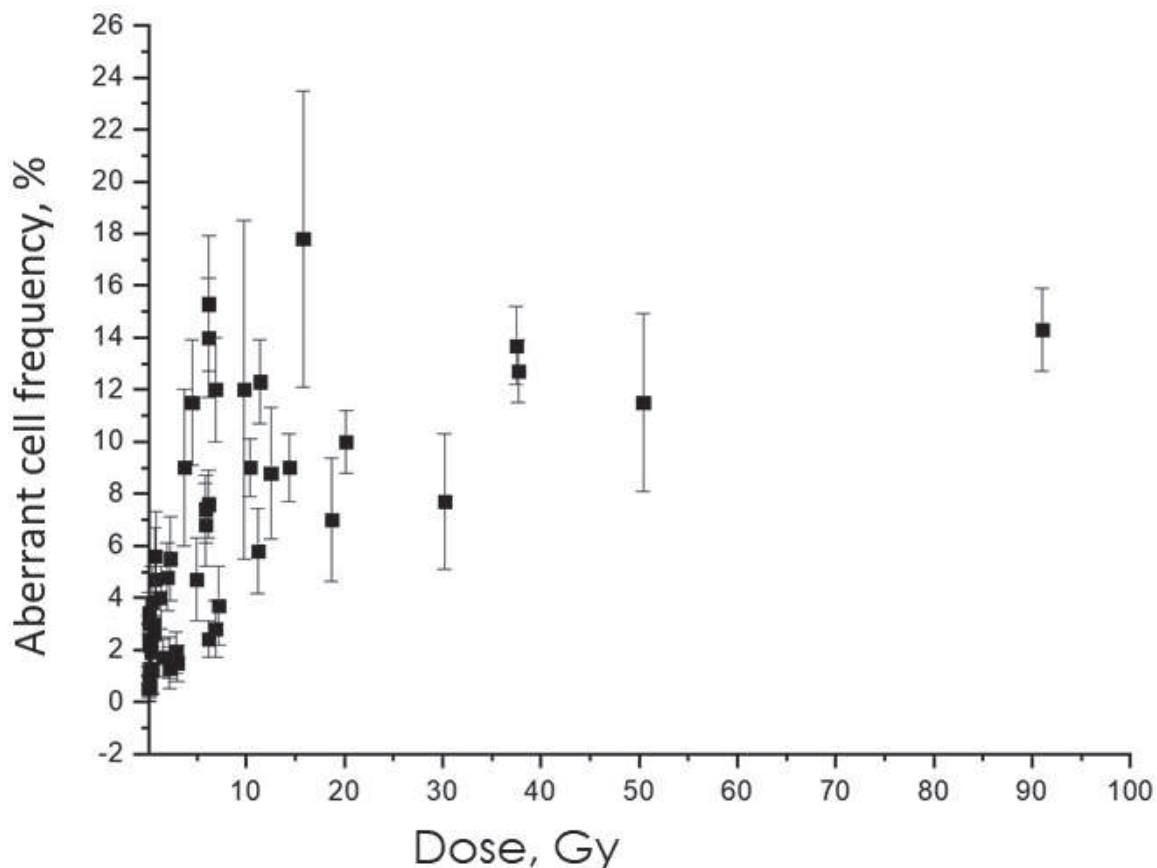


Figure 4.30. Dependence of the aberrant cell frequency yield on the absorbed β -dose rate for June grass (*Koeleria gracilis* Pers) from 0 to 2,500 $\mu\text{Gy/h}$ and from 0 to 15,000 $\mu\text{Gy/h}$

In addition to cytogenetic research, effects of STS nuclear tests on physiological and biochemical properties of dominant

plant species of the test site were studied. Low chronic doses of ionizing radiation were found to significantly change the activity of antioxidative ferments in experimental (raised from plant seeds growing under conditions exposed to radiation) and reference plants. This reduces damage to plants from exposure to radiation and ensures their radioresistance. Test plants and ferments have proved that this property is passed from one generation to another. The main research findings in this line are reflected in publications [211, 212, 213, 214, 215, 216].

Thus, specialists of the National Nuclear Center RK undertook a wide range of research in the STS territory in different years. Research findings obtained on environmental compartments of the test site are important and helpful not only for the Republic of Kazakhstan but also for the global scientific community.

Further utilization of STS as an international natural laboratory to study nuclear consequences

The STS territory is unique in terms of all kinds of research. Living organisms and plants, inhabiting and growing in areas with high concentrations of radionuclides in ecosystem components for a long time, are of interest from the perspective of studying the biological effect of ionizing radiation. As of today, unique data reflecting the effect of ionizing radiation at the morphoanatomic and cytogenetic levels has been obtained. Landscape diversity and various nature of radionuclide contamination at the test site allow obtainment of unique data that characterizes features of the redistribution of radionuclides amidst natural components in different ecosystems. As of today, a large set of parameters has been obtained to characterize redistribution of radionuclides in ‘water-plant’, ‘bottom sediments-plants’, ‘soil-plants’, ‘soil-animals’ and ‘plants-air’ systems for wild life and farm products of animal and vegetable origin. The efficiency of methods to reduce the transfer

of radionuclides to farm products by introducing food additives into farm animals' diet and by taking agrotechnical measures when raising crops (application of different fertilizer types, modification of moistening regime) was assessed.

In addition to research mentioned, the STS territory is prospective for testing and assessing the efficiency of various remediation scenarios for radioactively contaminated areas [217] and methods to reduce the amount of RAW (RAW reprocessing methods) as well as for holding exercises for different authorities and offices that respond to radiological emergencies.

CONCLUSION

Issues touched upon in this monograph mainly concern a part of the Semipalatinsk Test Site in which nuclear tests were not conducted. The history and the current state of testing sites are only summarized herein.

The work performed under the comprehensive ecological survey of the Semipalatinsk Test Site has allowed highly reliable definition of its current radioecological state, assessment of the impact of nuclear weapon tests on environmental compartments and objects – soil cover, ambient air, surface and ground waters, flora and fauna and calculation of exposure doses to man when living in the survey area.

Findings on the radiological state of the main environmental components enable to revise administrative boundaries of the Semipalatinsk Test Site in accordance with its radioecological state. A part of the test site territory, which poses a radiological hazard to the public, will be recommended to create a special procedure zone to stay. A part of the test site, which poses no radiological hazard to the public, can be potentially removed from the reserve land category and released to the economic turnover. According to preliminary data, given the radioecological state and logistics in the test site territory between testing sites, such part numbers approximately 9,000 sq. km, which is about 50 % of the Semipalatinsk Test Site.

Along with this, the comprehensive ecological survey was conducted since 2008 and allowed a guaranteed identification of the radioecological state of areas due to tests at the Semipalatinsk Test Site during the survey period. Since the test site area is not currently guarded or only controlled in some areas, one cannot guarantee that no radioactive sources could have illegally been brought to this territory (as a result of dismantling infrastructure of testing sites,

undesigned storage locations of radioactive substances etc.). In this regard, for ultimate decision-making it is necessary to update materials of the comprehensive survey of lands recommended for removal from reserve lands by conducting a follow-up survey. At the same time, it is not all about a follow-up comprehensive ecological survey of land plots because a section on prediction of the radiological situation at the Semipalatinsk Test Site is provided in materials. Given this prediction, land plots recommended for removal from reserve lands are identified. Because the case in hand is unpredicted actions of man-made nature, and a database of man-made objects, which were surveyed concerning radiological hazard they could pose, was created under the comprehensive survey of the Semipalatinsk Test Site. Thus, a follow-up survey implies the comparison of the available database of man-made objects (2008-2021) with data that became available at the time of decision-making on the status of areas and, if necessary, the survey of newly identified objects.

Despite the completion of the comprehensive survey of the Semipalatinsk Test Site, the study of the radioecological situation continues under the environmental state monitoring in order to control the radiological situation in radiation hazardous areas of the test site and in adjacent ones. Since the existing testing sites, at which nuclear tests were conducted, will still pose a hazard for a long time because of long half-lives of the major artificial radionuclides, environmental monitoring development and implementation is an important task. Further implementation of radiation monitoring will allow, from systematic observation data, identification of spatiotemporal dynamics of migration processes of radionuclides in the main environmental components in the territory of the Semipalatinsk Test Site. Strategically, monitoring of the Semipalatinsk Test Site will provide relevant and objective information on the current

radiological situation, will reveal adverse changes in progression of the radiological situation in a timely manner as well as make available information on the radiological situation to offices of state and the public.

