RADIOLOGICAL ASSESSMENT REPORTS SERIES

RADIOLOGICAL CONDITIONS AT THE SEMIPALATINSK TEST SITE, KAZAKHSTAN:

Preliminary assessment and recommendations for further study

INTERNATIONAL ATOMIC ENERGY AGENCY

The cover photograph shows ‘Ground Zero’, location of the first atmospheric nuclear explosion in 1949 at the Semipalatinsk test site.

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AND RECOMMENDATIONS FOR FURTHER STUDY

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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FOREWORD

There are various locations around the world that have been affected by radioactive residues. Some of these residues are the result of past peaceful activities, while others result from military activities, including residues from the testing of nuclear weapons. Stimulated by concern about the state of the environment, the movement away from military nuclear activities and improved opportunities for international co-operation, attention in many countries has turned to assessing and, where necessary, remediating areas affected by radioactive residues.

Some of these residues are located in countries where there is a lack of the infrastructure and expertise necessary for evaluating the significance of the radiation risks posed by the residues, and for making decisions on remediation. In such cases, governments have felt it necessary to obtain outside help. In other cases, it has been considered to be socially and politically necessary to have independent expert opinions on the radiological situation caused by the residues. As a result, the IAEA has been requested by the governments of a number of Member States to provide assistance in relation to its statutory obligation “to establish ... standards of safety for protection of health ... and to provide for the application of these standards ... at the request of a State”.

On 22 September 1995, a resolution of the General Conference of the IAEA called on all States concerned “to fulfil their responsibilities to ensure that the sites where nuclear tests have been conducted are monitored scrupulously and to take appropriate steps to avoid adverse impacts on health, safety and the environment of such nuclear testing”.

Representatives of the Kazakhstan Government informed the IAEA of their concern about the radiological situation in Semipalatinsk and western Kazakhstan during the ‘Forum on Strengthening Radiation and Nuclear Safety Infrastructures in Countries of the Former USSR’ that took place in Vienna in May 1993 under the auspices of the IAEA and the United Nations Development Programme. Subsequently, at the request of the Government of Kazakhstan, the IAEA undertook to carry out a study of the radiological situation at the Semipalatinsk test site. The findings are summarized in this report, which is issued in the Radiological Assessment Reports Series.

CONTENTS

1. SUMMARY

1.1. PREAMBLE

This report presents the findings of a study of the current radiological conditions at the former nuclear test site at Semipalatinsk, Kazakhstan, conducted by a team of international experts under the auspices of the IAEA. The study was initiated in response to a request of the Government of Kazakhstan for technical assistance from the IAEA. The objectives of this study were to assess the current and potential future radiation doses to the residents of the Semipalatinsk nuclear test site area and adjacent settlements, to advise on remedial action, where appropriate, and to recommend whether further radiological evaluation of the area is warranted.

The Semipalatinsk test site is situated in the north-east of Kazakhstan, 800 km north of the capital Almaty. It covers an area of approximately 19 000 km^2. Between 30 000 and 40 000 people are estimated to live outside of, but close to, the nuclear test site. A small number of people also live in settlements within the site itself.

Between 1949 and 1989, the former USSR conducted approximately 456 nuclear explosions at Semipalatinsk. Until 1963, the explosions were mainly carried out on the surface and in the atmosphere. Five of the surface tests were unsuccessful. After the signing of the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water in 1963, testing was conducted underground. The last nuclear explosion at the site was in 1989. During the 40 year period of testing, the total energy released from the explosions was equivalent to 17.4 Mt of TNT equivalent.

The IAEA has a statutory responsibility to establish standards for protection against radiation exposure and also to provide for the application of the standards upon the request of a Member State. While the IAEA standards are established for the peaceful uses of nuclear energy, their basic protection criteria can also be applied in principle to the particular radiological situation at the Semipalatinsk site.

In November 1993 and July 1994, the IAEA led missions to the Semipalatinsk test site to assess the current radiological conditions. The teams made field measurements, took samples and reviewed radiological surveys of the area carried out by organizations from Kazakhstan and the former USSR. The experts also gathered information from the local inhabitants about diet and customs relevant to dose assessment. The study focused upon key locations in and around the test site selected because they are population centres or because of identified residual activity levels.

The assessment is preliminary in nature. It does not constitute a comprehensive radiological survey of the site, which covers a very large surface area, but rather identifies the topics on which further study is needed in order to develop a full understanding of the radiological situation at the site. The study is concerned with the assessment of current radiological conditions for people living within and in the immediate vicinity of the test site. It does not address the assessment of radiation doses which may have been received in the past by populations living in the region from nuclear testing, or any effects on these populations from such doses.

1.2. CONCLUSIONS AND RECOMMENDATIONS

1.2.1. Radiological situation inside the nuclear test site

There is sufficient evidence to conclude that over most of the test site there is little or no residual radioactivity. However, both the Ground Zero and Lake Balapan areas are exceptions to this and are heavily contaminated. A radiological survey of Ground Zero conducted during the IAEA missions confirmed that the contamination in this area is relatively localized. It is recommended that a similar survey be conducted to define the distribution of residual radioactivity around Lake Balapan. More details regarding the tests undertaken are required to identify other potentially affected areas.

The missions could not corroborate the reported evidence of contamination by actinide residues from failed nuclear tests, and more information on the nature of the failed tests, the prevailing conditions and any supporting data would be needed before further investigations of this aspect could be considered.

Access to the Semipalatinsk test site is currently unrestricted, and limited reoccupation of the site has begun. It is estimated that persons making daily visits to Ground Zero or Lake Balapan would receive annual exposures in the region of 10 mSv, predominantly due to external exposure. If permanent inhabitation of Ground Zero or Lake Balapan were to occur in the future, annual exposures are conservatively estimated to be of the order of 100 mSv/a. This annual dose is above the action level at which intervention is expected to be undertaken under any circumstances and remedial action is considered necessary for the immediate areas around Ground Zero and Lake Balapan. The most appropriate remedial action at this time is to restrict access to the Ground Zero and Lake Balapan areas.

1.2.2. Radiological situation outside the nuclear test site

The measurements made around the test site during the IAEA missions were reasonably consistent with surveys of the area conducted by organizations from Kazakhstan and the former USSR. Hence, it is considered that the available data are sufficient to make a preliminary assessment of the radiological conditions outside the Semipalatinsk test site. The exception to this conclusion relates to the supply of drinking water. Since the IAEA missions did not analyse the entire drinking water supply, and could not assess the future security of the supply, it is recommended that a hydrological study be conducted to investigate the future possibility of radionuclides from the underground tests appearing in local drinking water sources. Depending on the results of this study, a monitoring programme for drinking water may be appropriate.

In most areas, external radiation dose rates and soil activity are the same, or close to, typical levels in other regions and countries where no nuclear weapons testing has been carried out. The estimated annual effective dose to persons outside the nuclear test site from residual radioactivity is at most 0.1 mSv (giving a total effective dose of 2.5 mSv/a when exposure to natural sources of radiation is included). Actual exposures are more likely to be of the order of a few microsieverts per year, a dose rate which is very close to the global average from fallout. On the basis of this evidence, intervention to reduce the radiation exposure of persons outside the Semipalatinsk test site is not considered to be justified.

2. THE SEMIPALATINSK TEST SITE

The Republic of Kazakhstan is located immediately to the south of the Russian Federation and west of China. It encompasses over 2.8 million km^2 of land area and has a population of over 19 million. Following World War II, the steppes of Kazakhstan became the first centre for nuclear weapons testing within the USSR (later, other test sites were also used, notably Novaya Zemlja). The Semipalatinsk test site, known as the ‘polygon’, is a 19 000 km^2 zone in the northeast of the country, 800 km north of the capital Almaty (Fig. 1). The zone lies southwest of the Irtysh River, which flows into Kazakhstan from China and which, for a short distance, forms part of the nuclear test site boundary (see Fig. 2).

Between 1949 and 1962, nuclear tests were carried out mainly in the atmosphere. Subsequently, after the signing of the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water (1963), only underground tests were conducted at Semipalatinsk. Nuclear testing at the site ceased in 1989. A total of 456 nuclear tests were conducted at the site, with the total energy released being 17.4 Mt of TNT equivalent. It is known that the site was used for other activities associated with, or in addition to, the testing of nuclear devices, for example the use of nuclear devices in mining operations and civil engineering. These activities are not, however, considered in this report.

The only on-site inhabitants during the testing programme were in the town of Kurchatov, purpose built to service the site, and the small settlements of Akzhar and Moldari along the northern edge of the site. Recently, there has been a limited amount of resettlement within the area, mostly by semi-nomadic farmers and herders. The bulk of the local population lives in settlements just outside the site border. The total population of these settlements is estimated to be 30 000–40 000.

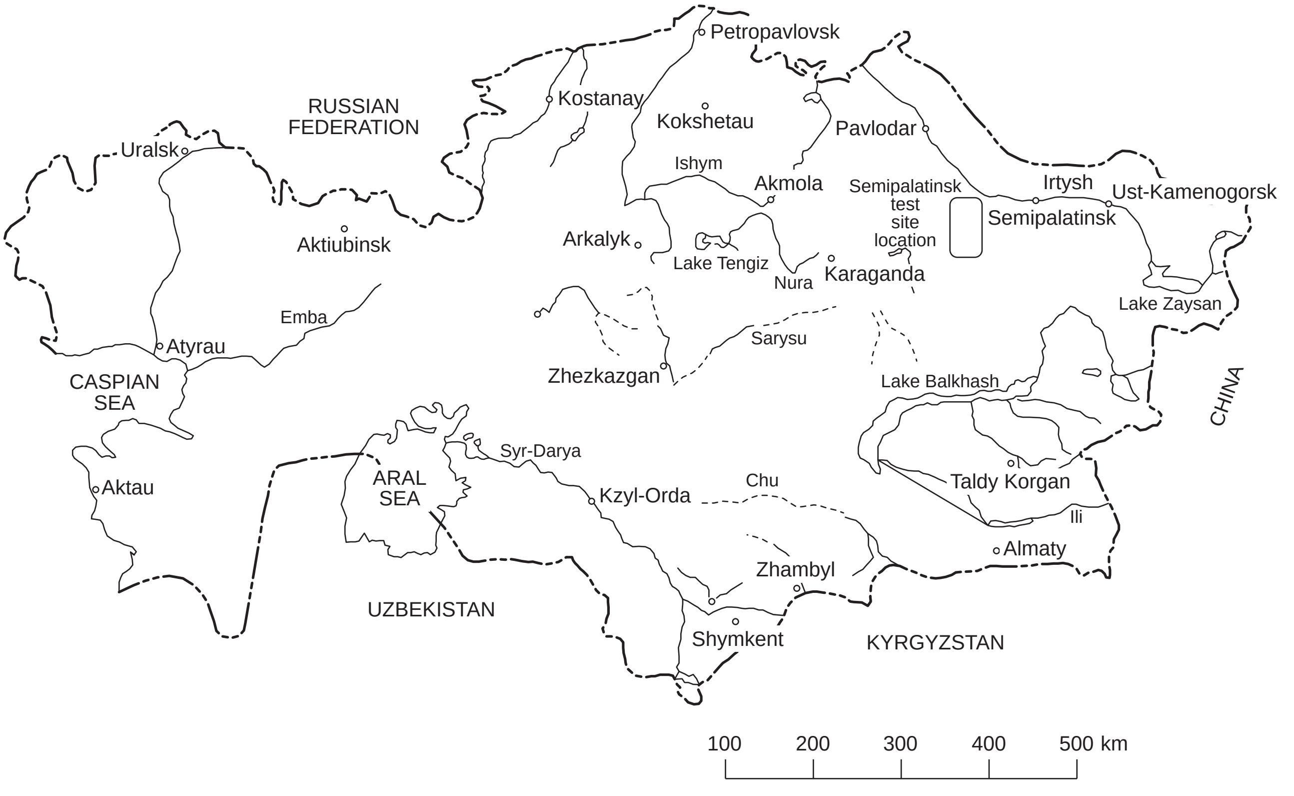

FIG. 1. Kazakhstan.

