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# METHODOLOGICAL ASPECTS OF CREATING A RADIOLOGICAL "PASSPORT" OF THE FORMER SEMIPALATINSK NUCLEAR TEST SITE

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## *Abstract*

*During its existence, 456 nuclear tests were carried out at the Semipalatinsk Test Site - 30 at the ground surface, 86 in the atmosphere and 340 underground. Radioactive fallout from ground surface tests is responsible for the present radiation conditions within the "Test Field". The radiation situation in the Degelen Mountains is caused by 209 underground tests carried out in local tunnels. Within the former Test Site there are three large and several small zones to which general access is prohibited for public health reasons: the "Test Field", the Degelen Mountains, lake Shagan, the rim of the lake, and the adjacent land to the north.*

*The information and characteristics, which have to be included in radiological passport of the former Semipalatinsk Test Site, are discussed along with general information about the Semipalatinsk site, its administrative status, the population distribution throughout the territory, all the economic activities taking place within the territory, the zones and structures representing a radiation hazard, and radio-hydrogeological conditions of the test site and the adjacent regions, biogenic conditions (topography, soil, vegetation), wildlife, fauna monitoring, etc.*

## 1. HISTORICAL BACKGROUND

The decision to establish the Semipalatinsk nuclear test site (STS) was taken on 21 August 1947. The first groups of personnel began moving onto the site on 1 June 1948.

The nuclear test site (Fig. 1) extends over parts of the Semipalatinsk (East Kazakhstan), Pavlodar and Karaganda provinces of the Republic of Kazakhstan. It has a total area of about 18 500 km$^2$ and its perimeter is about 600 km long. It is divided up among the three above-mentioned provinces in the ratio 54:39:7 respectively [1].

In 1949, together with the installation of facilities and structures for the conduct of nuclear tests, a small town (now called Kurchatov) was built beside the river Irtysh; it subsequently became the administrative centre of the nuclear test site.

The preparations for testing were completed in July 1949, and the first test of a nuclear device at the Semipalatinsk site took place on 29 August 1949. During the years 1949-90, altogether 456 nuclear tests were carried out at the site [1].

The site was an elaborate research complex. It consisted of the administrative centre at Kurchatov, where the laboratory facilities were also located, and a large number of experimental zones, the main ones being: the Balapan test field; Site 10 (the "Baykal" reactor complex); Site "G" (an underground seismic testing complex excavated in the Degelen Mountains); and Site "Sh" (which included the "Test Field"-"Opytnoe Pole" for atmospheric nuclear tests and later a reactor complex with a graphite-moderated research reactor). The STS had a highly developed infrastructure: a railway linking the town of Kurchatov with the city of Semipalatinsk and the Balapan test field; and a network of asphalted roads, water conduits and electricity and telephone lines [1].

## 2. THE RADIATION SITUATION AT THE TEST SITE

During its existence, 456 nuclear tests were carried out at the Semipalatinsk site-30 at the ground surface, 86 in the atmosphere and 340 underground. Radioactive fallout from ground surface tests are responsible for the present radiation situation within the "Test Field". The radiation situation in the Degelen hills is due to 209 underground tests carried out in tunnels dug into the Degelen Mountains [1].

In the Balapan test field and test field No. 7, a total of 131 underground tests were carried out in vertical shafts. However, the radiation situation-where the radiation levels differ from the natural background-is due mainly to an excavation blast in borehole 1004, carried out in order to create an artificial reservoir, and to blasts in boreholes 101 and 1003.

Within the former test site there are three large and several small zones to which general access is prohibited for public health reasons: the "Test Field", the Degelen Mountains, lake Shagan, the rim of the lake, and the adjacent land to the north.