The radioecological situation is also studied as part of measures for securing the test site area. All kinds of scientific research related to redistribution features of radionuclides amidst environmental components, in food chains, to the development and efficiency assessment of methods to remediate radioactively contaminated areas and the assessment of impact by nuclear consequences on biological features of biota is also undertaken.

As a whole, the comprehensive ecological survey of the territory of the Semipalatinsk Test Site has given answers to questions concerning the possibility for man to live in the test site territory safely. Answers obtained allow putting an end to speculations concerning the Semipalatinsk Test Site, reduction of radiophobia level, which undoubtedly furthers social and economic development of the region. Besides, specialists who undertook this research have gained a valuable experience, made up a unique resource and methodological framework, gained professional competences that make it possible to solve issues related to radioecological problems of the Republic of Kazakhstan at the global standards level.

Authors of the monograph express their gratitude to all staff members of the Institute of Radiation Safety and Ecology of the National Nuclear Center of the Republic of Kazakhstan for their contribution to the monograph. Special thanks to M. Abisheva, A. Aidarkhanova, M. Aktayev, Yu. Baklanova, F. Zhamaldinov, P. Krivitsky, A. Kunduzbayeva, V. Monayenko, Ye. Mustafina, A. Panitsky, Ye. Polivkina, S. Subbotin, Ye. Sysoyeva, A. Toporova, D. Turchenko for the material provided. Specific thanks to I. Dorozhkin, A. Omarkhanova, O. Seraya for assisting in technical issues.

LICENSES AND OPERATIONS CERTIFICATES

1. State licenses for types of activity

To conduct radioecological research, the National Nuclear Center RK has all the necessary licenses, which entitle to provide services (Figure 0.1, Figure 0.2, Figure 0.3, Figure 0.4, Figure 0.5).

20004749




ЛИЦЕНЗИЯ

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на занятие	Предоставление услуг в области использования атомной энергии <small>(наименование лицензируемого вида деятельности в соответствии с Законом Республики Казахстан «О разрешениях и уведомлениях»)</small>
Особые условия	Типы приборов, установок, материалов, с которыми лицензиат проводит работы, указаны в подвидах деятельности <small>(в соответствии со статьей 36 Закона Республики Казахстан «О разрешениях и уведомлениях»)</small>
Примечание	Неотчуждаемая, класс 1 <small>(отчуждаемость, класс разрешения)</small>
Лицензиар	Государственное учреждение "Комитет атомного и энергетического надзора и контроля". Министерство энергетики Республики Казахстан. <small>(полное наименование лицензиара)</small>
Руководитель (уполномоченное лицо)	Сергазин Гумар Екпинович <small>(фамилия, имя, отчество (в случае наличия))</small>
Дата первичной выдачи	
Срок действия лицензии	12.03.2025
Место выдачи	г.Нур-Султан

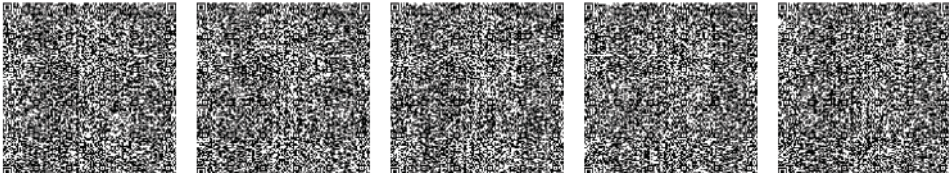


Figure 0.1. State license of RSE NNC RK for provision of services in atomic energy



ПРИЛОЖЕНИЕ К ЛИЦЕНЗИИ

Номер лицензии 20004749

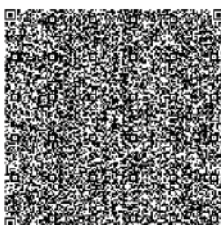
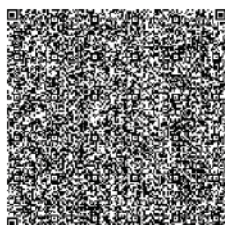
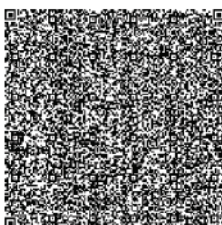
Дата выдачи лицензии 12.03.2020 год

Подвид(ы) лицензируемого вида деятельности:

- Определение содержания радионуклидов в продуктах, материалах, объектах окружающей среды, измерение концентрации радона и других радиоактивных газов
 - Измерение концентрации радона и других радиоактивных газов
 - Определение содержания радионуклидов в продуктах, материалах, объектах окружающей среды
- Индивидуальный дозиметрический контроль персонала
- Радиационный контроль территорий, помещений, рабочих мест, товаров, материалов, металлолома, транспортных средств

(наименование подвида лицензируемого вида деятельности в соответствии с Законом Республики Казахстан «О разрешениях и уведомлениях»)

Лицензиат	<p>Республиканское государственное предприятие на праве хозяйственного ведения «Национальный ядерный центр Республики Казахстан» Министерства энергетики Республики Казахстан</p> <p>071100, Республика Казахстан, Восточно-Казахстанская область, Курчатов Г. А., г. Курчатов, улица Бейбіт атом, дом № 2Б, БИН: 990240001722</p> <p>(полное наименование, местонахождение, бизнес-идентификационный номер юридического лица (в том числе иностранного юридического лица), бизнес-идентификационный номер филиала или представительства иностранного юридического лица – в случае отсутствия бизнес-идентификационного номера у юридического лица/полностью фамилия, имя, отчество (в случае наличия), индивидуальный идентификационный номер физического лица)</p>
Производственная база	<p>071100 Республика Казахстан, город Курчатов, улица Бейбіт атом, 10; 071100 Республика Казахстан, город Курчатов, улица Бейбіт атом, 2</p> <p>(местонахождение)</p>
Особые условия действия лицензии	<p>Типы приборов, установок, материалов, с которыми лицензиат проводит работы, указаны в подвидах деятельности</p> <p>(в соответствии со статьей 36 Закона Республики Казахстан «О разрешениях и уведомлениях»)</p>
Лицензиар	<p>Государственное учреждение "Комитет атомного и энергетического надзора и контроля". Министерство энергетики Республики Казахстан.</p> <p>(полное наименование органа, выдавшего приложение к лицензии)</p>
Руководитель (уполномоченное лицо)	<p>Сергазин Гумар Екпинович</p> <p>(фамилия, имя, отчество (в случае наличия))</p>



Осы құжат «Электронды құжат және электрондық цифрлық қолтаба туралы» Қазақстан Республикасының 2003 жылғы 7 қаңтардағы Заңы 7 бабының 1 тармағына сәйкес қызыл тасығыштағы құжатпен мұқият бірдей. Данышй документ согласно пункту 1 статьи 7 ЗРК от 7 января 2003 года "Об электронном документе и электронной цифровой подписи" равнозначен документу на бумажном носителе.

Figure 0.2. List of subtypes of activities according to the state license for provision of services in atomic energy



ЛИЦЕНЗИЯ

03.07.2019 года

19014222

Выдана	<p>Республиканское государственное предприятие на праве хозяйственного ведения «Национальный ядерный центр Республики Казахстан» Министерства энергетики Республики Казахстан</p> <p>071100, Республика Казахстан, Восточно-Казахстанская область, Курчатов Г.А., г.Курчатов, улица Бейбіт атом, дом № 2Б., БИН: 990240001722</p> <p><small>(полное наименование, местонахождение, бизнес-идентификационный номер юридического лица (в том числе иностранного юридического лица), бизнес-идентификационный номер филиала или представительства иностранного юридического лица – в случае отсутствия бизнес-идентификационного номера у юридического лица/полностью фамилия, имя, отчество (в случае наличия), индивидуальный идентификационный номер физического лица)</small></p>
на занятие	<p>Деятельность на территориях бывших испытательных ядерных полигонов и других территориях, загрязненных в результате проведенных ядерных испытаний</p> <p><small>(наименование лицензируемого вида деятельности в соответствии с Законом Республики Казахстан «О разрешениях и уведомлениях»)</small></p>
Особые условия	<p><small>(в соответствии со статьей 36 Закона Республики Казахстан «О разрешениях и уведомлениях»)</small></p>
Примечание	<p>Неотчуждаемая, класс 2</p> <p><small>(отчуждаемость, класс разрешения)</small></p>
Лицензиар	<p>Государственное учреждение "Комитет атомного и энергетического надзора и контроля". Министерство энергетики Республики Казахстан.</p> <p><small>(полное наименование лицензиара)</small></p>
Руководитель (уполномоченное лицо)	<p>Ертаев Ержан Ерболулы</p> <p><small>(фамилия, имя, отчество (в случае наличия))</small></p>
Дата первичной выдачи	29.07.2010
Срок действия лицензии	
Место выдачи	г.Нур-Султан