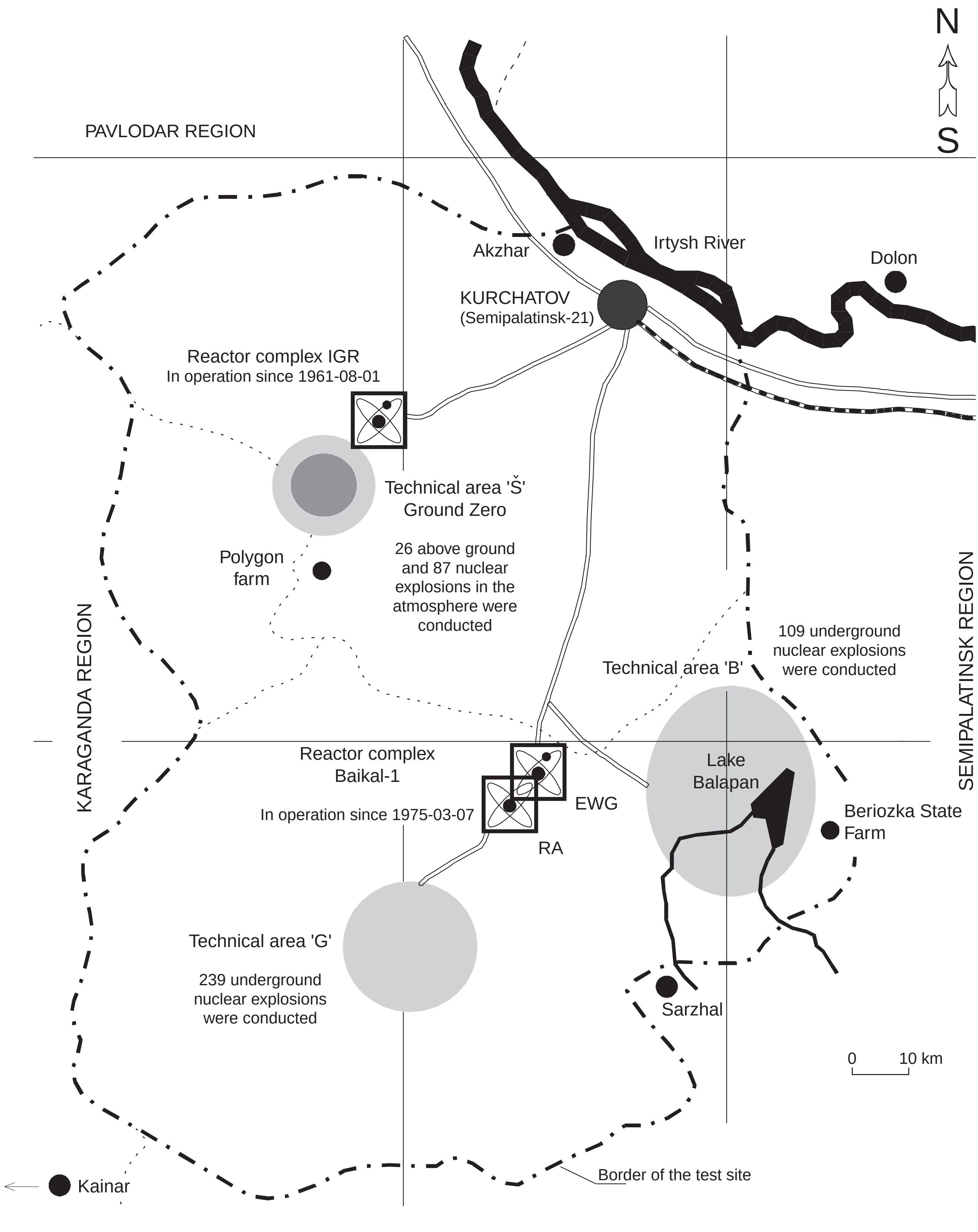

FIG. 2. Layout of the Semipalatinsk test site.

3. BACKGROUND

3.1. NUCLEAR WEAPONS TESTS

This section provides a summary of the tests carried out from 1949 to 1989 at the Semipalatinsk test site.

The USSR conducted about 456[1] nuclear tests at three locations, called ‘technical areas’, within the nuclear test site over a period of 40 years for military and peaceful purposes. The earliest tests were above ground (atmospheric and surface) and were carried out in the northern technical area Š. The centre of the first (surface) explosion is historically referred to as ‘Ground Zero’. There were 116 explosions between 29 August 1949 and 25 December 1962 [1], including 30 that were carried out on the surface. Five of these surface tests were not successful and resulted in the dispersion of plutonium in the environment.

The other 340 test explosions were conducted underground, in the widely separated technical areas in the south (between 1961 and 1989) and east (from 1968 to 1989). This total includes four cratering nuclear explosions at Chagan, Sary-Uzen, Tel’kem and Tel’kem-2, where the explosive charge was placed at a shallow depth below ground. Chagan was the first and largest of these tests and resulted in a lake about 0.5 km in diameter and about 100 m deep with cliffs up to 100 m high, called Lake Balapan or the ‘Atomic Lake’ (Fig. 3). A much smaller lake was also formed by the Tel’kem-2 test (Fig. 4). Of the tests carried out deep underground, 13 resulted in the release of radioactive gases to the atmosphere [2].

In this assessment, the emphasis is on the residual radioactivity from the nuclear testing. As such, the main

[1] The number differs depending on the source of information and the definition of ‘nuclear test’, ranging from 456 to 470. The data given in this report are taken from Ref. [1].

FIG. 3. Lake Balapan, which was created by the first cratering nuclear explosion. The lake is about 0.5 km in diameter and about 100 m deep, with cliffs up to 100 m high. The photograph was taken during the IAEA mission in November 1993.

FIG. 4. Lake Tel’kem-2, which resulted from the fourth and last cratering nuclear explosion. The test was carried out using three nuclear devices, each the equivalent of 240 t of TNT [1]. The photograph was taken during the IAEA mission in July 1994.

TABLE I. SUMMARY DATA FOR THE TESTS AT THE SEMIPALATINSK TEST SITE

Technical site and geographical location	Duration of testing		Predominant geology in test zone	Number of tests
Technical area Š Ground Zero N 50° 26′ E 77° 50′	First nuclear test Last	1949-08-29 1962-12-24	Sandstone	Surface: 26 Air: 87
Technical area G[a] Degelen Mountain N 49° 46′ E 77° 59′	First underground test Last	1961-10-11 1989-10-04	Granite, quartz–porphyry, syenite rock mountain massif	In mine galleries: 215
Technical area G[a] Degelen Mountain N 49° 59′ E 77° 38′	First underground test Last	1965-10-14 1980-04-04	Alevrolite, porphyry, sandstone	In boreholes: 24 (including one as part of the programme on peaceful nuclear explosions in borehole Sary-Uzen)
Technical area B Balapan N 49°43′ E 78° 29′	First underground test Last	1968-10-21 1968-11-12	Argyllite	In boreholes: 2 (excavation explosions as part of the programme on peaceful nuclear explosions in boreholes Tel’kem and Tel’kem-2)
Technical area B Balapan N 49° 56′ E 78° 29′	First underground test Last	1965-01-15 1989-10-19	Alevrolite, sandstone, Conglomerate	In boreholes: 107 (including the peaceful nuclear explosion which produced Lake Balapan)
	Total: 456 nuclear tests, of which 116 were above ground, 4 were excavation tests and 336 were underground explosions			

[a] Not visited by the IAEA teams.

FIG. 5. Beriozka State Farm, about 10 km from Lake Balapan at the Semipalatinsk test site. The photograph was taken during the IAEA mission in November 1993.

tests of interest are those that resulted in local fallout. These are surface tests, excavation experiments and underground tests from which radioactive materials inadvertently vented to the atmosphere. A summary of the nuclear tests undertaken at Semipalatinsk is presented in Table I.

3.2. LOCAL INHABITANTS INSIDE AND OUTSIDE THE TEST SITE

The only settlements within the nuclear test site during the 40 year test period were the town of Kurchatov (code named Semipalatinsk-21) north of technical area Š, built for servicing the test site, and the small settlements of Akzhar and Moldari along the northern edge. Recently, semi-nomadic farmers and herders have formed small scattered 'settlements' within the test site, notably a small farm about 10 km south of Ground Zero (about 15 persons — see Fig. 5), and the Beriozka State Farm about 10 km east of Lake Balapan (about 10 persons). There is some evidence that animals have been grazed in both the Ground Zero and Lake Balapan areas. It is not known if there are any settlements close to the other cratering test sites of Sary-Uzen, Tel'kem and Tel'kem-2. The latter was briefly visited by IAEA experts and there was clear evidence of animals grazing and drinking from the small lake that has formed.

The main local settlements are outside but close to the test site boundary. Some settlements along the southern and eastern borders lie within the estimated trajectory of the radioactive releases from the largest above ground explosions. A population of 30 000–40 000 is estimated to live in this area. The following settlements (see also Fig. 2) are the closest to the test site:

Northeast:
Akzhar (population about 1000),
Dolok (population about 30),
Dolon (population about 2000),
Moldari (population about 500),
Kurchatov (population about 11 000).

Southeast:
Sarzhal (population about 2000).

Southwest:
Kainar (population about 3000).

3.3. REQUEST FOR ASSISTANCE

Representatives of the Kazakhstan Government informed the IAEA of their concern about the radiological situation in Semipalatinsk and western

Kazakhstan during the Forum on Strengthening Radiation and Nuclear Safety Infrastructures in Countries of the Former USSR that took place in Vienna in May 1993 under the auspices of the IAEA and the United Nations Development Programme (UNDP). Subsequently, the Government of Kazakhstan requested the IAEA to provide assistance regarding the former test areas of Semipalatinsk and western Kazakhstan. The IAEA undertook to carry out a study of the radiological situation in the aforementioned areas. This commitment resulted in a series of activities to characterize and evaluate the radiological situation at the Semipalatinsk test site. The IAEA so far has not organized missions to the test areas in western Kazakhstan. The findings are summarized in this report and a chronology of relevant events follows.

4. PROGRAMME OF IAEA ASSISTANCE

4.1. FIRST MISSION

In November 1993, the IAEA initiated the first mission with the following objectives:

(a) To undertake the necessary reconnaissance for an assessment of the radiological situation at the Semipalatinsk test site and as guidance for future actions within the framework of the IAEA–UNDP initiative;

(b) To assist in strengthening the national infrastructure in the area of radiation protection, with emphasis on environmental monitoring.

Working towards these objectives, the team:

— Identified the most likely areas of radioactive contamination at the Semipalatinsk test site and off-site, based on the information provided by local government representatives;

— Performed radiation measurements and collected environmental samples at identified sites;

— Visited government laboratories to determine their capabilities for future co-operative efforts and to locate existing radiological assessment data.

Subsequently, at a meeting on 9 March 1994 at IAEA Headquarters in Vienna attended by a delegation from Kazakhstan, one of the five priority areas discussed was the concerns about Semipalatinsk for which the Kazakhstan authorities had requested assistance from the IAEA. In response to these concerns, the IAEA agreed to establish, through its technical co-operation programme, a reserve fund project to assist Kazakhstan in the radiological assessment of the Semipalatinsk test site.

4.2. SECOND MISSION

Following this development, the IAEA initiated the second mission. The terms of reference for this mission were:

(a) To take field measurements and samples in and around the test site;

(b) To collect and review information from Russian and Kazakh sources relevant to the current radiological situation at the test site;

(c) On the basis of (a) and (b), to undertake an assessment of the current and potential future doses to the residents in the Semipalatinsk area, and to determine whether further radiological evaluation and assessment were warranted.

The following measurements were made at key locations in and around the test site:

— The absorbed gamma dose rates in air at 1 m above ground were measured with an integrating pressurized ionization chamber and integrating compensated Geiger–Müller (GM) detectors. Where dose rates exceeded 1 μGy/h, measurements were made instead with a scintillation detector and GM detector survey meters.

— In situ gamma spectrometry (50–4000 keV) was undertaken with a high purity germanium detector at a reference height of 1 m above the ground. Gamma spectra were analysed to determine the deposition density of natural and artificial radionuclides and the contribution of these radionuclides to the total absorbed dose rate in air.

— Soil samples were taken at depths of 0–5, 5–10 and 10–15 cm for subsequent analysis by gamma spectrometry.

— Grass and vegetation samples were taken for analysis by gamma spectrometry and radiochemical analysis for ^{90}Sr, ^{238}Pu and $^{239+240}$Pu.

— Milk samples were taken for gamma spectrometry and radiochemical analysis for ^{90}Sr.

Experts from the team spoke to inhabitants in all the farms and settlements visited for the purpose of gaining information on the local diet and customs relevant to the dose assessment.

5. PERSPECTIVE ON GLOBAL NUCLEAR WEAPONS TESTING

This section provides a perspective on the atmospheric weapons testing at Semipalatinsk by summarizing the global deposition and subsequent radiation exposures that resulted from the era of nuclear weapons testing in the atmosphere.

5.1. RELEASES OF RADIOACTIVE MATERIAL TO THE ENVIRONMENT

Nuclear explosions in the atmosphere were carried out at several sites, mostly located in the northern hemisphere, between 1945 and 1980. The periods of most active testing were 1952–1958 and 1961–1962. In all, 520 tests were carried out, with a total fission and fusion yield of 545 Mt. The number and yield of worldwide atmospheric nuclear explosions have been estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and are summarized in Table II [3], together with data for tests undertaken at the Semipalatinsk test site [1].