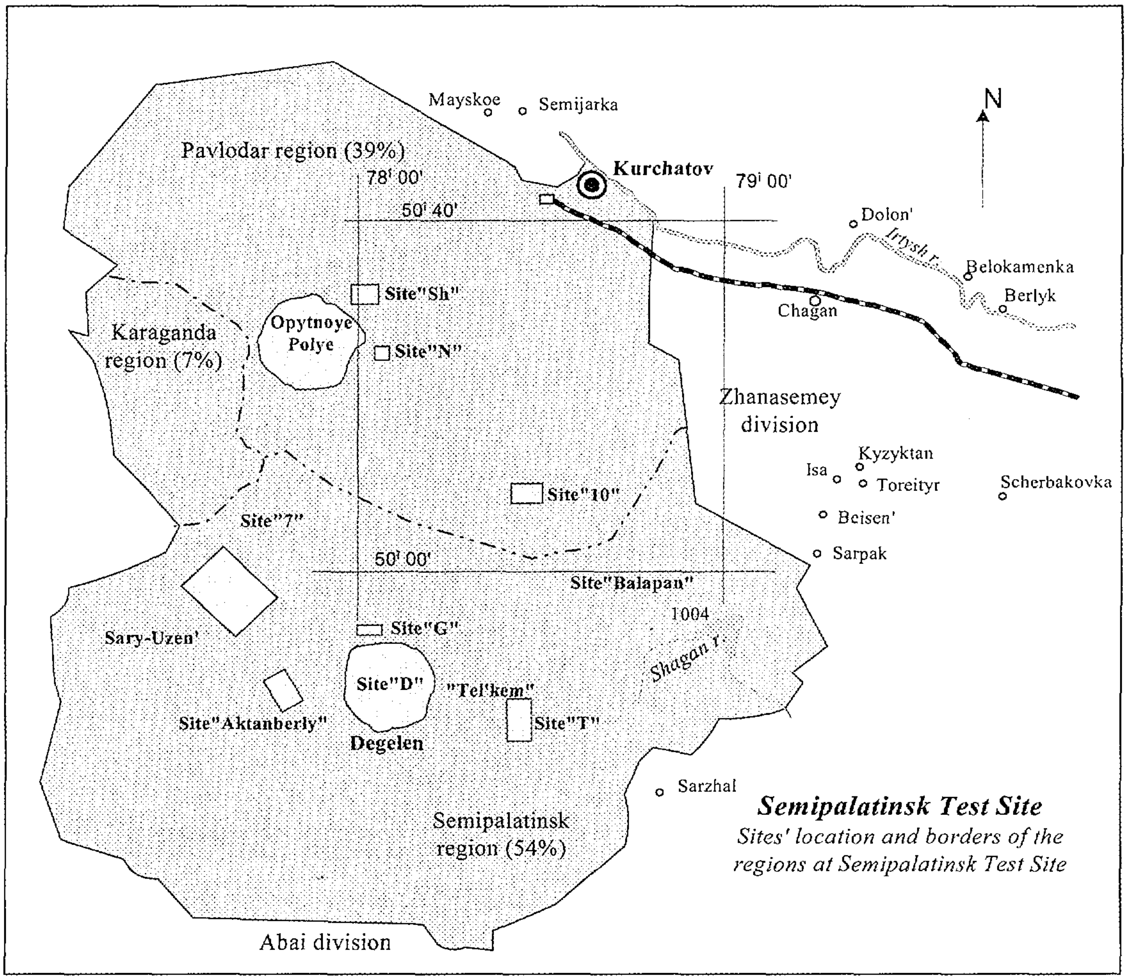
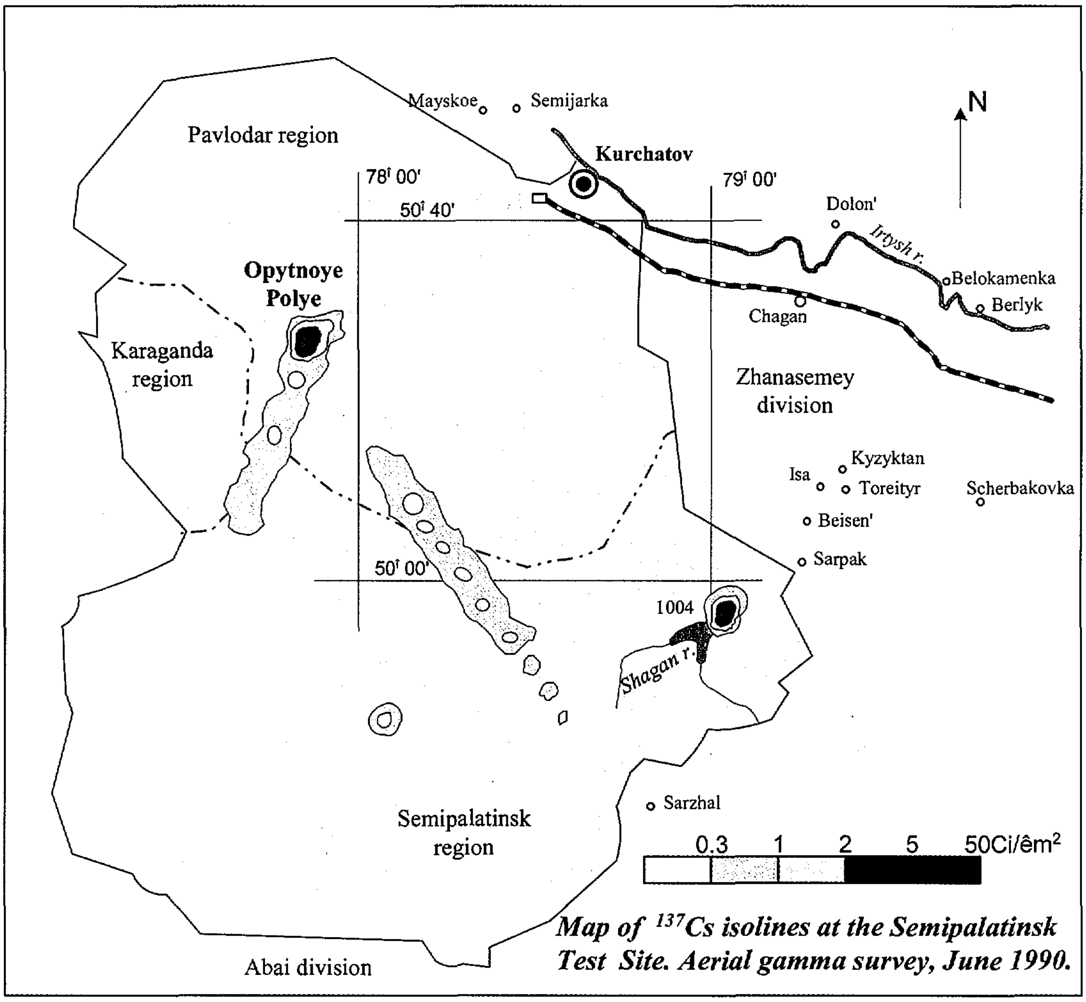