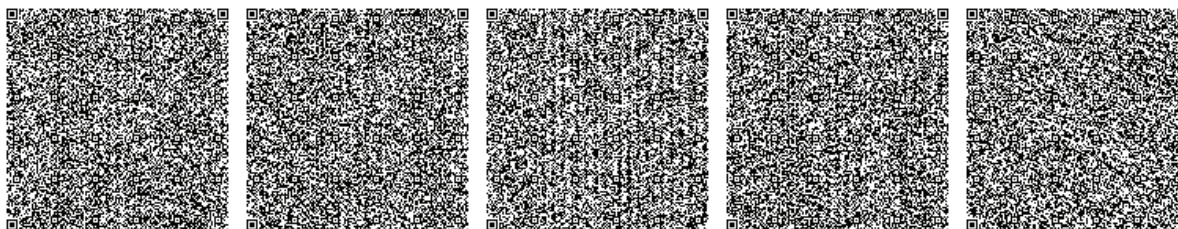


Figure 0.3. State license of RSE NNC RK for carrying out activities in areas of the former nuclear test sites and other areas contaminated due to nuclear testing



ЛИЦЕНЗИЯ

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071100, Республика Казахстан, Восточно-Казахстанская область, Курчатов Г. А., г. Курчатов, улица Бейбіт атом, дом № 2Б
БИН: 990240001722

(полное наименование, местонахождение, бизнес-идентификационный номер юридического лица (в том числе иностранного юридического лица), бизнес-идентификационный номер филиала или представительства иностранного юридического лица – в случае отсутствия бизнес-идентификационного номера у юридического лица/полностью фамилия, имя, отчество (в случае наличия), индивидуальный идентификационный номер физического лица)

на занятие

Деятельность по обращению с радиоактивными отходами

(наименование лицензируемого вида деятельности в соответствии с Законом Республики Казахстан «О разрешениях и уведомлениях»)

Особые условия

Типы отходов, с которыми лицензиат проводит работы, указаны в подвидах деятельности

(в соответствии со статьей 36 Закона Республики Казахстан «О разрешениях и уведомлениях»)

Примечание

Неотчуждаемая, класс 1

(отчуждаемость, класс разрешения)

Лицензиар

Государственное учреждение "Комитет атомного и энергетического надзора и контроля". Министерство энергетики Республики Казахстан.

(полное наименование лицензиара)

Руководитель
(уполномоченное лицо)

Сергазин Гумар Екпинович

(фамилия, имя, отчество (в случае наличия))

Дата первичной выдачи

Срок действия
лицензии

29.01.2025

Место выдачи

г.Нур-Султан

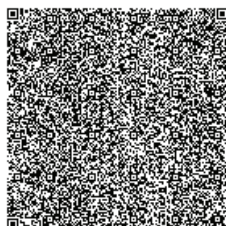
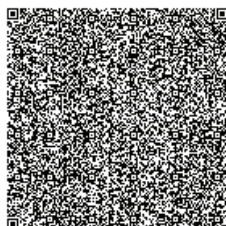
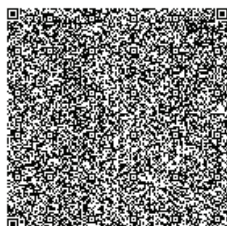
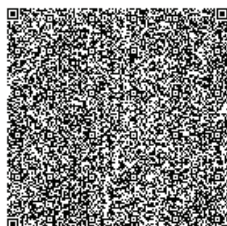
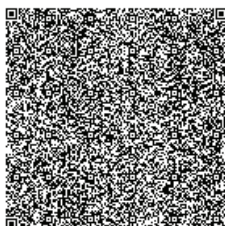


Figure 0.4. State license of RSE NNC RK for radioactive waste management



ПРИЛОЖЕНИЕ К ЛИЦЕНЗИИ

Номер лицензии 20001683

Дата выдачи лицензии 29.01.2020 год

Подвид(ы) лицензируемого вида деятельности:

- Радиационная реабилитация, рекультивация территорий и объектов
- Хранение и захоронение радиоактивных отходов
 - Захоронение радиоактивных отходов
 - Низкоактивных радиоактивных отходов
 - Среднеактивных радиоактивных отходов
 - Хранение радиоактивных отходов
 - Низкоактивных радиоактивных отходов
 - Среднеактивных радиоактивных отходов
- Дезактивация (очистка от радиоактивного загрязнения) помещений, оборудования и материалов
- Сбор и сортировка радиоактивных отходов
 - Низкоактивных радиоактивных отходов
 - Среднеактивных радиоактивных отходов

(наименование подвида лицензируемого вида деятельности в соответствии с Законом Республики Казахстан «О разрешениях и уведомлениях»)

Лицензиат

Республиканское государственное предприятие на праве хозяйственного ведения «Национальный ядерный центр Республики Казахстан» Министерства энергетики Республики Казахстан

071100, Республика Казахстан, Восточно-Казахстанская область, Курчатов Г. А., г. Курчатов, улица Бейбіт атом, дом № 2Б, БИН: 990240001722

(полное наименование, местонахождение, бизнес-идентификационный номер юридического лица (в том числе иностранного юридического лица), бизнес-идентификационный номер филиала или представительства иностранного юридического лица – в случае отсутствия бизнес-идентификационного номера у юридического лица/полностью фамилия, имя, отчество (в случае наличия), индивидуальный идентификационный номер физического лица)

Производственная база

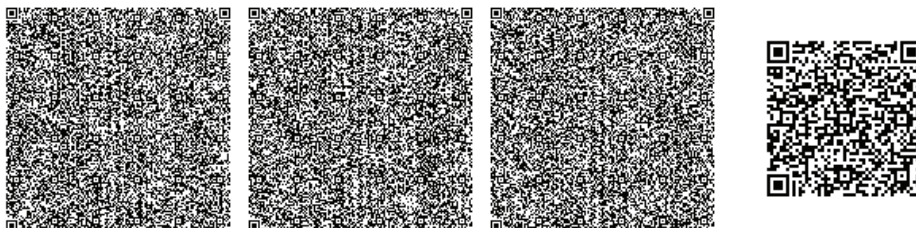
Республика Казахстан, Восточно-Казахстанская область, город Курчатов, улица Бейбіт атом 10; Республика Казахстан, Восточно-Казахстанская область, город Курчатов, улица Бейбіт атом 2

(местонахождение)

Особые условия действия лицензии

Типы отходов, с которыми лицензиат проводит работы, указаны в подвидах деятельности

(в соответствии со статьей 36 Закона Республики Казахстан «О разрешениях и уведомлениях»)



Осы құжат «Электронды құжат және электрондық цифрлық қолтаңба туралы» Қазақстан Республикасының 2003 жылғы 7 қаңтардағы Заңы 7 бабының 1 тармағына сәйкес қағаз тасығыштағы құжатпен маңызды бірдей. Данный документ согласно пункту 1 статьи 7 ЗРК от 7 января 2003 года "Об электронном документе и электронной цифровой подписи" равнозначен документу на бумажном носителе.

Figure 0.5. List of subtypes of activities according to the state license for radioactive waste management

2. Accreditation certificate of the test center 'Radioecological Research Center'

The test center 'Radioecological Research Center' operates on the premises of Institute's laboratories and departments. The center is accredited under the accreditation system of the Republic of Kazakhstan to meet GOST ISO/IEC 17025-2009 'General Requirements for Competencies of Test and Calibration Laboratories' (Figure 0.6).



ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ, САУДА ЖӘНЕ
ИНТЕГРАЦИЯ МИНИСТРЛІГІНІҢ, ТЕХНИКАЛЫҚ РЕТТЕУ
ЖӘНЕ МЕТРОЛОГИЯ КОМИТЕТІ

ҰЛТТЫҚ АККРЕДИТТЕУ ОРТАЛЫҒЫ

АККРЕДИТТЕУ АТТЕСТАТЫ



KZA168DAC8569C3AE3

Аккредиттеу субъектілерінің тізілімінде тіркелген

№ KZ.T.07.2142

12 Қазан 2018 жылдан

12 Қазан 2023 жылға дейін жарамды

БСН 130441025754, Қазақстан Республикасы Энергетика министрлігі «Қазақстан Республикасының Ұлттық ядролық орталығы» шаруашылық жүргізу құқығындағы республикалық мемлекеттік кәсіпорнының «Радиациялық қауіпсіздік және экология институты» филиалы, заңды мекен-жайы: Қазақстан, Восточно-Казахстанская область, Курчатов г.а., Красноармейская к-сі, 2, нақты мекен-жайы: Қазақстан, Восточно-Казахстанская область, Курчатов г.а., Красноармейская к-сі, 2; Қазақстан, Восточно-Казахстанская область, Курчатов г.а., Құнанбай к-сі, 18; Қазақстан, Восточно-Казахстанская область, Курчатов г.а., Құнанбай к-сі, 16 Қазақстан Республикасының аккредиттеу жүйесінде ГОСТ ИСО/МЭК 17025-2009. Сынау және калибрлеу зертханаларының құзыреттілігіне қойылатын жалпы талаптар (Сынақ орталығы) талаптарына сәйкес аккредиттелген.

Сәйкестікті бағалаудың объектілері: Сынақ орталығы.

Аккредиттеу саласы ақпараттық жүйеде келтірілген.

Бұл құжат тіркеушінің ақпараттық жүйесінің сәйкестікті бағалау саласындағы электронды аккредиттеу қызметі арқылы қалыптастырылған.

Бұл құжат «Электрондық құжат және электрондық цифрлық қолтаңба туралы» Қазақстан Республикасының 2003 жылғы 7 қаңтардағы №370-II Заңының 7-бабының 1-тармағына сәйкес қағаз жүзіндегі құжатқа баламалы болып табылады.

Электрондық құжаттың дұрыстығын ғаламтор желісі арқылы тексеруге болады <https://techreg.qoldau.kz/ru/acc/subjects>



КОМИТЕТ ТЕХНИЧЕСКОГО РЕГУЛИРОВАНИЯ И
МЕТРОЛОГИИ МИНИСТЕРСТВА ТОРГОВЛИ И ИНТЕГРАЦИИ
РЕСПУБЛИКИ КАЗАХСТАН

НАЦИОНАЛЬНЫЙ ЦЕНТР АККРЕДИТАЦИИ

АТТЕСТАТ АККРЕДИТАЦИИ



KZ8C098EE2C18A3BAA

Зарегистрирован в реестре субъектов аккредитации
№ KZ.Т.07.2142
от 12 Октябрь 2018 г.
действителен до 12 Октябрь 2023 г.

БИН 130441025754, Филиал «Институт радиационной безопасности и экологии» Республиканского государственного предприятия на праве хозяйственного ведения «Национальный ядерный центр Республики Казахстан» Министерства энергетики Республики Казахстан., юридический адрес: Казахстан, Восточно-Казахстанская область, Курчатов г.а., ул. Красноармейская, 2, фактический адрес: Казахстан, Восточно-Казахстанская область, Курчатов г.а., ул. Красноармейская, 2; Казахстан, Восточно-Казахстанская область, Курчатов г.а., ул. Кунанбая, 18; Казахстан, Восточно-Казахстанская область, Курчатов г.а., ул. Кунанбая, 16 аккредитован(а) в системе аккредитации Республики Казахстан на соответствие требованиям ГОСТ ИСО/МЭК 17025-2009. Общие требования к компетентности испытательных и калибровочных лабораторий (ИЦ).

Объекты оценки соответствия: Испытательный центр.

Область аккредитации приведена в информационной системе.

Данный документ сформирован электронным сервисом аккредитации в области оценки соответствия Регистраторской информационной системы.

Данный документ согласно пункту 1 статьи 7 ЗРК от 7 января 2003 года №370-II «Об электронном документе и электронной цифровой подписи» равнозначен документу на бумажном носителе.

Проверить подлинность электронного документа Вы можете в реестре субъектов аккредитации <https://techreg.qoldau.kz/ru/acc/subjects>

**Figure 0.6. Accreditation certificate of the test center
'Radioecological Reseach Center'**

3. Certificates of Conformity to operating ST RK ISO 9001-2016 (ISO 9001:2015) and ST RK ISO 14001-2016 (ISO 14001:2015)

**ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ МЕМЛЕКЕТТІК
ТЕХНИКАЛЫҚ РЕТТЕУ ЖҮЙЕСІ**
"Менеджмент жүйелерін сертификаттаудың республикалық орталығы" ЖШС
МЖ СРО
Нұр-Сұлтан қ-сы, Сарайшық к-сі, 5/1 үй, 15 кеңсе

KZ.Q.01.0448 КСС № 0106773

СӘЙКЕСТІК СЕРТИФИКАТЫ

Мемлекеттік тізілімде 2019 ж. «18» желтоқсан тіркелді
№ KZ.7100448.07.03.00216 2022 ж. «18» желтоқсан дейін жарамды
Алғашқы сертификаттау күні 2013 ж. «25» сәуір

Осы сертификат ҚР ЭМ «Қазақстан Республикасының Ұлттық ядролық орталығы» ШЖК РМК, ҚР. ШҚО, Қурчатов қ-сы, Бейбіт атом қ-сі, ғим. 2 Б берілді және **ЖҮЙЕНІҢ** сапа менеджменті

сертификаттау саласы қосымша құжат КССК №0018635 бойынша

катысты

ҚР СТ ISO 9001-2016 (ISO 9001:2015) «Сапа менеджменті жүйелері. Талаптар» талаптарға сәйкес келетінін куәландырады

 М.О.

Сәйкестікті растау жөніндегі органның басшысы
немесе ол уәкілеттік берген тұлға

 Каримова Н.А.
қолы инициалдары, тегі

 Губарева С. Н.
қолы инициалдары, тегі

Астана қаласы, "МЖСРО" РМК



ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ МЕМЛЕКЕТТІК
ТЕХНИКАЛЫҚ РЕТТЕУ ЖҮЙЕСІ

Менеджмент жүйесінің сәйкестік сертификатына

ҚОСЫМША 0018635



Қосымша № KZ.7100448.07.03.00216
сәйкестік сертификатының ажырамас
бөлігі болып табылады

Ядролық физика, қатты дене физикасы, радиациялық материалтану, ядролық реакторлар физикасы мен техникасы, соның ішінде ядролық және термоядролық қондырғыларды, пондаушы сәулелену көздерін, ядролық материалдарды, радиоактивті заттарды пайдалану арқылы, атом энергетикасының қауіпсіздігін негіздеу, радиэкология және жарылыс ісі саласында ғылыми зерттеулер жүргізу; ядролық материалдармен, пондаушы сәулелену көздерімен және радиоактивті заттармен, пайдаланылған ядролық отынды қоса алғанда радиоактивті қалдықтармен жұмыс істеу, соның ішінде есепке алу және бақылау, радиоактивті қалдықтар қоймаларын құру және қауіпсіз пайдалану; атом (ядролық және термоядролық) энергиясын пайдалану объектілерін жобалау, салу, пайдалануға енгізу, пайдалану, консервациялау және пайдаланудан шығару; ядролық қондырғылар мен ядролық материалдарды физикалық қорғауды қамтамасыз ету; ядролық сынақтардың салдарларын зерделеу және жою, ядролық сынақтар жүргізілген жерлерді радиэкологиялық мониторингілеу; ядролық-физикалық және химиялық әдістерді қолдана отырып, заттардың құрамына талдамалық зерттеулер жүргізу; сәулелттік және құрылыстық жобалау, құрылыс-монтаждау жұмыстарын орындау; табиғатты қорғау іс-шараларын әзірлеу және орындау; өнеркәсіптік қалдықтарды өңдеу бойынша ғылыми зерттеулер жүргізу және технологиялар әзірлеу; өнеркәсіптік қалдықтармен жұмыс істеу, соның ішінде өнеркәсіптік қалдықтар полигондарын құру және қауіпсіз пайдалану; деректер базаларын және географиялық ақпараттық жүйелерді құру жолымен ғылыми зерттеулердің нәтижелерін қорытындылау және жүйелендіру; атом саласы үшін ғылыми және ғылыми-техникалық кадрларды даярлау және біліктілігін арттыру; қауіпті өндірістік объектілерде авариялық-құтқару жұмыстарын және басқа да қауіпті жұмыстарды жүргізу (газдан құтқару, іздеу-құтқару, радиациялық авариялардың салдарын жою жұмыстары)



Сәйкестікті растау жөніндегі органның басшысы
немесе ол уәкілеттік берген тұлға

[Signature]
қолы

Каримова Н.А.
инициалдары, тегі

[Signature]
қолы

Сарапшы-аудитор

Губарева С.Н.
инициалдары, тегі



Figure 0.7. Certificate of Conformity to ST RK ISO 9001-2016 (ISO 9001:2015) 'Quality Management Systems. Requirements.'

ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ МЕМЛЕКЕТТІК
ТЕХНИКАЛЫҚ РЕТТЕУ ЖҮЙЕСІ

"Менеджмент жүйелерін сертификаттаудың республикалық орталығы" ЖШС
МЖ СРО

Нұр-Сұлтан қ-сы, Сарайшық к-сі, 5/1 үй, 15 кеңсе



KZ.Q.01.0448



КСС № 0106774

СӘЙКЕСТІК СЕРТИФИКАТЫ

Мемлекеттік тізілімде 2019 ж. «18» желтоқсан тіркелді

№ KZ.7100448.07.03.00217 2022 ж. «18» желтоқсан дейін жарамды

Алғашқы сертификаттау күні 2015 ж. «26» тамыз

Осы сертификат ҚР ЭМ «Қазақстан Республикасының Ұлттық ядролық орталығы» ШЖҚ РМК, ҚР, ШҚО, Курчатов қ-сы, Бейбіт атом к-сі, ғим. 2 Б

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Сәйкестікті растау жөніндегі органның басшысы
немесе ол уәкілеттік берген тұлға

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**ГОСУДАРСТВЕННАЯ СИСТЕМА
ТЕХНИЧЕСКОГО РЕГУЛИРОВАНИЯ РЕСПУБЛИКИ КАЗАХСТАН**
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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ МЕМЛЕКЕТТІК
ТЕХНИКАЛЫҚ РЕТТЕУ ЖҮЙЕСІ

Менеджмент жүйесінің сәйкестік сертификатына

ҚОСЫМША 0018636



Қосымша № KZ.7100448.07.03.00217
сәйкестік сертификатының ажырамас
бөлігі болып табылады

Ядролық физика, қатты дене физикасы, радиациялық материалтану, ядролық реакторлар физикасы мен техникасы, соның ішінде ядролық және термоядролық қондырғыларды, қондаушы сәулелену көздерін, ядролық материалдарды, радиоактивті заттарды пайдалану арқылы, атом энергетикасының қауіпсіздігін негіздеу, радиоэкология және жарылыс ісі саласында ғылыми зерттеулер жүргізу; ядролық материалдармен, қондаушы сәулелену көздерімен және радиоактивті заттармен, пайдаланылған ядролық отынды қоса алғанда радиоактивті қалдықтармен жұмыс істеу, соның ішінде есепке алу және бақылау, радиоактивті қалдықтар қоймаларын құру және қауіпсіз пайдалану; атом (ядролық және термоядролық) энергиясын пайдалану объектілерін жобалау, салу, пайдалануға енгізу, пайдалану, консервациялау және пайдаланудан шығару; ядролық қондырғылар мен ядролық материалдарды физикалық қорғауды қамтамасыз ету; ядролық сынақтардың сақталуын зерделеу және жою, ядролық сынақтар жүргізілген жерлерді радиоэкологиялық мониторингілеу; ядролық-физикалық және химиялық әдістерді қолдана отырып, заттардың құрамына талдамалық зерттеулер жүргізу; сәулеттік және құрылыстық жобалау, құрылыс-монтаждау жұмыстарын орындау; табиғатты қорғау іс-шараларын әзірлеу және орындау; өнеркәсіптік қалдықтарды өңдеу бойынша ғылыми зерттеулер жүргізу және технологиялар әзірлеу; өнеркәсіптік қалдықтармен жұмыс істеу, соның ішінде өнеркәсіптік қалдықтар полигондарын құру және қауіпсіз пайдалану; деректер базаларын және географиялық ақпараттық жүйелерді құру жолымен ғылыми зерттеулердің нәтижелерін қорытындылау және жүзеге асыру; атом саласы үшін ғылыми және ғылыми-техникалық кадрларды даярлау және біліктілігін арттыру; қауіпті өндірістік объектілерде авариялық-құтқару жұмыстарын және басқа да қауырт жұмыстарды жүргізу (газдан құтқару, іздеу-құтқару, радиациялық авариялардың салдарын жою жұмыстары)



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Figure 0.8. Certificate of Conformity to ST RK ISO 14001-2016 (ISO 14001:2015) 'Ecological Management Systems. Requirements and Application Manual'

ANNEX 2

LOGISTICS AND METHODOLOGY FRAMEWORK USED IN WORK

1. Transport support of work

For the field work, the Institute used such in-house vehicles as:

- dual-purpose off-road vehicles (UAZ) to do field work and transport environmental samples to Institute's laboratories;
- specialized mobile laboratories mounted on 'Ford' and 'KamAZ' motor vehicles enabling laboratory research using a high-tech equipment in the field;
- trucks to relocate the infrastructure of field camps, equipment and other cargos.

2. Environmental sampling

To collect environmental samples, necessary mechanisms, equipment and instruments of different purpose were applied.

The main sampling equipment as part of the comprehensive ecological survey is listed in the table (Table 0.1).

Table 0.1. Equipment used in the field work

Type of equipment	Purpose
Flow rate meter-sampler of radioactive gas and aerosol mixtures 'BRIZ'	Air aerosol sampling
Meteorological station Davis Vantage Vue	Meteorological parameter measurements
Navigating receiver Garmin GPSMAP 62s	Positioning afield
Type of equipment	Purpose
Drill rig LBU 50-07 mounted on KamAZ 43118 motor vehicle	Drilling and borehole clean-up
Drill rig URB 2A2 on Ural chassis	Drilling and borehole clean-up

Deep-borehole pump Groundfos	Borehole washing and water sampling
Electric contact borehole hawser level gage USK-TE	Measurement of ground water level
Hydrologic instrument (digital thermometer)	Measurement of hydrogeological parameters
Point water sampler Solinst 429	Water sampling
Hydrologic instrument Solinst 316L	Water sampling
Deck-based compressor KV 12/12	Drilling and borehole clean-up
Residential module involving: living quarters, decontamination station, diesel-power generator (DPG), household premises. AATs 8742-01	Field infrastructure
Dosemeter-radiometer MKS-AT1117M	Radiation parameter measurements (α - and β -particle fluence, EDR)
Dosemeter-radiometer MKS-AT6130	Radiation parameter measurements (β -particle fluence, EDR)
Satellite geodesic equipment GNSS Trimble Epoch 50	Positioning system of sampling points
Dosimetric control system of personnel HARSHAW 6600	Provision of individual dosimetric control of personnel

3. Laboratory research

Institute's laboratories are equipped with necessary technical facilities and have available equipment that passed the annual metrological calibration test. For laboratory analyses, measurement procedures entered in the State Registry of the Republic of Kazakhstan were applied.

Reliability of measurements was assured by the Institute's operating quality management and ecological management system (ISO 9001:2015, ISO 14001:2015, ISO 19011:2011) as well as by accreditation certificate in place.

The main equipment for laboratory activities as part of the comprehensive ecological survey is listed in the table (Table 0.2).