Since the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water was signed in Moscow on 5 August 1963, almost all nuclear test explosions have been conducted underground. Some gaseous fission products were unintentionally vented during a few underground tests, but the available data are insufficient to allow an assessment of the radiological impact. The total explosive yield of the underground tests is estimated to have been 90 Mt, much smaller than that of the earlier atmospheric tests. Although most of the underground debris remains contained, it is a potential source of human exposure. The earlier atmospheric tests remain the principal source of worldwide exposure from nuclear weapons testing.

Table III [4] shows UNSCEAR's estimates of the activity of radionuclides produced and globally dispersed in atmospheric nuclear testing. Limited data on testing at the Semipalatinsk test site indicate that the contribution from this site to the total worldwide release to the atmosphere from nuclear testing is about 0.6%. This figure is based on data reported in Ref. [4] for ^{90}Sr and ^{137}Cs contributions to the atmosphere from testing at Semipalatinsk. The remaining radionuclide contributions are estimated on the basis of this ratio.

The radioactive debris from an atmospheric nuclear test is partitioned between the local ground or water surface and tropospheric and stratospheric regions, depending on the type of test, location and yield. The subsequent precipitation or falling out of the debris is termed *local fallout*, *tropospheric fallout* or *stratospheric fallout*.

Local fallout can comprise as much as 50% of the production for surface tests and includes radioactivity in large aerosol particles, which are deposited within about 100 km of the test site. Some areas at the Semipalatinsk

TABLE II. NUMBER AND YIELD OF ATMOSPHERIC NUCLEAR EXPLOSIONS FOR WEAPONS TESTING[a]: WORLDWIDE AND IN SEMIPALATINSK [1, 3]

Year	Worldwide [3]		Semipalatinsk [1]	
	Number	Estimated yield (Mt)	Number	Estimated yield (Mt)
1945–1951	26	0.8	1	0.04
1952–1954	31	60	10	0.1
1955–1956	44	31	7	3.4
1957–1958	128	81	19	1.7
1959–1960	3	0.1	0	0.0
1961–1962	128	340	46	1.2
1963	0	0.0		
1964–1969	22	12.2		
1970–1974	34	12.2		
1975	0	0.0		
1976–1980	7	4.8		

[a] No atmospheric weapons tests have been recorded after 1980.

TABLE III. ACTIVITY OF RADIONUCLIDES PRODUCED, RELEASED TO THE ATMOSPHERE AND GLOBALLY DISPERSED IN ATMOSPHERIC NUCLEAR EXPLOSIONS

Radionuclide	Half-life	Estimated activity (excluding local fallout)			
		Normalized release (PBq/Mt)		Total activity (EBq)	
		Fission	Fusion	From worldwide testing	From testing at Semipalatinsk
^{3}H	12.32 a	0.026	740	240	1.44
^{14}C[a]	5730 a	—	0.67	0.22	0.0013
^{54}Mn	312.5 d	—	15.9	5.2	0.031
^{55}Fe	2.74 a	—	6.1	2	0.012
^{89}Sr	50.55 d	590	—	91.4	0.55
^{90}Sr	28.6 a	3.90	—	0.604	0.0035[b]
^{91}Y	58.51d	748	—	116	0.70
^{95}Zr	64.03 d	922	—	143	0.86
^{103}Ru	39.25 d	1540	—	238	1.43
^{106}Ru	371.6 d	76.4	—	11.8	0.071
^{125}Sb	2.73 a	3.38	—	0.524	0.003
^{131}I	8.02 d	4200	—	651	3.9
^{137}Cs	30.14 a	5.89	—	0.912	0.0066[b]
^{140}Ba	12.75 d	4730	—	732	4.4
^{141}Ce	32.50 d	1640	—	254	1.52
^{144}Ce	284.9 d	191	—	29.6	0.18
^{239}Pu	24 100 a	—	—	0.006 52	<0.0001
^{240}Pu	6560 a	—	—	0.004 35	<0.0001
^{241}Pu	14.4 a	—	—	0.142	0.001

[a] For simplicity it is assumed that all ^{14}C is due to fusion.

[b] From Ref. [4].

test site were severely contaminated by local radioactive fallout, and concentrations of ^{137}Cs and ^{90}Sr remain relatively high, together with lesser amounts of $^{239+240}Pu$ and ^{241}Am.

Tropospheric fallout consists of smaller aerosols which are not carried across the tropopause after the explosion and which deposit with a mean residence time of up to 1 year. During this period the debris becomes dispersed, although not well mixed, in the latitude band of injection, following trajectories governed by wind patterns. From the viewpoint of human exposures, tropospheric fallout is important for nuclides with a half-life of a few days to two months, such as ^{131}I, ^{140}Ba or ^{89}Sr.

Stratospheric fallout, which comprises a large part of the total fallout, is due to those particles which are carried to the stratosphere and later give rise to worldwide fallout, the major part of which is in the hemisphere of injection. Stratospheric fallout accounts for most of the worldwide residues of long lived fission products. Exposure of humans to fallout activity consists of internal irradiation (inhalation of radioactive materials in surface air and ingestion of contaminated foodstuffs) and of external irradiation from radioactivity present in surface air or deposited on the ground.

5.2. RADIATION EXPOSURES

The contributions of the radionuclides released by atmospheric nuclear testing to the total dose commitment and the collective dose to the world's population have been estimated by UNSCEAR and are reported in Table IV, together with the contribution from testing undertaken at Semipalatinsk.

The cumulative world population doses (over time) listed in Table IV indicate that the long lived radioisotope ^{14}C is the dominant contributor to the total effective dose commitment, accounting for 70% of the effective dose commitment to the world's population. However, if one

TABLE IV. DOSE COMMITMENT AND COLLECTIVE DOSE TO THE WORLD'S POPULATION FROM ATMOSPHERIC NUCLEAR WEAPONS TESTING

Radionuclide	Dose commitment (mSv)		Collective effective dose (man·Sv)	
	From all tests	From tests at Semipalatinsk	From all tests	From tests at Semipalatinsk
^{14}C	2.58[a]	0.02	25 800 000	168 000
^{137}Cs	0.47	0.003	1 890 000	13 200
^{90}Sr	0.11	0.0007	435 000	2830
^{95}Zr	0.09	0.0006	278 000	1810
^{106}Ru	0.07	0.0005	222 000	1440
^{54}Mn	0.06	0.0004	189 000	1230
^{144}Ce	0.05	0.0003	181 000	1180
^{131}I	0.05	0.0003	165 000	1070
^{3}H	0.05	0.0003	164 000	1070
^{95}Nb	0.04	0.0003	131 000	850
^{125}Sb	0.03	0.0002	88 000	570
^{239}Pu	0.02	0.0001	58 000	380
^{140}Ba	0.02	0.0001	53 000	340
^{241}Am	0.02	0.0001	51 000	330
^{103}Ru	0.01	0.0001	41 000	270
^{240}Pu	0.01	0.0001	39 000	250
^{55}Fe	0.008	0.000 05	26 000	170
^{241}Pu	0.005	0.000 03	17 000	110
^{89}Sr	0.003	0.000 02	11 000	72
^{91}Y	0.003	0.000 02	8900	58
^{141}Ce	0.001	0.000 01	4700	31
^{238}Pu	0.001	0.000 01	2300	15
Total (rounded)	3.7	0.027	30 000 000	195 000

[a] For simplicity it is assumed that all ^{14}C is due to fusion.

considers the dose commitment only to the year 2200, ^{14}C only contributes 19% to the truncated effective dose committed to the world's population. Thus, in this relatively short time interval all other radionuclides will have delivered effectively all their contribution to the dose and ^{14}C will not yet have fully run the course of its radiological impact.

The average individual dose commitment to the world's population for all individuals over infinite time from all atmospheric testing is about 3.7 mSv. The contribution from the tests undertaken at Semipalatinsk is about 0.03 mSv (see Table IV).

The total collective effective dose to be hypothetically incurred by the world's population over an infinite time period, attributable to the full series of atmospheric tests of nuclear weapons at Semipalatinsk, is approximately 30 million man·Sv, of which about 0.2 million man·Sv are attributable to tests undertaken at Semipalatinsk. About one quarter of the collective dose will have been delivered by the year 2200; the remainder, due to ^{14}C, will be delivered over approximately the next 10 000 years. In comparison, the global collective dose attributable to natural sources over 50 years is 650 million man·Sv.

Further perspective on these figures is provided in Table V. Although atmospheric testing of nuclear weapons represents the human made source resulting in the largest collective dose, this is considerably smaller than the collective dose delivered unavoidably in a lifetime by exposure to natural background radiation.

These global estimates include a contribution from the doses to people close to the sites used for atmospheric tests. Although this contribution is small in global terms, some local doses have been substantial [5].

TABLE V. COLLECTIVE DOSE COMMITMENT BY THE WORLD'S POPULATION FOR CONTINUING PRACTICES AND FOR SINGLE EVENTS

Source	Basis of commitment	Collective dose (million man·Sv)
Natural sources	Current rate for 50 years	650
Medical exposure	Current rate for 50 years	
Diagnosis		90
Treatment		75
Nuclear weapons testing	**Completed practice (all nuclear weapons tests)**	**30**
	Completed practice (nuclear weapons tests at Semipalatinsk)	***0.2***
Nuclear power	Total practice to date	0.4
	Current rate for 50 years	2
Severe accidents	Events to date	0.6
Occupational exposure	Current rate for 50 years	
Medical		0.05
Nuclear power		0.12
Industrial uses		0.03
Defence activities		0.01
Non-uranium mining		0.4
Total (all occupations)		0.6

6. RADIOLOGICAL CONDITIONS AT THE SEMIPALATINSK TEST SITE

The most significant residual radionuclides remaining in the area from the nuclear tests are ^{137}Cs, ^{90}Sr, ^{238}Pu, $^{239+240}Pu$ and ^{241}Am. These are found to varying degrees in the terrestrial environment. At the time when the investigations were conducted, only limited data on the residual radiation levels in and around the nuclear test site were available. The experts had to rely upon assistance from the Russian experts and local representatives to identify the sites most worthy of attention. International experts used their own equipment and sampling methods to collect environmental samples and to conduct on-site field measurements. The samples were analysed by independent laboratories in Austria, France, Slovenia, the United States of America and at the Agency's Laboratories. This aspect of the experts' work was not intended to provide a comprehensive radiological picture of the conditions at the test site. Instead, the aim was to take sufficient measurements and samples to corroborate existing measurement data for the site.

Since the first nuclear test, a large database on radioecological information has been accumulated by the competent authorities of the former USSR. Data relevant to the present and future exposure of the local population were reviewed jointly by the project participants and experts from the IAEA. A comparison of these data with the results obtained from the missions is given in this section. Detailed results of the measurements and the analysis of samples collected during both missions are included in the individual laboratory reports [6–13].

In reviewing the available environmental measurement data, the experts noted that:

(a) External radiation levels are well known, especially at the settlements on the perimeter of the nuclear test site; the on-site situation has been well characterized by means of aerial surveys, but in situ measurements at specific locations of interest are not always available.

TABLE VI. MEASURED[a] ACTIVITY PER UNIT DRY WEIGHT OF SOIL FROM OUTSIDE THE SEMIPALATINSK TEST SITE (Bq/kg)

Location	^{137}Cs	^{90}Sr	^{238}Pu	$^{239+240}Pu$
Moldari	5–9	<24	0.2	0.4–1.4
Dolok	<27	<3	0.2	0.4
Sarzhal and surrounding pasture	6–72 (80)	<20 (5)	0.4 —	0.2 (7)
Kainar	<0.2–50 (52)	— (5)	— —	— (1.6)
Akzhar and surrounding pasture	13–60	—	—	—
Dolon	47–55 (24–60)	— (16)	— —	— (30–250)
Sarapan	(44)	(18)	—	—
Other settlements (approximately 15 in total)	(5–100)	(8–63)	—	(0.2–7)

[a] The upper figures given are results from the missions. The figures in parentheses are from data collected by the former USSR [2]. The results given are mostly for a soil depth of 0 to 5 cm.

FIG. 6. A state farm in Dolon, reportedly the most contaminated settlement outside the nuclear test site. The photograph was taken during the IAEA mission in November 1993.

(b) Soil activity concentrations are available for the most radiologically important radionuclides at most occupied locations off-site, but for few locations on-site.
(c) Air concentrations have been measured in the past both on and off the site, but not recently;
(d) Few measurements have been made of radionuclide concentrations in food and water.