FIG.1.The map of the Semipalatinsk Test Site.

In 1989, while nuclear tests were still being carried out at the Semipalatinsk site, a complex research project called "Region-1" and devoted to radiological and seismic investigations both of the site and of adjacent areas got under way, with the participation of teams from many institutes of the Soviet Ministries of Atomic Energy, Defence and Health and many Kazakhstan institutes. An aerial gamma spectrometry survey of the entire site was carried out during the first two years.

In 1994, a joint study was carried out by the V.G. Khlopin Radium Institute, Kazakhstan's National Nuclear Centre and a number of United States laboratories under contract to the US Defence Nuclear Agency. Individual sections of the "Test Field" and territory near lake Shagan were investigated. The results confirmed the available data regarding the general radiation situation at the former Semipalatinsk test site.

According to data obtained through the aerial gamma spectrometry survey, there are two large trails of radioactivity extending out from the "Test Field" (see Fig. 2). One trail extends south-eastwards, with a bearing of ~145°, and the area with a contamination density of over 11 GBq/km$^2$ (0.3 Ci/km$^2$) measures 90 km x 10 km. This trail is due mainly to the detonation of a thermonuclear device on 12 August 1953. There are about 250 km$^2$ with a contamination density of 37 to 74 GBq/km$^2$ (1 to 2 Ci/km$^2$) and about 25 km$^2$ with contamination density of 74 to 185 GBq/km$^2$ (2-5 Ci/km$^2$).