Table 0.2. Equipment used for laboratory activities

Equipment type	Purpose
Alpha-spectrometers with solid-state detectors	Determination of $^{239+240}\text{Pu}$ activity concentration
Gamma-spectrometers with ultra-pure germanium solid-state detectors	Determination of activity concentrations of γ -emitting radionuclides
Liquid scintillation beta-spectrometers	Determination of activity concentrations of β -emitting radionuclides
Scintillation beta-spectrometers	
Inductively coupled plasma mass-spectrometers	Determination of low-background concentrations of radionuclides
Inductively coupled plasma atomic emission spectrometer	
Laser isotope water analyzer	Determination of the ratio of stable $^2\text{H}/^{18}\text{O}$ isotopes
Ultra-pure water device (deionizer)	To draw ultra-pure water
Medical electric aquadistillator	Production of distilled water
Laboratory mixer	Mixing liquid samples in conical flasks
Undulating shaker	Mixing liquid samples in conical flasks
Laboratory centrifuge	Separation of inhomogeneous liquid systems
Electric heating platforms	Heating liquids (solutions) and temperature maintenance
Hot plates with ceramic platforms	Sample heating, evaporation and drying
pH-meter S-220 Seven Compact	Measurements of pH and oxidation-reduction potential
Muffle furnaces	Environmental sample ashing
Desiccators	Drying, heating, thermal treatment in air medium
Disc vibrating mills	Grinding
Laboratory balance	Measurements of substance mass
Heating mantle	Distillation of water, soil samples
Magnetic mixers	Sample concentrating
Freezers	Storage of samples at a low temperature
Refrigerators	
Analytical sieving machine	Soil fractionation
pH-meter/ion meter	pH measurement
Spectrophotometers	Measurement of a transmission coefficient, optical density
Meteorological aneroid barometer	Atmospheric pressure measurement

4. Methodological support of the comprehensive ecological survey

Determination of the radiological state of soil cover

Determination of the areal activity of radionuclides in soil consisted in three stages: soil sampling (topsoil and stratified sampling), sample preparation for laboratory analyses and determination of the content of radionuclides.

Topsoil was sampled as per GOST 17.4.3.01-83 [218] at junction points of a 1×1 km survey grid. The sampling area of each point soil sample was 200 cm² and the sampling depth – 5 cm.

Soil was sampled layerwise at a spacing of 0-3, 3-6, 6-9, 9-12, 12-15, 15-18, 18-21, 21-24, 21-27, 27-30, 30-35, 35-40, 45-50 cm. In specific cases, on underdeveloped soils, intervals were 0-2, 2-5, 5-10, 10-15 cm. The sampling area of each layer within the testing site was 200 cm². Places of stratified soil sampling were selected given the distribution of soil contours and covered all the main soil types, subtypes and geni in the STS territory.

Determination of ¹³⁷Cs and ²⁴¹Am activities

Sample preparation to determine activities of gamma-emitting ¹³⁷Cs and ²⁴¹Am consisted of:

- soil sample drying until the air-dry state;
- separation of inclusions (vegetation and stones) from the soil bulk;
- sieving a dried sample through a 2×2 mm mesh;
- sampling an averaged 500-900 g subsample from the total soil sample by squaring and placing it in a plastic container;
- sending the plastic container with the averaged subsample to be analyzed by gamma-spectrometry.

¹³⁷Cs and ²⁴¹Am activities in soil samples were determined with solid-state gamma-spectrometers as per the measurement procedure using ‘SpectraLine’ software [219].

The measurement time of soil samples lasted from 2 to 8 hours depending on the activity of a measured sample.

Determination of ^{90}Sr and $^{239+240}\text{Pu}$ activities

Sample preconditioning to determine the content of ^{90}Sr and $^{239+240}\text{Pu}$ consisted of the following processes: – subsampling 150 g of soil by squaring from an air-dry sample that underwent a gamma-spectrometric measurement;

- powdering the soil subsample with a laboratory mill;
- subsampling 60-70 g of soil from a soil sample after powdering followed by putting it in the porcelain crucible;
- calcining the subsample in the porcelain crucible in the muffle furnace for 8 hours at 550 °C to remove organic substances (fragments of plants, animals etc).

Determination of $^{239+240}\text{Pu}$ activity

A radioactive tracer – ^{242}Pu and a carrier – yttrium chloride (YCl_3) were previously spiked into a calcined and mineralized soil sample to keep record of losses and control the chemical yield. Thereafter, the sample was treated with concentrated acid solutions (HF , HNO_3 , HCl) resulting in a 3 mole/l nitric-acid solution containing extracted plutonium and yttrium isotopes. Resulted soil solutions were passed through glass columns that were filled with fluoroplastic cuttings having an extractant spread on them – trioctylamine. At the same time, plutonium isotopes were retained on columns, and those of strontium-yttrium and other macroadmixture passed with the eluting solution (3M HNO_3). Thereafter, plutonium isotopes were isolated from ion-exchangeable columns using a solvent solution – isopropyl alcohol. To prepare a spectrometric source, plutonium isotopes were coprecipitated with a slightly soluble compound – neodymium fluoride (NdF_3). The resulted precipitate was attached to the membrane filter.

$^{239+240}\text{Pu}$ activity in prepared samples was determined with solid-state alpha-spectrometers [221]. At the same time, the measurement

time of samples depended on a source activity and required statistical accuracy. The average exposure time was 4 hours.

Determination of ^{90}Sr activity

Yttrium isotopes were separated from those of strontium by precipitating a slightly soluble compound – calcium fluoride (CaF_2). The resulted precipitate was separated from the mother liquor by centrifuging, dissolved while boiling in a weak solution of 0.5 mole/l hydrochloric acid and, in order to purify it from interfering radionuclides and matrix elements, passed through glass columns filled with fluoroplastic cuttings with an extractant spread on it – Di-2-ethyl-hexyl phosphoric acid (D2EHPhA). Yttrium isotopes were eluted with 6 mole/l hydrochloric acid and were extra purified by isolating from the solution of slightly soluble yttrium hydroxide ($\text{Y}(\text{OH})_3$). The resulted yttrium precipitate was separated from the mother liquor and dissolved with a 1M HNO_3 solution. The resulted solution was quantitatively transferred to a scintillation vial, and ^{90}Y activity is measured. Because analytes have radioactive equilibrium between Sr and Y, measured ^{90}Y activity is equal to that of ^{90}Sr .

Thus, ^{90}Sr activity in samples was determined by directly measuring the activity concentration of daughter ^{90}Y in a sample solution as per Cherenkov radiation with a liquid scintillation spectrometer [220]. The measurement time of environmental samples was 2 hours.

Definition of the radiological state of surface and ground waters

Surface water samples were collected from springs and surface water bodies (lakes, creeks). Surface waters were sampled as per general sampling requirements of ST GOST R51593-2003 [221], ST RK GOST R 51592-2003 [222] and ST RK 1545-2006 [223].

Ground water samples were collected from wells and boreholes. Ground waters were sampled as per general sampling requirements of ST GOST R51593-2003 [222], ST RK GOST R 51592-2003 [223] and ST RK ISO 5667-11-2012 [224].

All water samples were collected with a sampler (batometer) that was submerged in the surface water body to a given depth. Samples were collected in 0.02 l and 10 l plastic containers. Once collected, water samples were filtered through a 'blue ribbon' and acidified with nitric acid to pH=2–3. Water samples that were collected to determine the content of ^3H were immediately transported to the laboratory and analyzed without being acidified. Acidified (conserved) water samples could be stored prior to being analyzed for 1 month at longest.

Determination of ^{137}Cs and ^{241}Am activities

Prior to laboratory measurements, water samples were prepared for determination of activities of gamma-emitting ^{137}Cs and ^{241}Am as per procedure requirements [225]. To that end, radionuclides being determined were chemically concentrated from the 10 l water sample with relevant reagents (^{137}Cs was coprecipitated on copper hexacyanoferrate, ^{241}Am – on ferrum hydroxide).

^{137}Cs and ^{241}Am activities in samples of surface and ground waters were determined with solid-state gamma-spectrometers as per the measurement procedure using 'SpectraLine' software [220]. The measurement time varied from 2 to 8 hours depending on the activity of a measured water sample.

Determination of ^{90}Sr and $^{239+240}\text{Pu}$ activities

Samples of surface and ground waters collected at the test site were also prepared for determination of ^{90}Sr and $^{239+240}\text{Pu}$ activities as per procedure requirements [226].

Radionuclides being determined were chemically concentrated from at least the 10 l water sample with relevant reagents ($^{239+240}\text{Pu}$ was coprecipitated on ferrum hydroxide, ^{90}Sr – on calcium carbonate).