6.1. RADIOACTIVITY IN SOIL

6.1.1. Outside the nuclear test site

Data from the former USSR include measurements of ^{137}Cs in soil in 1991–1992 from over 500 locations, and for ^{90}Sr and $^{239+240}$Pu from approximately 25 locations around the nuclear test site [2]. Sampling points were either in or close to centres of population. In addition, in the village of Dolon, 50 soil samples were taken (for $^{239+240}$Pu analysis) from in and around the village in 1993. A summary of these results and those obtained by the missions are given in Table VI.

The ^{137}Cs results from the missions all fall within the range of 5 to 100 Bq/kg determined by the more extensive Russian survey in 1991–1992. Most results are at the lower end of this range which is typical of global fallout levels [14]. The ^{90}Sr measurements from the former USSR are much less comprehensive, and no substantive corroboration of results is possible. However, the results which are available do not show any large disagreement.

The mission results for plutonium in soil fall within the range of 0.2 to 7 Bq/kg determined by measurements by the former USSR (see Table VI). A better corroboration of results would require the joint analysis of duplicate samples. For perspective, the concentrations of ^{239}Pu in surface soil in central southern England as a result of weapons fallout are in the range of 0.5 to 1.7 Bq/kg [14]. The main distribution of results thus ranges from typical global fallout levels to a few times higher. The exception to this is Dolon (see Fig. 6), where much higher plutonium levels (by up to a factor of 100) have been recorded [2]. Measurements of ^{241}Am in soil samples at this location during the mission also suggest the presence of significant levels of plutonium. It is also noted that relatively large particles contaminated with $^{239+240}$Pu have been reported as being present in the soil in Dolon [2]. Further studies are required to corroborate this.

6.1.2. Inside the nuclear test site

An aerial survey of the test site was undertaken in June 1990 [2]. This survey used gamma spectrometry to determine the distribution of ^{137}Cs across the site. The soil survey results (Table VII, Fig. 7) indicate the areas of high ^{137}Cs activity and generally support the aerial gamma survey results shown in Fig. 8. Measurements of activity (Figs 9 and 10) from inside the nuclear test site are scarce in comparison with the data available for outside.

High levels of actinide and fission products are present close to Ground Zero and Lake Balapan. At 1 km from Ground Zero the contamination levels are much lower. The second mission confirmed that dose rates fall rapidly with distance from the centre of Ground Zero. A similar programme of measurements for Lake Balapan is recommended to establish the extent of the contamination around the lake and crater.

There is evidence [15] of actinide contamination from the failed detonations conducted in the Ground Zero area (see Table VII). However, insufficient data are available to fully characterize the extent and scale of this contamination.

Outside the two main areas (Ground Zero and Lake Balapan), sample data are extremely scarce, although the aerial survey results imply that contamination by ^{137}Cs and other gamma emitting radionuclides is not widespread. Attempts to establish dispersion of ^{137}Cs from these two main areas revealed no distinct pattern of contamination.

The aerial survey included the site of the Tel'kem-2 cratering experiment which resulted in a small lake. The second mission visited this lake at the request of the residents of Sarzhal. The mission was not allowed to take samples from this location, but in situ measurements suggested that there is a significant level of actinide contamination, in the form of large particles or fragments. More data on this and other similar sites are required.

6.2. RADIOACTIVITY IN FOODSTUFFS

Information regarding the levels of artificial radionuclides in foodstuffs is sparse; no recent data from the former USSR or Kazakhstan have been identified. The low concentrations of artificially created radionuclides in soil from the vicinity of the main settlements suggest, however, that the local food chain is unlikely to be a significant pathway of exposure. This is supported by a limited food sampling programme carried out during the missions. Table VIII shows the measured activity concentrations in samples collected randomly from settlements outside the test site and from the two farms inside the test site. The values for ^{137}Cs, ^{90}Sr and Pu isotopes are of the same order or slightly higher than typical activity concentrations in European countries [16].

The results for drinking water (Table VIII) are based on a few samples taken from local wells outside the test site and one sample from the Beriozka State Farm, which is inside the test site close to Lake Balapan (Fig. 2). Although these results indicate that ^{137}C and ^{90}Sr contamination is not significant, it is not appropriate to extend this conclusion to other water sources. Drinking water is mainly supplied by local wells in each settlement or farm. The possible future contamination of

TABLE VII. MEASURED[a] ACTIVITY PER UNIT DRY WEIGHT OF SOIL FROM INSIDE THE SEMIPALATINSK TEST SITE (Bq/kg)

Location	^{137}Cs	^{90}Sr	^{238}Pu	$^{239+240}$Pu	^{241}Am
Lake Balapan	8 000–50 000	2 500	1 000–6 000	3 000–14 000	450–1 060
	10 000				
Beriozka State Farm	7–43	<19	<2	4–5	<0.5
Ground Zero		50			
Inside 1 km	600–24 000	11 000	—	—	10–440
	100–1 000				*30–230*
1 km from centre	6–300	—	—	—	10–20
Polygon farm	300	—	—	—	160
Sites of failed explosions	—	—	—	—	*30–1 200*

[a] The results in normal type are for samples taken during the missions. The results in italics are from Ref. [15].

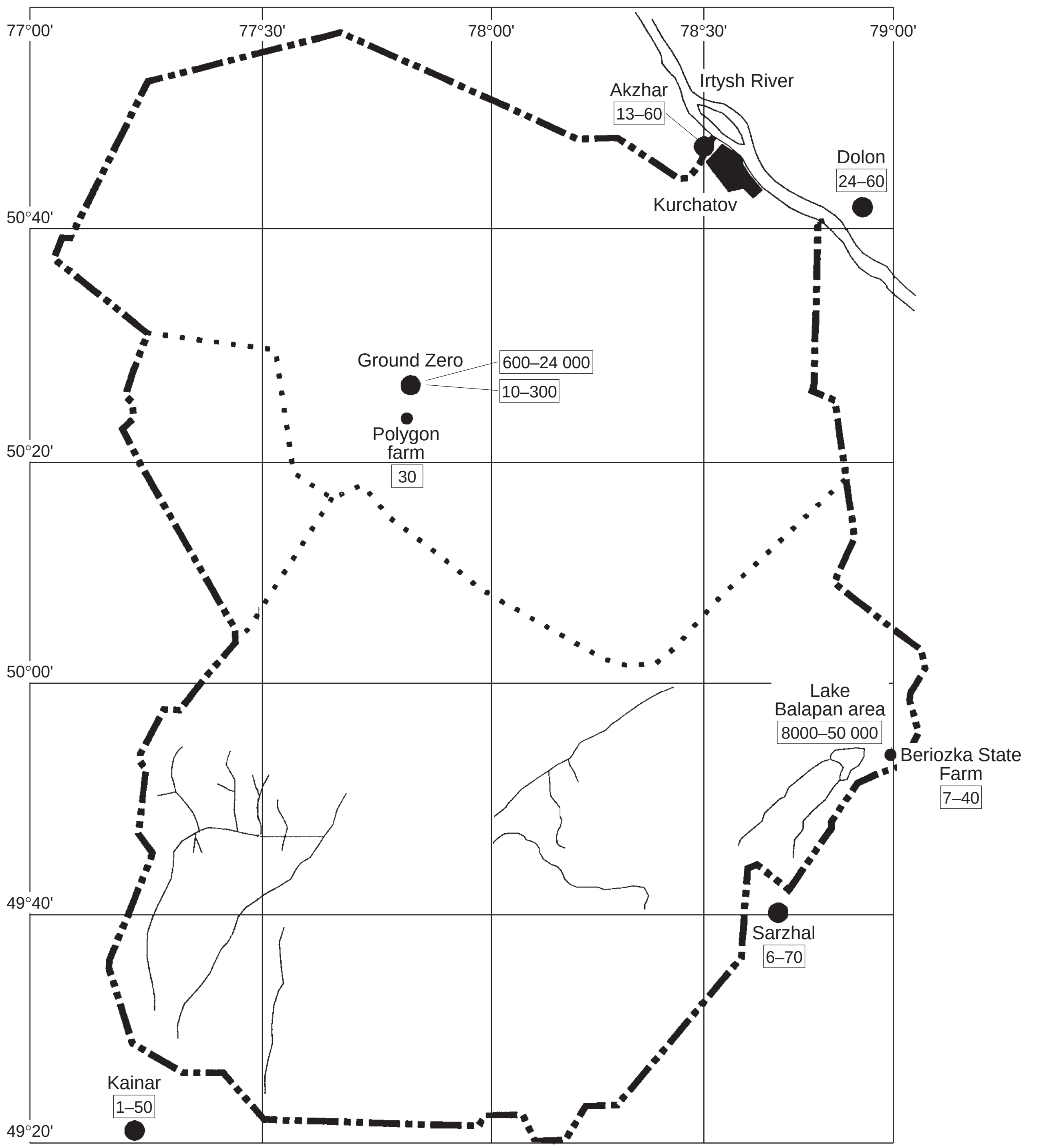

FIG. 7. Activity concentrations (given in the boxes) of ^{137}Cs in soil samples (in Bq/kg).

the groundwater, owing to the leaching of radionuclides from underground tests, must be considered. A hydrological study of the area should be undertaken to establish if there is likely to be a future threat to the water supply and, if so, where this might occur. Depending on the results of this study, a systematic programme of sampling and analysis may be necessary.

6.3. RADIOACTIVITY IN AIR (RESUSPENSION)

The levels of activity in the air were not measured during the missions. Air sampling was carried out by the former USSR at positions in and around the test site. The last available data are for monthly samples taken during 1991–1992 [17]; they indicate negligible

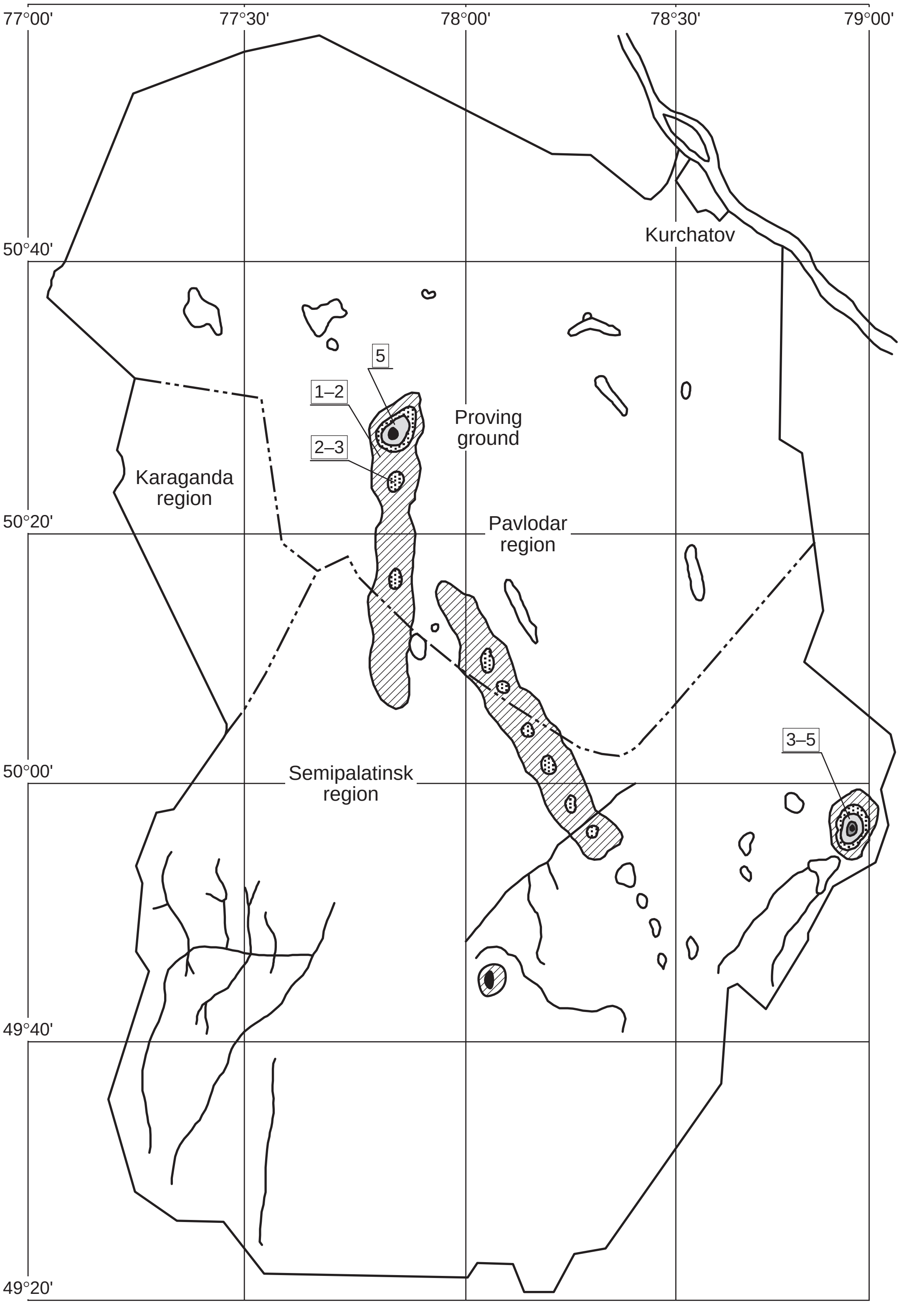

FIG. 8. Aerial gamma survey in 1990. The surface contamination values by ^{137}Cs (given in the boxes) are in Ci/km^2.