***Map of $^{137}$Cs isolines at the Semipalatinsk Test Site. Aerial gamma survey, June 1990.***

FIG.2. Map of $^{137}$Cs soil deposition at the Semipalatinsk Test Site.

The second trail starts at location P-1 and has the shape of an arc extending from north to south. Its surface area is about the same as that of the first trail, but there is a higher surface contamination density at the start of the trail-i.e. at location P-1 itself and within the "Test Field". There are six spots with dose rates exceeding 100 μR/hour. The spots are not symmetrical; their maximum dimensions vary from 2km (at location P-1) to 0.75 km. Near the other location, the large westernmost spot consists of four smaller spots with dose rate levels higher than 200 μR/hour. These are the central zones of the ground surface blasts. The highest dose rate, exceeding 1400 μR/hour, is measured at location P-1. In a number of cases, the contours of the $^{137}$Cs-contaminated spots and sections of the "Test Field" differ. In the epicentral zones of the atmospheric nuclear blasts, the $^{137}$Cs contamination density reaches 750-1100 and 1800 GBq/km$^2$ (20-30 and 50 Ci/km$^2$ respectively). Within the "Test Field", the total surface area with a contamination density greater than 185 GBq/km$^2$ (5 Ci/km$^2$) is about 10 km$^2$.

A third large trail is due to a peaceful nuclear explosion-an excavation blast-which took place on 15 January 1965 in borehole 1004 and produced the artificial lake Shagan. There are diverse contamination levels within this zone. Thus, according to data obtained through the aerial gamma spectrometry survey, the gamma dose rate around the rim of the crater containing the lake does not exceed 1 mR/hour. The trail extends in a north-westerly direction. The main gamma emitters around lake Shagan are $^{60}$Co, $^{137}$Cs, $^{152}$Eu and $^{154}$Eu. These radionuclides are localized in the heaped-up rocks constituting the rim of the crater; the $^{137}$Cs is spread much more widely. The dose rate varies from 60 to 500 μR/hour. There is a dose rate higher than 500 μR/hour in the zone comprising the crater rim and the lake itself-a zone with a diameter of ~1km. It should be noted that the area with a $^{137}$Cs contamination density of 11-37 GBq/km$^2$ (0.3-1 Ci/km$^2$) is large, 35 km x 12 km. Away from these trails, the $^{137}$Cs contamination density is spotty, varying over the range 11-2 GBq/km$^2$ (0.3-0.05 Ci/km$^2$).

According to data obtained through the aerial gamma spectrometry survey, most of the test site has a $^{137}$Cs contamination density of less than 11 GBq/km$^2$ (0.3 Ci/km$^2$). The radioactive trail surface area with a contamination density of more than 1 Ci/km$^2$ accounts for about 0.5%. On the basis of calculations and estimates, it has been established that the surface soil layer (down to not more than 20 cm) at the former Semipalatinsk test site contains the following radionuclides, formed as a result of ground surface tests:

- $^{137}$Cs, with an activity of 110 TBq (3000 Ci) in January 1995, which is about 8% of the total radioactivity produced by the ground surface blasts;
- $^{90}$Sr, whose activity is estimated to be less than 90 TBq (2500 Ci), which is less than 10% of the total;
- $^{239}$Pu, whose activity has also been estimated but must be confirmed after additional studies.

The bulk of these radionuclides is concentrated outside the "Test Field" and is 2-3 times greater than the radionuclide inventory due to global fallout.

In the years 1996-99, an enormous amount of work was done at the former Semipalatinsk test site, under contracts with the US Defence Threat Reduction Agency, to "liquidate" the experimental complex in the Degelen Mountains; all tunnels where tests had taken place or which had been prepared for tests were sealed.

The radiation background on portal rock area of the closed tunnels ranges from 14 μR/hour (tunnel Z-6) to 120 μR/hour (tunnel A-1Sh). For most of the sealed tunnels, the dose rate on portal rock areas does not exceed 25 μR/hour. The greatest contamination is found in on portal rock area of tunnels A-1, A-1Sh, 810, 608 and 177, where the $^{137}$Cs concentration on the ground surface exceeds 1 MBq/m$^2$. On portal rock areas of tunnels Zh-3, 143 and 139, at bonfire points in a shed where cables removed without authorization were burned, spots with high $^{239+240}$Pu and $^{241}$Am contamination levels formed.