^{90}Sr activity in samples of surface and ground waters was determined by daughter ^{90}Y with a liquid-scintillation beta-spectrometer as per the

procedure for measurement of activities of radionuclides [226]. The measurement time of each water sample was 2 hours.

$^{239+240}\text{Pu}$ activity in counting samples was determined with solid-state alpha-spectrometers as per the procedure for determination of activity concentrations of artificial radionuclides in environmental compartments [226]. The measurement time depended on a source activity and required statistical accuracy. The average measurement time of each water sample was 4 hours.

Determination of ^3H activity

Water samples to determine the content of ^3H were prepared using recommendations of the international standard ISO 9698:2019 (E) [9] as per the following procedure:

- distillation of water samples with a rotary evaporator to purify samples from interfering beta-emitting radionuclides and compounds that intervened scintillation measurements;
- mixing a 3 ml water sample (aliquot) purified from impurities with a scintillation cocktail in the 1:3 ratio (sample – scintillator ratio).

The content of ^3H in samples of surface and ground waters was determined with a liquid scintillation beta-spectrometer using the international standard ISO 9698:2019 [227]. At the same time, the exposure time per one sample was 10 hours.

Definition of the radiological state of ambient air

Average annual volumetric activities of radionuclides resulted from nuclear testing were determined in ambient air in two ways: by calculation and determination of a one-time volumetric activity.

Determination of average annual volumetric activities of radionuclides in ambient air by calculation

To determine average annual volumetric activities of radionuclides in ambient air by calculation, point soil samples were collected as per

GOST 17.4.3.01-83 [219]. The sampling area of each point soil sample was 100 cm², and the sampling depth – 5 cm.

Soil sample preparation for determination of the content of radionuclides

Particle-size fractionation

To fractionate soil into particle-size fractions, two techniques were sequentially used: ‘wet’ sieving and sedimentation.

‘Wet’ sieving. A 600 g soil sample was wetted in distilled water and ground in the porcelain mortar with a rubber-tipped pestle. The resulted soil suspension was transferred in portions to the 250, 40 μm sieve column. Sieves were placed in the descending order of meshes from top to bottom. Thus, 1,000-40 μm fractions were separated by ‘wet’ sieving. Next, a fraction that passed through the 40 μm sieve underwent the sedimentation analysis.

Sedimentation analysis. A soil suspension that resulted from sieving was transferred to a 1 l volumetric cylinder (water column was 352 cm high), shaken until fully detached from the bottom and settled as long as required. Once the settling time ran out, a supernatant suspension was decanted, and the precipitate from the bottom was collected to a separate container together with a 1,000-40 μm fraction, dried and weighed. The settling time of the suspension averaged 17 minutes and was adjusted depending on suspension temperature as per the standard procedure [227]. Unsettled particles in the decanted suspension were centrifuged. The centrifuged fraction was transferred to the porcelain cup, dried and weighed.

Determination techniques of activities of ¹³⁷Cs, ²⁴¹Am, ¹³⁷Cs and ²⁴¹Am were applied exactly as described in the subsection ‘Determination of the radiological state of soil cover’ (ANNEX 2) as per procedures [220, 221].

Determination of one-time volumetric activities of radionuclides in ambient air

Air aerosols were sampled in accordance with GOST 17.2.3.01-86 [11] at a height of 1.5 m above the ground. At the same time, the

air sampling place was chosen at the open firm ground site with free air access on all sides in order to prevent measurement distortion due to vegetation. To determine the contamination level of ambient air with radioactive aerosols, samples were collected using the aspiration technique with a filtration and ventilation unit through the fine fibrous Petryanov filter in accordance with ST RK STB 1058-2006 [229]. The filtration and ventilation unit ensured 1,500 m³/h. The average volume of air pumped through the filter was 3,700 m³ (3.7×10^6 l).

Determination of ¹³⁷Cs and ²⁴¹Am activities

An air aerosol sample was ashed in the muffle furnace for 6 hours at 390 °C.

Thereafter, the ashed air sample was weighed, placed in the 5 ml plastic container and sent to gamma-spectrometric measurements.

¹³⁷Cs and ²⁴¹Am activities in samples were determined with solid-state gamma-spectrometers as per the procedure [230]. The exposure time of air samples was 4 hours and longer depending on the activity of a measured sample.

Determination of ⁹⁰Sr and ²³⁹⁺²⁴⁰Pu activities

Prior to the radiochemical analysis to determine ²³⁹⁺²⁴⁰Pu and ⁹⁰Sr activities, air aerosol samples were preconditioned. Each sample was additionally ashed in the muffle furnace for 5-6 hours at 550 °C, whereupon the sample in the form of ash was weighed, thoroughly mixed and divided into two equal parts, of which one was sent to the radiochemical isolation of ²³⁹⁺²⁴⁰Pu, the other one – to the radiochemical isolation of ⁹⁰Sr.

Determination of ⁹⁰Sr activity

A stable strontium solution was spiked into the ash subsample, whereupon the sample was treated, when heated, with a 6M HCl solution with a small amount of H₂O₂ added to extract strontium isotopes to the solution.

Strontium isotopes were radiochemically purified and isolated from the acid leached solution by sequentially precipitating collectors (ferrum hydroxide and strontium carbonate). A fraction containing isolated strontium isotopes was settled for two weeks to accumulate daughter – ^{90}Y . Following radioactive equilibrium, yttrium was separated from the parent radionuclide by precipitating in the form of $\text{Y}(\text{OH})_3$ hydroxide, transferred to a 1M muriatic solution and then to a polyethylene vial to measure ^{90}Y activity with a liquid-scintillation spectrometer.

The measurement time of each air aerosol sample was 2 hours.

Determination of $^{239+240}\text{Pu}$ activity

^{242}Pu isotopic tracer was spiked into a prepared subsample of the ash sample. The subsample was then treated, when heated, with concentrated solutions of hydrofluoric and nitric acids and their mixtures until soil matrix was fully dissolved and plutonium isotopes were solubilized.

Plutonium isotopes were stabilized in a IV-valent state and passed through ion-exchangeable columns filled with a strong-base anionite to remove macro- and microelements, impurities of other alpha-emitting radionuclides. Next, plutonium isotopes were isolated from the resulted acid solution onto stainless steel disks with an electrolysis unit and sent to alpha-spectrometric measurements.

$^{239+240}\text{Pu}$ activity in counting samples was determined with solid-state alpha-spectrometers similar to the procedure for determination of activity concentrations of artificial radionuclides in environmental compartments [221].

The measurement time depended on the source activity and the required statistical accuracy. The average exposure time was 4 hours.

Definition of the radiological state of flora

Plant samples were mixed samples or individual plant species that form the basis of animals' forage diet in the STS territory.

Plants were sampled from a 2-4 m² area depending on the growth density and productivity of plants. The weight of each sampled plant was at least 300 grams. Aboveground parts of herbaceous plants were cut off up to 3 cm above soil, tall grasses – up to 6 cm, and the current annual increment of semishrubs was cut off too.

Determination of ¹³⁷Cs and ²⁴¹Am activities

Plant sample preparation for analyses to determine activities of radionuclides consisted of the following stages:

- washing plant samples in running water to remove external dirt;
- baking plant samples at 100±2 °C for 3-5 hours until completely baked;
- charring plant samples by calcination on the electrolyte at the initial temperature of 150–250 °C under the vent hood or in the muffle furnace at 400 °C while occasionally stirring until white or light grey ash was produced;
- powdering the ashed sample and putting it in the plastic container;
- sending the plastic container with an averaged subsample to the gamma-spectrometric analysis.

¹³⁷Cs and ²⁴¹Am activities in samples were determined with solid-state gamma-spectrometers as per the procedure [231]. The measurement time of plant samples was 4 hours and longer depending on the activity of a measured sample.

Determination of ²³⁹⁺²⁴⁰Pu and ⁹⁰Sr activities

²³⁹⁺²⁴⁰Pu and ⁹⁰Sr activities in samples were determined as per the measurement procedure for activities of radionuclides [221].

Preconditioning of plant samples to determine ²³⁹⁺²⁴⁰Pu and ⁹⁰Sr activities consisted of the following stages:

- subsampling plants by squaring from the sample that was measured by gamma-spectrometry followed by being placed in the laboratory porcelain cup;

- calcining the subsample in the porcelain cup for a long time (from 32 to 96 h and longer) in the muffle furnace at 550 °C to remove organic matter;
- sieving the ashed plant sample to remove impurities (coal, sand) and determine the ashing coefficient of a sample;
- subsampling ash of the required mass to the glass container to be sent to radiochemical isolation of $^{239+240}\text{Pu}$ and ^{90}Sr .