FIG. 9. Gamma dose rate measurements at Lake Balapan during the IAEA mission in November 1993.

FIG. 10. In situ gamma spectrometric and exposure dose rate measurements during the IAEA mission in July 1994.

TABLE VIII. MEASUREMENT RESULTS FOR FOOD AND WATER SAMPLES OBTAINED OUTSIDE THE NUCLEAR TEST SITE

Sample	Activity concentration (Bq/kg fresh weight)				
	^{137}Cs	^{90}Sr	^{238}Pu	$^{239+240}$Pu	^{241}Am
Grass	2–4		0–0.006	0.1–0.3	—
Hay	3		0.16 Dolon	Dolon	
Vegetables	0.7				—
Milk[a]	<0.2	0.1–0.6			<0.2
Meat	<0.5	<0.1–1			—
Drinking water[a]	<0.1–0.3	0.003		—	—

[a] Results are in terms of Bq/L.

TABLE IX. ABSORBED DOSE RATES IN AIR IN SETTLEMENTS OUTSIDE THE NUCLEAR TEST SITE (1991–1994)

Location	Dose rate at 1 m above ground (μGy/h) (Mission 2)
Entire perimeter (over 500 measurements in 1991–1992)	(0.06–0.17)
Dolok	0.07
Sarzhal and surrounding pasture	0.08–0.09 (0.12)
Kainar	0.08–0.11 (0.13)
Akzhar and surrounding pasture	0.08
Dolon	0.09 (0.10)
Other settlements (approximately 20 in total)	(0.07–0.14)

Note: Results in parentheses are from Ref. [2]. A cosmic ray dose rate of 0.03 μGy/h has been subtracted from the published results to give the dose rate from terrestrial sources to make them comparable to the results from the second mission.

TABLE X. ABSORBED DOSE RATE IN AIR INSIDE THE NUCLEAR TEST SITE (1991–1994)

Location	Dose rate at 1 m above gound (μGy/h) (Missions 1 and 2)
Lake Balapan	0.1–33 (up to 40)
Ground Zero	
1 km from centre	0.1
Inside 1 km	0.1–17
Southeastern plume	0.09
Polygon farm	0.10
Beriozka State Farm	0.2
Sary-Uzen	(0.5)
Lake Tel'kem-2	0.2–1.0 (0.3)

Note: Data in parentheses are taken from Ref. [2].

airborne levels of ^{137}Cs and $^{239+240}$Pu in Dolon and other villages.

6.4. RATES OF ABSORBED DOSE IN AIR

6.4.1. Outside the test site

The rates of absorbed dose from terrestrial sources outside the nuclear test site have been extensively measured, as shown in Table IX. Taken together, the results represent a survey of approximately 600 locations around the entire nuclear test site perimeter between 1991 and 1994. All nearby centres of population are thought to be included.

The values measured outside the test site are almost entirely within the range of the dose rates due to natural sources measured in different countries and reported by UNSCEAR (0.024–0.160 μGy/h) [13]. In situ gamma ray spectrometry during the second mission permitted the contribution from artificially created radionuclides to be assessed. This indicated that ^{137}Cs was the only artificial radionuclide that was detectable.

6.4.2. Inside the test site

The aerial survey previously described indicated that the absorbed dose rate over the entire test site is within the range of 0.07 to 1 μGy/h. In fact, the survey suggests that over a large part of the site the dose rate is within the range normally found in other countries as a result of natural sources of radiation [13]. The limited measurements performed during the missions within the nuclear test site confirmed this.

The resolution of the aerial survey does not allow dose rates in very localized areas to be quantified; this requires ground based surveys. Most of the data on gamma dose rates measured in situ are from the missions and are summarized in Table X. Measurements made at Ground Zero with survey meters indicated that the dose rate changed rapidly with increasing distance from the epicentre such that values close to normal background were indicated at distances of a few hundred metres. Similar variations were observed in and around the Lake Balapan crater, and a systematic survey of this area is recommended.

Local data on the dose rates at other locations such as Tel’kem and Sary-Uzen are scarce, but do indicate that other minor explosion sites exist and dose rates may be significant. These may not have been identified by the aerial survey, and more information on the existence of such sites is needed if there is to be full characterization of the site.

7. ESTIMATES OF PRESENT AND FUTURE DOSES TO PERSONS IN AND AROUND THE TEST SITE

7.1. SOURCES AND PATHWAYS OF EXPOSURE

The radiation exposure of persons living within and in the vicinity of the Semipalatinsk test site results from two sources: (1) natural sources of radiation; and (2) residues from nuclear weapons testing. For natural sources of radiation, the main exposure pathways are external exposure to cosmic radiation, and external and internal exposure to terrestrial radionuclides. For residual activity, the main exposure pathways of relevance are external exposure due to radioactive materials on the ground and internal exposure arising from the ingestion of radioactive materials in locally produced foodstuffs. The ingestion pathway includes the intake of foods, possibly small quantities of soil, and drinking water. Inhalation of resuspended radioactive materials is also a plausible pathway of exposure.

Another potential route of internal exposure is from cuts and wounds. This may occur when wounds become contaminated with dust and soil, or by larger radioactive particles or fragments (usually referred to as 'hot particles'). The significance of this pathway will depend upon several factors, notably the prevalence of hot particles, the frequency of incidents leading to cuts and wounds, the treatment applied to the wounds and the behaviour of hot particle fragments when embedded in human tissue. Data on these factors are not available and the contribution from this exposure route has not been assessed. This pathway has been studied with respect to another test site where the potential incidence of contaminated wounds in the local population was regarded as being significant [18]. The main conclusion of this other study was that the exposure from contaminated wounds would be very small in comparison to internal exposures from inhalation and ingestion. It is considered that this conclusion should also apply to Semipalatinsk. The second mission noted evidence of actinide particles around Lake Tel'kem-2, but no systematic measurements were possible. An assessment of the distribution and nature of such particles around this location, other similar excavations and at the sites of the failed tests in the northern technical area would be required in order to fully assess the significance of this exposure route.

TABLE XI. AVERAGE ANNUAL EFFECTIVE DOSES DUE TO NATURAL SOURCES OF RADIATION IN THE ENVIRONMENT (mSv)

Source	Global average annual effective dose in areas of normal background radiation
Cosmic rays	0.38
Cosmogenic radionuclides	0.01
Terrestrial radionuclides:	
^{40}K	0.3
^{238}U series:	
$^{238}U \rightarrow ^{234}U \rightarrow ^{230}Th$	0.014
^{226}Ra	0.004
$^{222}Rn \rightarrow ^{214}Po$	1.2
$^{210}Pb \rightarrow ^{210}Po$	0.05
Total ^{238}U series	1.4
^{232}Th series	0.27
Total (rounded)	2.4

7.2. RADIATION DOSES DUE TO NATURAL SOURCES

UNSCEAR has estimated the worldwide exposure to natural background radiation. The average annual effective dose is 2.4 mSv [13], apportioned as shown in Table XI.

Both the total dose and the contribution due to its different natural sources vary from place to place in the world. In some areas the total dose can be up to an order of magnitude higher than the average. In Kazakhstan, the average natural background radiation is comparable with the worldwide values.

7.3. RADIATION DOSES DUE TO RESIDUES FROM NUCLEAR TESTING

Radiation doses to the local population have been estimated from the radiological data discussed in Section 6. External radiation exposure has been assessed from measured absorbed dose rates. Internal radiation exposure from inhalation has been assessed on the basis of soil activity concentrations and assumptions regarding the levels of dust resuspended. Owing to the limited data on the level of radioactive contamination in local foodstuffs, the ingestion pathway has been modelled using environmental transfer factors from soil to the food chain and a typical local diet. The ingestion of soil has also been assessed, including the deliberate ingestion of soil (a condition known as 'pica') by children. Details of the methodology used to estimate doses are given in the Appendix.

Information on local dietary habits, collected during the missions by talking to local inhabitants, indicates that the majority of foodstuffs used in the settlements are locally produced. The principal exceptions are flour, rice and sugar. The diet appears to be dominated by animal products and bread or other flour based foodstuffs. Fruit and vegetable production is variable but generally low; indeed, some individuals claimed to consume no fruit or vegetables. Table XII summarizes the information provided by individuals in the settlements during the mission in 1994. On the basis of these observations, the average adult diet given in Table XIII was used in the assessment. Proportionately smaller diets were assumed for 1–2 year old and 7–12 year old children.

7.3.1. Exposures outside the nuclear test site

The majority of local people live outside the nuclear test site and the annual exposure of these people from continuous occupation of this area has been estimated. The village of Dolon has been found to have significantly higher levels of plutonium in the soil, and the potential exposure of persons in this village has been specifically assessed. The estimated doses to adults are given in Table XIV. The exposure of children (1–2 and 7–12 years of age) has also been estimated and, in all cases, the total annual doses are lower than those for adults.

The values in Table XIV do not include exposure due to the deliberate ingestion of soil (pica). Doses from such an exposure pathway have been assessed as contributing about 10% to the total doses given in the table. However, such intakes are considered to be unlikely and, even if they did occur, evidence suggests that pica cases are intermittent and would not extend for periods as long as one year at a sustained rate of intake.

TABLE XII. SUMMARY OF DIETARY INFORMATION PROVIDED BY THE INHABITANTS OF VARIOUS SETTLEMENTS

		Dolon
Home produced	Meat	Beef, mutton, poultry
	Vegetables	Carrots, tomatoes, cabbage, potatoes, cucumbers
	Fruit	Plums, melon
	Milk	Mostly turned into milk products (produce 1 L or more per day per person)
	Eggs	
Brought in from elsewhere	Bread	
	Flour	
	Sugar	
	Rice	
	Animal feed	Hay, wheat, barley and millet
		Beriozka State Farm
Home produced	Meat	
	Milk	No vegetables, no fruit
	Eggs	
Brought in from elsewhere	Flour	Bread is made at the farm
		Akzhar
Home produced	Meat	As for Dolon (<1 kg per day for 3 persons)
	Vegetables	As for Dolon (1–2 kg per day for 3 persons in summer)
	Fruit	Blackcurrants, strawberries
	Milk	As for Dolon (<1 L per day per person)
	Mushrooms	From the woods
Brought in from elsewhere	Bread	1–2 kg per day for a family of 3 persons (includes 1 child)
	Flour	

TABLE XIII. LOCAL ADULT DIET USED IN THE PRELIMINARY ASSESSMENT

Foodstuff	Intake rate ($g \cdot d^{-1}$)
Meat[a]	400
Offal[a]	50
Bread[b]	500
Sugar[b]	50
Vegetables	200
Fruit	100
Milk[c]	1500

[a] Includes meat/offal from cows, sheep, horses and goats.
[c] Not produced locally and not assumed to be contaminated.
[c] Includes milk from cows, horses, sheep and goats. The value also includes the weight of fresh milk, which is turned into products such as cream and cheese.

In summary, the annual dose estimated to persons living in the settlements is 0.06 mSv (Table IX), with a higher value of 0.14 mSv at Dolon. Because of the cautious assumptions made in the assessment, these values are likely to be in the upper range, and a more realistic estimate of the dose to an average person living in the settlements is likely to be about one tenth of these estimates. These estimates of annual dose have to be added to the radiation dose rate from natural sources, which has an average worldwide value of 2.4 mSv/a. The maximum annual dose to persons living in settlements outside the nuclear test site from natural sources plus residual activities is, therefore, 2.5 mSv. The average annual dose from residual activity is sufficiently small as to not be distinguishable from the natural background dose rate (2.4 mSv/a).

7.3.2. Exposures within the nuclear test site

7.3.2.1. Visitors

There are no settlements within the Lake Balapan area or at Ground Zero, and the evidence suggests that these places are visited infrequently by only a small number of individuals. It has been cautiously assumed that persons visit these areas for one hour per day and that this time is spent in the most highly contaminated areas. It is also assumed that they keep animals which take 10% of their feed from these areas. Inadvertent soil ingestion is also assumed to take place in these areas at the same proportional rate as in the outer area. It is assumed that fruits and vegetables are not grown within the Lake Balapan and Ground Zero areas since there was no evidence of this taking place.

TABLE XIV. ESTIMATED ANNUAL EFFECTIVE DOSES TO PERSONS LIVING AROUND THE TEST SITE

Pathway	Annual dose (mSv)	
	Dolon	Other settlements
External gamma	0.01	0.01
Inhalation		
^{238}Pu	0.007	—
$^{239+240}$Pu	0.04	0.001
^{241}Am	0.004	—
Ingestion		
^{137}Cs	0.03	0.03
^{90}Sr	0.02	0.02
^{238}Pu	0.004	—
$^{239+240}$Pu	0.02	0.001
^{241}Am	0.002	—
Total (rounded)	0.14	0.06

TABLE XV. ESTIMATED ANNUAL EFFECTIVE DOSES TO VISITORS TO LAKE BALAPAN AND GROUND ZERO, AND TO POTENTIAL FUTURE PERMANENT INHABITANTS

Pathway	Annual dose (mSv)	
	Frequent visitors	Future permanent inhabitants
External gamma	10	90
Inhalation		
^{238}Pu	0.05	1.2
$^{239+240}$Pu	0.2	3.5
^{241}Am	0.02	0.4
Ingestion		
^{137}Cs	3.0	30
^{90}Sr	0.06	10
^{238}Pu	0.07	0.6
$^{239+240}$Pu	0.2	2.0
^{241}Am	0.02	0.2
Total (rounded)	14	140

The doses to visitors to these areas are dominated by the external exposure pathway. The dose received is heavily dependent upon the occupancy of the area, and a wide range of possible doses may be estimated depending upon the assumptions made. Given this, it is considered that the values in Table XV indicate the level of dose that a small number of visitors may currently be receiving.

It was noted during the missions that a few families and individuals were living within the Semipalatinsk nuclear test site in addition to those at the Polygon and Beriozka farms. It was not clear whether their residence is permanent and it is likely that their doses will fall between the levels for those received by persons living in the settlements outside the test site and the more hypothetical doses calculated for visitors to Ground Zero or Lake Balapan. As was mentioned previously, these hypothetical doses are fairly significant.

7.3.2.2. Potential future settlement

There is nothing which would prevent persons from settling in the most contaminated areas. The most pessimistic future scenario is one in which persons permanently inhabit the Lake Balapan or Ground Zero areas; the exposure of such persons has been estimated. It has been pessimistically assumed that they remain permanently within the area and derive all crops and animal products from this area. The current doses to visitors and potential future doses to permanent inhabitants are given in Table XV.

External exposure is also the main exposure pathway for persons who might in the future permanently inhabit the Lake Balapan or Ground Zero areas. Ingestion also makes a significant contribution owing to the production of food in the contaminated areas. It should be noted that the estimates of external dose include outdoor occupancy and indoor shielding factors. For persons living a predominantly outdoor lifestyle, or inhabiting dwellings which afford a lower shielding factor, the estimated doses could be significantly higher.

In summary, the estimated annual doses to visitors and permanent residents from residual activity on the site are 14 and 140 mSv, respectively. The total annual doses from residual radioactivity plus natural sources of radiation are 16.4 and 142 mSv, respectively.

8. RADIATION PROTECTION CRITERIA

8.1. PROTECTION AGAINST RADIATION

As mentioned earlier, exposure to radiation may have detrimental effects on the health of people, which is why standards of safety for protection against radiation have been established. It should be emphasized that radiation and radioactive substances are a natural, permanent and inherent feature of the human environment. Both in Semipalatinsk and generally, people are unavoidably and continuously exposed to radiation from natural sources, such as that from outer space and naturally radioactive materials in the geosphere. In addition, they are exposed nowadays to many artificial sources of radiation which are widely used for human welfare. The background exposure caused by these natural and artificial sources is incurred in different measure by everyone and, therefore, radiation exposure can only be controlled and restricted, but not eliminated entirely.

International radiation safety standards such as the Basic Safety Standards (BSS) [19] are intended to provide requirements on safety for the national regulation of the peaceful, beneficial uses of radiation and nuclear energy only. The practice of nuclear weapons testing was therefore not considered in their establishment. However, the BSS do consider chronic exposure situations.

This section describes the protection policy and main requirements of the BSS with the aim of deriving guidance for dealing with the particular radiological conditions at the Semipalatinsk nuclear test site.

8.2. INTERNATIONAL RADIATION SAFETY STANDARDS

The BSS are the worldwide agreed radiation safety standards set out by the specialized sponsoring international organizations. They rely on scientific information on radiation levels and health effects compiled globally by UNSCEAR, a body set up by the United Nations General Assembly in 1955; the latest report of UNSCEAR to the UN General Assembly was issued in 1993. The safety criteria in the BSS are based primarily on the recommendations of the International Commission on Radiological Protection (ICRP), a non-governmental scientific organization founded in 1928 to establish basic principles and recommendations for radiation protection; the most recent recommendations of the ICRP were issued in 1991 [20].

8.3. ACTIVITIES INVOLVING RADIATION EXPOSURE

The BSS apply to two classes of activities involving radiation exposure: these are *practices* and *interventions*. Practices are those activities which make deliberate use of radiation sources for a beneficial purpose — such as the use of X rays in medical diagnosis — where the use may lead to adventitious radiation doses in addition to the doses due to natural background radiation which people always incur. Interventions are activities to reduce the doses caused by existing de facto situations where radiation exposure is significant — such as exposure to elevated background radiation levels due to natural sources or exposure to residues from past events and activities where the doses incurred are sufficiently high. In this latter case it is feasible and reasonable to take remedial measures to reduce the doses to some extent.

8.4. PRACTICES

For practices, the BSS state that:

> "No practice or source within a practice should be authorized unless the practice produces sufficient benefit to the exposed individuals or to society to offset the radiation harm that it might cause... The normal exposure of individuals shall be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs or tissues, caused by the possible combination of exposures from authorized practices, exceeds any relevant dose limit... In relation to exposures from any particular source within a practice... protection and safety shall be optimized in order that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable, economic and social factors being taken into account, within the restriction that the doses to individuals delivered by the source be subject to dose constraints."

These radiation protection requirements for practices are referred to as *justification of practices, optimization of protection* and *limitations of individual doses.*

In summary, therefore, the BSS require that *additional* doses above background levels expected to be delivered by the *introduction* or *proposed continuation* of a *practice* be restricted. The restriction is intended to be applied *prospectively* to control and constrain the forecast extra doses and aims to ensure that:

— The practice is *justified*, taking into account the doses it will deliver to people;
— The protection against the radiation exposure caused by the sources involved in the practice has been *optimized* in order to keep all doses as low as reasonably achievable under the prevailing circumstances;
— The addition of doses (above the background dose) expected to be incurred by any individual does not exceed prescribed dose limits (the currently established limit for members of the public being 1 mSv in a year under normal circumstances and up to 5 mSv in a year in special circumstances).

8.5. INTERVENTIONS

For interventions, the BSS state that:

> "Intervention is justified only if it is expected to achieve more good than harm, with due regard to health, social and economic factors. If the dose levels approach or are expected to approach [specified] levels, protective actions or remedial actions will be justified under almost any circumstances... Optimized intervention levels and action levels shall be specified in plans for intervention situations, on the basis of the guidelines given [in the BSS], modified to take account of local and national conditions, such as: (a) the individual and collective exposures to be averted by the intervention; and (b) the radiological and non-radiological health risks and the financial and social costs and benefits associated with intervention."

The radiation protection requirements for interventions are referred to as *justification of interventions* and *optimization of the protective measures.*

In summary, therefore, the BSS require that:

— Existing radiation exposure situations shall be assessed in order to determine whether an intervention is justified to *reduce* the doses being delivered because of the situation;
— Should the intervention be justified and therefore undertaken, the form, nature and scale of the protective measures should be optimized in order to ensure that they are not disproportionate to the benefit gained from the reduction in radiation doses.

Importantly, as dose limits are applicable to the increases in the radiation dose expected to arise from a practice, they are not applicable to interventions, which by definition are intended to reduce (rather than increase) doses.

8.6. THE SITUATION AT THE SEMIPALATINSK TEST SITE

The situation at Semipalatinsk does not fit the concept of a *practice.* The practices identified for the application of the BSS include the use of radiation or radioactive substances for medical, industrial, veterinary, agricultural and educational purposes, as well as the generation of nuclear electricity. The practice of nuclear weapons testing is not contemplated in international standards intended to regulate the peaceful, beneficial uses of radiation and nuclear energy. The additional doses caused by such a 'practice' can no longer be controlled prospectively, and what remains is an exposure situation only amenable to *intervention*, i.e. to the introduction of remedial protective measures aimed at reducing the radiation doses caused by the existing situation.

8.7. INTERVENTION SITUATIONS

Two types of *intervention situations* are recognized in the BSS. The first relates to *emergency exposure situations*, such as in the immediate aftermath of a radiological accident, requiring protective actions to reduce or avert the temporary (short term) doses caused by the situation. The second relates to *chronic exposure situations* where long term environmental radiation levels exist leading to continuing exposure of a resident population, usually at a relatively low dose rate, requiring remedial actions to reduce the exposure rate.

8.8. GENERIC INTERVENTION LEVELS

The underlying policy on intervention as set out in the BSS is that the decision on whether or not intervention should be contemplated and how much the existing dose levels should be reduced depends on the circumstances of each individual case. In order to determine whether and when an intervention should be undertaken, *intervention levels* are established. These levels should be determined in terms of the doses expected to be averted by a specific *remedial action* intended to protect people from exposure. The intervention levels are usually expressed in quantities derived from the avertable dose. In the case of chronic exposure situations these derived levels are usually referred to as *action levels.* They are always expressed in terms of dose rate or activity concentration above which remedial actions to reduce exposure levels should be carried out. Remedial action — or *remediation* — is therefore the term used in this report to refer to a protective action taken when a specified *action level* is exceeded in a chronic exposure situation in order to reduce radiation doses that might otherwise be received.

Intervention action levels, therefore, are expected to be established ad hoc, i.e. on a case by case basis, and tailored to the specific circumstance of the intervention situation. However, there has been a recognized need for simple and internationally agreed guidance on *generic levels* applicable to any intervention situation, particularly in cases of chronic exposure.

8.8.1. Guidelines for justifying interventions

The BSS establish that if doses approach levels at which the likelihood of deleterious health effects is very high, intervention would be expected to be undertaken under almost any circumstances. These quasi-mandatory levels, which are set up in the BSS, depend on the organ exposed, and for chronic exposure situations vary from a level of equivalent dose of 100 mSv per year for the lens of the eye to 400 mSv per year for the bone marrow (see Table XVI).

TABLE XVI. LEVELS OF THE EQUIVALENT DOSE RATE AT WHICH INTERVENTION IS EXPECTED TO BE UNDERTAKEN UNDER ANY CIRCUMSTANCES

Organ or tissue	Equivalent dose rate (mSv/a)
Gonads	200
Lens of the eye	100
Bone marrow	400

From the established levels of equivalent doses and on the basis of recommended weighting factors to take account of the radiosensitivity of the relevant organs, it could be construed that intervention would not be ‘expected to be undertaken under any circumstances’ unless the *annual effective dose exceeds several tens of millisieverts.* At lower doses, proposed interventions need to be justified on a case by case basis.

8.8.2. Guidelines for emergency exposure situations that may be applicable to chronic exposure situations

8.8.2.1. Intervention levels for relocation and resettlement

Temporary relocation and permanent resettlement are among the more extreme protective measures available to control exposures to the public in the event of a radiological emergency. Table XVII shows the generic levels established in the BSS for temporary relocation and permanent resettlement.

Temporary relocation is used to mean the organized and deliberate removal of people from the area affected during an extended, but limited, period of time (typically several months) to avert exposures principally from radioactive material deposited on the ground and from inhalation of any resuspended radioactive particulate material. During this period, people would typically be housed in temporary accommodations. As the situation is temporary, the generic guidelines to initiate and terminate relocation refer to relatively high levels of dose: 30 mSv and 10 mSv per month, respectively.

Permanent resettlement is the term used for the deliberate removal of people from the area with no expectation of return. Permanent resettlement should, according to the BSS, be considered if the lifetime dose over 70 years cannot be reduced by other means and is projected to exceed 1 Sv. This lifetime dose corresponds to an average annual dose of about 14 mSv, or about 1.2 mSv/month for a lifetime. When doses are below this level, permanent resettlement is unlikely to be necessary.

TABLE XVII. GENERIC LEVELS FOR TEMPORARY RELOCATION AND PERMANENT RESETTLEMENT

Intervention	Initiate	Terminate
Temporary relocation	30 mSv/month	10 mSv/month
Permanent resettlement	Lifetime dose > 1 Sv	

It can thus be construed that if doses fall below an *average annual effective dose of about 10 mSv*, this would indicate the possible termination of relocation if it has been instituted.