^{90}Sr activity in samples that were radiochemically analyzed was determined with a liquid scintillation beta-spectrometer with the 2-hour measurement time.

$^{239+240}\text{Pu}$ activity in counting samples prepared after the radiochemical analysis was determined with solid-state alpha-spectrometers. The measurement time varied with the plant sample activity and averaged 4 hours.

The work on determination of the radiological state of fauna

Activities of ^{137}Cs and ^{90}Sr under study were determined in two ways: by experiment and calculation.

Experimental determination of activity concentrations of ^{137}Cs and ^{90}Sr in animals' muscular tissues (meat)

Animals' muscular tissues (meat) were sampled in accordance with general sampling requirements of ST RK 1510-2006 [231].

Determination of ^{137}Cs and ^{90}Sr activities

Activities of $^{239+240}\text{Pu}$ and ^{90}Sr in samples were determined as per the measurement procedure for activities of radionuclides

Determination of ^{137}Cs activity

Meat sample preparation consisted of the following steps:

- formation of the combined sample of muscular tissue weighing at least 1,000 g of point one-piece samples weighing at least 200 g;

- mincing the combined meat sample (with previously removed fat and tendon inclusions) through a 4 mm mesh and thorough mixing of the resulted mass;

- baking the minced sample at 105 ± 2 °C for 24–40 hours (depending on sample moisture and its mass) until fully baked;

- milling a baked sample to homogeneity;

- charring the minced baked sample in the porcelain cup by calcining at 400 °C;

- pestling the cooled charred sample in the porcelain cup to homogeneity followed by putting it in the preweighed plastic container and sending it to the gamma-spectrometric analysis.

^{137}Cs activity in samples was determined with solid-state gamma-spectrometers as per the procedure [231]. The exposure time of meat samples averaged 4 hours and longer depending on the activity of a measured sample.

Determination of ^{90}Sr activity

Samples of animal origin were prepared for the radiochemical analysis to determine ^{90}Sr as per the measurement procedure [232].

Preconditioning of samples of animal origin to determine ^{90}Sr activity consisted of the following stages:

- subsampling by squaring from the charred sample measured by gamma-spectrometry followed by being placed in the laboratory porcelain cup;

- calcining the subsample in the porcelain cup for a long time (from 32 to 96 h and longer) in the muffle furnace at 550 °C to remove organic matter;

- sieving the ashed sample through a 0.1 mm mesh to remove impurities (coal, sand) determination of the ashing coefficient of a sample;

- subsampling ash of the required mass to the glass vessel to be sent to radiochemical isolation of ^{90}Sr .

^{90}Sr activity in samples was determined by daughter ^{90}Y with scintillation beta-scintillation spectrometers as per the measurement procedure for activities of radionuclides [221].

The exposure time per each sample was 2 hours.

Determination of ^{137}Cs and ^{90}Sr activity concentrations in muscular tissues (meat) of animals by calculation

To determine ^{137}Cs and ^{90}Sr activity concentrations in muscular tissues of animals by calculation, hoofed animals' faeces sampled from the STS territory were used.

Faeces were sampled in accordance with GOST 27262-87 [233].

Samples of animals' faeces to determine the content of radionuclides were prepared as follows:

- a faeces sample was air dried at 100 ± 2 °C for 3–5 hours until fully dried;
- a dried sample was placed in the porcelain cup followed by charring at 350–400 °C;
- a cooled charred sample was pestled or milled to homogeneity.

Determination of ^{137}Cs and ^{241}Am activities

The subsample of sufficient mass was collected from the charred faeces sample, placed in the preweighed plastic container to be sent to the gamma-spectrometric measurement.

^{137}Cs and ^{241}Am activities in samples were determined with solid-state gamma-spectrometers as per the procedure [230].

The exposure time of samples averaged 4 hours depending on the activity of a measured sample.

Determination of ^{90}Sr activity

Faeces samples to determine the content of ^{90}Sr are prepared as per the procedure [221].

Preconditioning of samples of animal origin to determine ^{90}Sr activity consisted of the following stages:

- subsampling plants by squaring from the sample that was measured by gamma-spectrometry followed by being placed in the laboratory porcelain cup;

- calcining the subsample in the porcelain cup in the muffle furnace for a long time (from 32 to 96 h and longer) at 550 °C to remove organic matter;

- sieving the ashed plant sample to remove impurities (coal, sand) and determine the sample ashing coefficient;

- subsampling ash of the required mass to the glass vessel to be sent to the radiochemical isolation of ^{90}Sr .

^{90}Sr activity in faeces samples that underwent the radiochemical analysis was determined with a liquid scintillation beta-spectrometer with the 2-hour measurement time.

Quality control of laboratory analysis results

The quality control system of analytical results developed in Institute's laboratories is in place and operating. Its integral part is to calibrate measurement facilities, certify test equipment, carry out preventive maintenance of the main and auxiliary equipment, update procedures and utilize certified procedures.

According to the operating procedure, each work stage of a sample is controlled – from being accepted by the Institute's laboratory building to the obtainment of measurement results. Following all the procedures ensured sample separation by activity and prevention of cross-contamination during the work.

The Institute also exercised a prompt quality control of findings. It was based upon reference measurements that were separately performed for each blank sample collected (reproducibility control) or upon a repeated analysis of a work sample (repeatability control). For

example, repeatability control of measurements was exercised for the same series of work samples – for each 10th sample. IAEA's reference standards representing environmental compartments were analyzed to check reproducibility of results according to the work plan. Besides, a so-called 'blank' sample is used in each batch to control purity and cross-contamination of samples. This sample is an uncontaminated environmental compartment.

Controlled reproducibility and analytical accuracy of results for reference standards are listed in the table (Table 1.2).

Table 0.4. Reproducibility and accuracy control results

Analysis type	Gamma-spectrometric analysis	Radiochemical determination of ⁹⁰ Sr	Radiochemical determination of ²³⁹⁺²⁴⁰ Pu
Mean deviation, %	16	14	7

In 2019, interlaboratory comparison tests were conducted involving a certified center 'Center for Comprehensive Ecological Research' RSE 'Institute of Nuclear Physics' and a certified test center 'EcoExpert' Ltd. These tests were conducted in accordance with ST RK ISO/IEC 43-1-2003 requirements. 3 highly homogenized dry samples were used as reference samples to determine artificial radionuclides ²⁴¹Am, ¹⁵²Eu, ⁶⁰Co, ⁹⁰Sr in soils and subsoils. Results of the interlaboratory comparison showed that the deviation of results for ²⁴¹Am did not exceed 5 %, for ¹⁵²Eu – 8 %, for ⁶⁰Co – 2 %, for ⁹⁰Sr – 9 %. Findings correspond to the reproducibility standard calculated from results of interlaboratory comparison tests. In calculations, a permissible discrepancy of results (standard deviation), being equal to 20 %, was taken into account for indicators being determined as per the procedure in use.

In 2020, the Institute participated in interlaboratory comparison tests provided by 'TC Agrostandart-XXIcentury' Ltd. Results proved to be within normal limits, i.e. 'good'.

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Monograph
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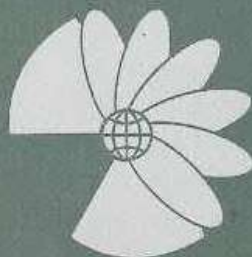
COMPREHENSIVE RADIOECOLOGICAL SURVEY OF THE SEMIPALATINSK TEST SITE

2021

This monograph provides outcomes of the comprehensive radioecological survey of the territory of the former Semipalatinsk Test Site. The survey was conducted by specialists of the National Nuclear Center of the Republic of Kazakhstan between 2008 and 2021. Outputs enabled to determine the current radiological situation in the territory, identify areas posing hazard to man and the environment and the ones to be potentially released to the economic turnover. The book is intended for specialists engaged in radioecology, radiation safety, environmental protection as well as for a wide audience interested in topical issues of the ecological state at the former Semipalatinsk Test Site.



*dedicated to 30th
anniversary of
Semipalatinsk
Test Site shut-down*



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