8.8.3. Guidelines for a quasi-chronic exposure situation

8.8.3.1. Radioactivity in foodstuffs

The BSS establish that if there is no shortage of food and there are no other compelling social or economic factors, action levels for the withdrawal and substitution of specific supplies of food and drinking water which have been contaminated with radioactive substances should be based on the guidelines for foodstuffs in international trade established by the Codex Alimentarius Commission (CAC) [21]. These are included in the BSS as recommended generic action levels for activity in foodstuffs. The levels are limited to radionuclides usually considered relevant to emergency exposure situations [22]. All the relevant radionuclides for the prevailing situation at Semipalatinsk are included (see Table XVIII).

The levels are recommended for use by national authorities as the generic action levels in their emergency plans unless there are strong reasons for adopting substantially different values. Use of these internationally recognized levels by national authorities would have the considerable advantage of helping to retain public confidence and trust. Moreover, the use of such values helps to prevent anomalies that might otherwise occur between neighbouring countries. When a foodstuff is exported from a country, it must meet certain standards in order that it may be exempted from any further monitoring or control by the receiving country and any subsequent receiving countries. Thus, the internationally agreed standards established by the CAC are essential in order that the international trade in food is not severely disrupted by excessive monitoring and administrative and legal requirements.

The CAC's action levels for activity concentration in foodstuffs are conceptually 'non-action' levels. This means that the residual individual doses from consumption of foodstuffs containing such levels are considered acceptable without any actions to be taken to reduce the levels.

Depending on the annual 'food basket' [21] of the population, the doses resulting from the CAC's levels will vary, but — with the FAO figure for total food consumption of 550 kg per year (not including drinking water) — the consumption of food of which every component has activity concentrations at the CAC action levels would result in *a maximum annual committed effective dose of up to about 10 mSv*. This figure assumes that the food basket is contaminated to the full CAC values for the whole year.

8.8.4. Guidelines for a chronic exposure situation

The BSS establish that, in the case of a chronic exposure situation, remedial actions are not normally likely to be necessary unless relevant (generic) *action levels* are exceeded. As stated earlier, an action level is a level of dose rate or activity concentration above which remedial or protective actions should be undertaken to protect people; generally, they are specified separately for different remedial actions. The BSS establish action levels only for the case of exposure to radon in air for both dwellings and workplaces. As the former involves members of the public, it could be used as sound reference for other generic chronic exposure situations involving the public.

TABLE XVIII. GENERIC ACTION LEVELS FOR FOODSTUFFS

Radionuclide	Foods destined for general consumption (kBq/kg)	Milk, infant food and drinking water (kBq/kg)
^{134}Cs, ^{137}Cs, ^{103}Ru, ^{106}Ru, ^{89}Sr	1	1
^{131}I		0.1
^{90}Sr	0.1	
^{241}Am, ^{238}Pu, ^{239}Pu	0.01	0.001

TABLE XIX. ANNUAL EFFECTIVE DOSES TO ADULTS FROM NATURAL SOURCES

Source of exposure	Global average exposure (mSv)	Typical elevated exposure (mSv)
Cosmic rays	0.38	2.0
Terrestrial gamma rays	0.46	4.3
Radionuclides in the body (except radon)	0.23	0.6
Radon and its decay products	1.3	10
Total (rounded)	2.4	—

8.8.4.1. *Radon in dwellings*

The BSS establish that the optimized action levels for remedial action relating to chronic exposure situations involving radon in dwellings should, in most situations, fall within a yearly average concentration of 200–600 Bq·m^{-3} of ^{222}Rn in air. Thus, the optimized action level for radon in dwellings can be translated approximately to an *annual effective dose from about 3 to about 10 mSv.*

8.8.5. Reference for comparison: Doses due to natural background radiation

As stated earlier, the worldwide individual average annual dose incurred among the global population owing to radiation from natural sources is estimated to be 2.4 mSv [3, 23], of which about half is mainly due to cosmic and terrestrial background radiation and half is due to exposure to ^{222}Rn. There is, however, a large variability in the annual effective doses caused by natural sources. It is common to find large regions with exposures elevated by up to an order of magnitude and smaller regions with even higher levels. Table XIX indicates average typical and elevated values of annual effective doses to adults from natural sources. The elevated values are representative of large regions, but much higher atypical values may occur locally.

The effective dose rate due to cosmic radiation depends on the height above sea level and the latitude. The annual effective doses in areas of high exposure (locations at higher elevations) are about five times the average. The terrestrial effective dose rate depends on the local geology, with a high level typically being about ten times the average; the effective dose to communities living near some types of mineral sand may be up to about 100 times the average. The effective dose from radon decay products depends on the local geology and housing construction and use, with the dose in some regions being about ten times the average. Local geology and the type and ventilation of some houses may combine to give effective dose rates from radon decay products of several hundred times the average.

A range of the worldwide annual effective dose from natural sources would be 1–20 mSv, with values in some regions of the order of 30–50 mSv and high levels of above 100 mSv.

In summary, although the global average annual effective dose due to natural background radiation is of the order of a few millisieverts, *annual effective doses of about 10 mSv* are not unusual and very high annual effective doses of about 100 mSv are found in some places.

As national authorities have considered these situations and decided not to take protective actions against typical elevated background levels, it appears that doses caused by these levels can be used as another comparative reference for deciding on interventions in chronic exposure situations.

8.9. GENERIC GUIDANCE FOR REHABILITATION OF AREAS OF CHRONIC EXPOSURE

From the earlier discussion it appears that an *annual effective dose of up to about 10 mSv* can be used as a *generic* guideline for action levels for considering protective remedial actions to rehabilitate areas subject to chronic exposure, such as the areas with residual radionuclides from nuclear weapons testing in Semipalatinsk. For doses below the guidance action levels, the situation could, after due consideration, generally be taken as being safe for the population.

It is emphasized, however, that this generically acceptable action level of annual dose *does not imply that below such a level it is never worthwhile reducing the radiation exposure*. If it is justified on radiological grounds, intervention for purposes of radiological protection should always be undertaken, and the form, scale and duration of the intervention would be determined by a process of optimization of protection.

In addition, it is essential to keep in mind that there are levels of effective dose at which intervention would almost always be justified on radiological grounds. As indicated before, the BSS implicitly indicate that *an annual effective dose of several tens of millisieverts* would almost always justify some kind of intervention.

One point of confusion is whether it is the doses due to the residual radionuclides or the total dose (including doses due to the natural background radiation) that should be compared with the action level. In this report both dose values are presented. The doses due to the natural background radiation will be assumed to remain constant at the worldwide average level of about 2.4 mSv and the total doses (i.e. the dose from residual radionuclides plus natural background radiation) are also presented (in parentheses) for reference purposes.

8.10. APPLICATION OF GENERIC INTERVENTION LEVELS TO SEMIPALATINSK

The exposure resulting from the terrestrial contamination caused by nuclear weapons tests at Semipalatinsk can be categorized as an intervention situation.

Persons remaining outside the test site are estimated to receive very small radiation doses from residual radioactivity, which is less than 0.1 mSv/a (or 2.5 mSv/a when natural background is added). As such, it is considered that there is no need for intervention in these cases.

Within the test site, the exposure of persons depends upon the location of the areas occupied and the duration of the occupancy. Persons who have already settled in the test site might receive effective doses of 10 mSv/a or more if they frequently visit the Lake Balapan or Ground Zero areas. Although the assumptions made in estimating this dose are regarded as cautious, the actual dose received will depend critically on the time spent in these areas. As such, the actual exposure of persons could be higher or lower than the estimated value. In the case of hypothetical permanent residency in the Lake Balapan or Ground Zero areas, the annual doses could exceed 100 mSv/a. The probability of such resettlement in the future is difficult to assess. It is, however, recognized that the areas in question are habitable, and there is currently no effective barrier to access. Therefore, resettlement in these areas is considered to be *possible*. In view of this, and noting that the estimated doses are in excess of the dose rate guideline at which intervention would almost always be justified, intervention to prevent access to the highly contaminated areas around Lake Balapan and Ground Zero is considered to be necessary. Any such intervention will also serve to reduce the doses currently received by persons who visit these two areas.

The pattern of contamination observed and the results of the dose assessment indicate that external dose rate measurements provide a reasonable basis for determining the extent of the two affected areas. Measurements suggest that dose rates quickly reduce with distance to below 1 $\mu Sv \cdot h^{-1}$. Restricting access to areas with a higher dose rate would ensure that annual doses could not exceed 10 mSv and, in practice, would be unlikely to exceed 1 mSv.

The Semipalatinsk test site is generally habitable and the Lake Balapan and Ground Zero areas are small in comparison with the total land area available for (re)settlement. In addition, there seem to be no special agricultural or other reasons for wishing to settle in these areas. Restricting access is not, therefore, likely to inconvenience settlers.

Physically restricting access is a relatively inexpensive countermeasure and is the recommended course of action at this time. It may not necessarily be regarded as a satisfactory long term solution. However, most of the currently estimated dose is from radionuclides with half-lives of about 30 years or less, and this is significant for the long term prospects of the site.

9. CONCLUSIONS AND RECOMMENDATIONS

Before coming to the main conclusions of this report it is worth repeating the original objectives of the project. In particular, it is important to be clear about the nature of the original request for assistance and the scope of the assessment.

Firstly, the principal aim was to assess the *current* radiological conditions for people living within and in the immediate vicinity of the Semipalatinsk nuclear test site. No attempt has been made to assess the radiation doses received in the past from nuclear testing, or any effects on the local population from such doses.

Secondly, the intention has been to identify situations where intervention is needed, to advise on suitable remedial actions in such situations and to identify the needs for future studies, if required. It is stressed that the assessment is preliminary in nature; it does not constitute a comprehensive radiological assessment of the whole site, but rather shows the areas where further study is needed in order to develop a full understanding of the radiological situation at the test site.

The Semipalatinsk test site covers a very large land area in which various activities associated with, and in addition to, nuclear explosions have been conducted. In this report, attention is focused on those locations which by virtue of their population or their residual activity levels might be significant in terms of the current radiation exposure of local persons. A detailed radiological assessment of the entire test site and all activities involving radiation would require very substantial resources beyond those available to the IAEA.

9.1. RADIOLOGICAL SITUATION INSIDE THE NUCLEAR TEST SITE

1. It is considered that **there is sufficient evidence to indicate that most of the area has little or no residual radioactivity from the nuclear tests. The Ground Zero and Lake Balapan areas, both of which are heavily contaminated, are clear exceptions.**

2. The measurements made at Ground Zero are sufficient to determine the pattern of contamination. In particular, it is indicated that contamination is relatively localized. **A similar survey is recommended to define the distribution of residual radioactivity around Lake Balapan.**

3. There is some evidence that contamination levels may also be significant at the other smaller nuclear excavation sites, such as Tel'kem and Sary-Uzan. However, insufficient data are available to reach any firm conclusions. **More details regarding the tests undertaken are required to identify other potentially affected areas. This might then be followed by radiological surveys, as appropriate.**

4. The missions could not corroborate the existence of actinide residues from the failed nuclear tests. **Descriptions of the nature of the failed tests, the prevailing conditions and any supporting data are needed before further investigations can be considered.**

5. There is no restriction of access to the nuclear test site, and limited reoccupation has already begun. An assessment of the exposure of persons who visit the Ground Zero and Lake Balapan areas on a daily basis has been undertaken. **This indicates annual exposures in the region of 10 mSv, predominantly due to external exposure.**

6. There are as yet no settlements within the Ground Zero or Lake Balapan areas. **If permanent occupation were to occur in the future, estimated annual exposures would be around 140 mSv/a**. External exposure is the main exposure pathway (65% of the total dose), followed by ingestion of locally produced food (31%) and inhalation of resuspended radionuclides (4%).

7. The estimated annual dose for conditions of permanent occupancy at Ground Zero and Lake Balapan is above the action level at which intervention is expected to be undertaken under any circumstances. **Remedial action is, therefore, considered necessary for the immediate areas around Ground Zero and Lake Balapan.** This action is recommended to avert the exposure of future inhabitants of these areas. It should also ensure that the current exposure of persons living in the nuclear test site and visiting these areas regularly is reduced.

8. It is recommended that **the most appropriate remedial action at this time is to restrict access to the Ground Zero and Lake Balapan areas.**

9.2. RADIOLOGICAL SITUATION OUTSIDE THE NUCLEAR TEST SITE

9. Measurements made by the IAEA experts corroborate, to a reasonable degree, the more extensive surveys carried out by different organizations from Kazakhstan and the former USSR. **The combined results are considered sufficient to form the basis of a preliminary assessment of the radiological situation of the area around the Semipalatinsk test site.**

The one exception to the above conclusion is the drinking water supply. While samples of drinking water taken by the missions showed no elevated levels of artificial radionuclides, sampling was not comprehensive. As such it is difficult to draw general conclusions about the entire water supply. In addition, the results do not provide any guarantee about the future security of the water supply. **A hydrological study is recommended to investigate the future possibility of radionuclides from the underground tests appearing in local drinking water sources. Depending on the results of this study, a monitoring programme for drinking water may be appropriate.**

10. **In most areas, external radiation dose rates and soil activity are the same as, or close to, typical levels in other regions and countries where no nuclear weapons testing has been carried out.** Some areas show small increases, but these are not significant in terms of the exposure of persons locally.

11. The estimated annual effective dose to persons outside the nuclear test site from residual radioactivity is **at most** 0.1 mSv (2.5 mSv/a when exposure to natural sources of radiation is included). This estimate is deliberately conservative; **actual exposures are more likely to be of the order of a few microsieverts per year, a dose rate which is very close to the global average from fallout** (the only reservation to this conclusion concerns the need for further confirmation of the levels of radionuclides in drinking water).

12. The village of Dolon has a higher plutonium deposition level than other settlements and has been the subject of more comprehensive soil sampling. However, **estimated annual doses remain low** (0.14 mSv/a or 2.5 mSv/a when exposure to natural sources of radiation is included).

13. **Intervention to reduce the radiation exposure of persons outside the Semipalatinsk test site is not considered to be justified.**

Appendix

METHOD OF ASSESSING RADIATION DOSES

A.1. FORM OF THE DOSE ASSESSMENT

The objective of the dose assessment is to estimate the radiation exposure of persons living in and around the test site from the pathways discussed in Section 7 of this report. This assessment includes the doses that are currently received and also the doses that might be received in the future from resettlement within the test site. Two areas are considered:

(1) The area around the nuclear test site perimeter, which includes the settlements visited during the missions. The village of Dolon has been identified as having higher levels of actinide deposition (as compared with other settlements) and is specifically considered.
(2) The Ground Zero and Lake Balapan areas. Both of these areas have been identified as having very elevated levels of radioactive contamination.

Current exposure levels are estimated for persons living in area 1 and also for those who regularly visit area 2. Potential future exposure levels are estimated for persons permanently settling in area 2.

A.2. ANALYSIS OF THE PATHWAYS

A.2.1. External gamma dose

At the Lake Balapan and Ground Zero areas, dose rates significantly above normal background levels were measured and these results were used directly to assess the doses from external radiation. In other areas, the gamma dose rate was not measurably different from what would be expected from typical background levels of radiation. Excluding the expected cosmic radiation component (30 nGy/h) leaves a measured range of 70–170 nGy/h from terrestrial sources. In comparison, UNSCEAR [3] quotes a range of national average dose rates from natural terrestrial sources of 24–160 nGy/h. To assess the external exposure from residual radioactivity, the dose rate from ^{137}Cs contamination on the ground was estimated from the in situ gamma spectrometric measurements, and this is used in the assessment.

A factor of 0.7 was used to convert absorbed dose into the effective dose equivalent [3]. Account was also taken of indoor occupancy for the assessment of doses to those living in the settlements around the nuclear test site. UNSCEAR uses an average outdoor occupancy factor of 0.2 and a building shielding factor of 0.2. Fallout shielding factors in the range of 0.05 to 0.19 for above ground buildings in and around the Semipalatinsk test site have previously been measured. A value of 0.2 is used in this assessment.

A.2.2. Inhalation of resuspended material

Inhalation doses have been assessed by combining the soil activity concentration measurement results with assumptions regarding the air dust loading (very few site specific data are available). From observations during the mission in July 1994, dust is readily resuspended, especially where the soil is not covered with vegetation. In the centre of settlements, for example, dust from open areas (roadside, yards, etc.) is visibly resuspended by the action of the wind, the movement of people and animals and especially by moving vehicles. The same is true outside the settlements on unsurfaced roads and, to a lesser extent, in open pasture. Frequent rain showers, some heavy, were observed during this mission but a rapid drying of the soil usually followed. During the mission in November 1993, the ground was frozen hard and there was no visible resuspension of material, even behind moving vehicles on unsurfaced roads.

In the absence of the results of dust measurements and individual habit data, it is assumed that individuals spend half their time on passive activities (sleeping, eating, watching television), during which the dust loading is 0.5 $mg \cdot m^{-3}$. A further 25% of their time is spent on semi-active activities when the average dust loading is 1 $mg \cdot m^{-3}$. The remaining 25% of their time is assumed to either be spent on vigorous activity (riding, digging), travelling in vehicles, or being in close proximity to passing vehicles. For these activities a dust loading of 5 $mg \cdot m^{-3}$ is assumed. This gives a weighted mean dust loading of 1.75 $mg \cdot m^{-3}$, which is considered to be a conservatively high value. This value is used for all categories of person and for all areas considered in this assessment.

TABLE XX. DOSE COEFFICIENTS FOR INHALATION

Nuclide	Lung retention type[a]	f_1	Committed effective dose per unit intake (Sv/Bq)		
			Adults	Children (12–17 a)	Infants (1–2 a)
^{90}Sr	F	0.3	2.4×10^{-8}	4.1×10^{-8}	5.2×10^{-8}
^{137}Cs	F	1	4.6×10^{-9}	3.7×10^{-9}	5.4×10^{-9}
^{238}Pu	S	1.0×10^{-5}	1.6×10^{-5}	1.9×10^{-5}	4.0×10^{-5}
$^{239+240}$Pu	S	1.0×10^{-5}	1.6×10^{-5}	1.9×10^{-5}	3.9×10^{-5}
^{241}Am	S	5×10^{-4}	1.6×10^{-5}	1.9×10^{-5}	4.0×10^{-5}

[a] F: fast; S: slow.

f_1: gut transfer factor.

The following inhalation rates are assumed:

— Adults: 8400 m^3/a,
— Children: 5500 m^3/a,
— Infants: 1400 m^3/a.

These values are based upon a Western critical group, but are considered to be a reasonable approximation for the local population.

Dosimetric data for inhaled radionuclides have been taken from Ref. [19] and those for the most significant radionuclides are given in Table XX.

A.2.3. Ingestion

Ingestion doses are estimated from ground contamination levels, terrestrial transfer factors and information on local dietary habits. The diet of children is assumed to be in the same proportion, but scaled down according to the energy expenditure ratios of 3000:2000:1200 kilocalories per day for adults:children 5–7 years old:children 1–2 years old [24]. No reduction of activity is assumed to occur during food preparation.

In the case of drinking water, the few samples taken from local wells indicated little or no detectable ^{137}Cs activity (the limit of detection is estimated to be equivalent to an annual dose of less than 7 µSv for a consumption rate of 3 L/d). This pathway is not considered further in this assessment, but difficulty in predicting the future contamination of the water supply is acknowledged.

Transfer factors from soil to plant and from plant to grazing animal used in the assessment are summarized in Tables XXI and XXII [25]. The factors for meat and offal are based upon the values derived for sheep, which are more restrictive than those for beef and are more representative of the local diet. In the absence of any other information, the milk transfer factor, which is based upon that derived for cow's milk, is assumed to be appropriate for milk from all other farm animals (i.e.

TABLE XXI. CONCENTRATION FACTORS FOR THE UPTAKE OF RADIONUCLIDES FROM SOIL TO PLANTS

Nuclide	Concentration (Bq/kg fresh weight per Bq/kg dry soil)	
	Fruits and vegetables	Pasture
^{90}Sr	3×10^{-1}	5×10^{-2}
^{137}Cs	7×10^{-3}	3×10^{-2}
^{238}Pu	1×10^{-5}	1×10^{-4}
$^{239+240}$Pu	1×10^{-5}	1×10^{-4}
^{241}Am	5×10^{-5}	1×10^{-4}

TABLE XXII. TRANSFER FACTORS FROM ANIMAL INTAKE TO ANIMAL PRODUCTS

Nuclide	Concentration in food (Bq/kg or Bq/L per Bq/d of animal intake)		
	Meat	Offal	Milk
^{90}Sr	3×10^{-3}	3×10^{-3}	2×10^{-3}
^{137}Cs	5×10^{-1}	5×10^{-1}	5×10^{-3}
^{238}Pu	4×10^{-4}	3×10^{-2}	1×10^{-6}
$^{239+240}$Pu	4×10^{-4}	3×10^{-2}	1×10^{-6}
^{241}Am	4×10^{-4}	3×10^{-2}	1×10^{-6}

TABLE XXIII. DOSE COEFFICIENTS FOR INGESTION

Nuclide	f_1	Committed effective dose per unit intake (Sv/Bq)		
		Adults	Children	Infants
^{90}Sr	0.3	2.8×10^{-8}	6.0×10^{-8}	7.3×10^{-8}
^{137}Cs	1	1.3×10^{-8}	1.0×10^{-8}	1.2×10^{-8}
^{238}Pu	5×10^{-4}	2.3×10^{-7}	2.4×10^{-7}	4.0×10^{-7}
$^{239+240}$Pu	5×10^{-4}	2.5×10^{-7}	2.7×10^{-7}	4.2×10^{-7}
^{241}Am	5×10^{-4}	2.0×10^{-7}	2.2×10^{-7}	3.7×10^{-7}

TABLE XXIV. ADULT EFFECTIVE DOSE PER UNIT SOIL CONTAMINATION

Nuclide	Annual dose (μSv/a per Bq/kg dry soil)		
	Inhalation	Ingestion	Total
^{90}Sr	—	0.96	0.96
^{137}Cs	—	0.59	0.59
^{238}Pu	0.24	0.13	0.37
$^{239+240}$Pu	0.24	0.14	0.38
^{241}Am	0.24	0.11	0.35

horses, sheep and goats). All the radionuclides present in fresh milk are assumed to be retained in any derived milk products.

Animals mostly graze in and around settlements in the outer area, although the missions noted clear evidence of animals grazing around Lake Balapan and on and around Ground Zero. During the summer the animals graze outdoors, and are kept and fed indoors during the winter. It is assumed that winter animal feed has the same activity concentration as the grazed pasture. Fruit and vegetables appear to be grown principally in small plots adjacent to houses and farms in the settlements.

The inadvertent human ingestion of soil is also considered in this assessment. Food preparation and cooking is mainly carried out indoors, and it is not considered that the contamination of food with soil is significant. Bread may be baked in outdoor clay ovens, but again it is not considered that soil contamination is significant. The consumption of unwashed fruit and the general rural lifestyle would, however, result in some soil consumption, and a value of 1 g/d is assumed for adults. Children and infants are also expected to ingest soil during play and the same intake rate is assumed.

The deliberate ingestion of soil by children (i.e. pica) has been modelled assuming an ingestion rate of 20 g/d for a period of 6 months [26]. The dosimetric data used in the assessment for ingestion of radionuclides are given in Table XXIII [19].

A.3. CONTAMINATION LEVELS AND ESTIMATED DOSES

As the first end point of the assessment, annual doses from the exposure pathways described earlier have

TABLE XXV. CONTAMINATION LEVELS ASSUMED IN THE ASSESSMENT

Nuclide	Soil activity concentration (Bq/kg dry weight)		
	Outside the nuclear test site		Inside the nuclear test site: Lake Balapan and Ground Zero
	Dolon	Other settlements	
^{90}Sr	20	20	10 000
^{137}Cs	50	50	50 000
^{238}Pu	30	1	5 000
$^{239+240}$Pu	150	5	15 000
^{241}Am	15	0.5	1 500

been estimated for unit soil concentrations. The results for adults are given in Table XXIV. The results for children and infants are lower with the exception of the ingestion of ^{90}Sr by infants, which is 50% higher than the adult value. The table does not include the exposure from pica, which is only likely to affect a small number of children for a few months. The effect of this condition has, however, been assessed in relation to the contamination levels found in the soil in the settlements, as discussed in Section 6.

The second end point is to estimate the current and future annual doses to individuals on the basis of the measured dose rate and contamination levels. Conservative values for the soil contamination levels have been selected from the measurement results, and these values are given in Table XXV. The village of Dolon is specifically addressed owing to the much higher values of plutonium in soil that have been reported. It is worth noting that the assessment uses transfer factors which are based upon well mixed soil. The values in Table XXV are based principally on measurements in the top few centimetres of undisturbed soil. This is likely to lead to an overestimate of the ingestion doses, especially in the case of the actinide.

For external gamma radiation, persons are assumed to be exposed to an average dose rate of 40 µGy/h at Lake Balapan and Ground Zero and 0.005 µGy/h from artificial radionuclides in all other areas.

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