On the basis of the criterion whereby a territory must be evacuated if the level of soil contamination by $^{137}$Cs is 555 kBq/m$^2$ (15 Ci/km$^2$) or higher, it may be concluded that collectors of scrap metal must be kept away from the portal rock faces of tunnels A-1, A-1Sh, 506, 810, 608, 511, 609, 165, 104 and 177 and a number of others. The portal rock faces of tunnels Zh-3, 143 and 139 must also be off-limits, owing to high levels of $^{239+240}$Pu and $^{241}$Am contamination.

A comparison of the results obtained with data from a study of the tunnels and portal rock face areas carried out during the period 1996-98, before the sealing of the tunnels, showed that after sealing the radiation situation in 1999 at the sealed tunnel portals and portal rock areas of tunnels had not deteriorated-in fact, there had in most cases been a decline in radiation levels and in the density of contamination by artificial radionuclides.

In the case of nine sealed tunnels, water is still flowing out and the concentrations of tritium, $^{137}$Cs and $^{90}$Sr in the resulting streams significantly exceed the permissible levels [2][1]. It has been established, within the limits of measurement error, that the tritium concentration has remained almost unchanged. An exception are the streams from tunnels 609 and 176, in which the tritium concentration has declined almost by a factor of two.

The $^{90}$Sr concentration in the streams from tunnels A-1Sh, 504 and 503 have, within the limits of measurement error, remained almost unchanged. A clear reduction in the $^{90}$Sr concentration, almost by a factor of two, has been noted with case of tunnels 165 and 104. In the case of four tunnels (511, 609, 176 and 177) there has been a concentration increase by a factor of two-three accompanied by a decline in the water flow rate.

In the case of six tunnels (A-1Sh, 503, 609, 176, 165 and 104), the concentration of $^{137}$Cs in the water has hardly changed. The concentration in the streams from tunnels 504, 511 and 177 has declined by more than a factor of ten.

The concentration of $^{239+240}$Pu in the water from tunnels 503, 176 and 165 has remained almost unchanged. A significant decline in the $^{239+249}$Pu concentration has been noted in the water from tunnels 504, 511 and 177. The $^{239+240}$Pu concentration in the water from tunnel 104 has increased substantially (almost by a factor of ten), but it is still below the permissible maximum.

An extremely important point is that the tritium, $^{90}$Sr and $^{137}$Cs concentrations in the streams from these nine tunnels appreciably exceed the permitted levels [2] in virtually all cases:

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[1] According to [2], the permissible concentrations in drinking water are the following: for tritium - 7.7 kBq/l, for $^{90}$Sr - 5 Bq/l, for $^{137}$Cs - 11 Bq/l, and for $^{239}$Pu or $^{249}$Pu - 0.6 Bq/l.

- for tritium, the concentration was found throughout the observation period to significantly exceed (by a factor of 2-100) the permissible level in the case of all the tunnels;
- for $^{90}$Sr, the permissible level was exceeded by a factor of 20-140;
- for $^{137}$Cs, the permissible level was exceeded by a factor of 3-270 in the case of eight tunnels (only in the case of tunnels 511 and 177 was the concentration below the permissible level).

A less dangerous situation is developing with plutonium, whose concentration exceeds the permissible limit only in the case of the stream from tunnel 503. Thus, it may be said that the concentrations of tritium, $^{137}$Cs and $^{90}$Sr in the streams from all nine tunnels significantly exceed the permissible limits.

Radiochemical analyses of water samples from the natural streams Uzun-Bulak, Kara-Bulak and Baitles, which flow out from the Degelen hills, have shown that the concentrations of $^{90}$Sr, $^{137}$Cs and $^{235\text{-}240}$Pu in the water of those streams are below the permissible levels for drinking water. Over the years, however, the water of those streams has become radioactively contaminated by tritium, whose concentration exceeds the permissible level by a factor of 10-20.

The highest radiation levels are encountered along the valleys formed by the streams from tunnels 104 (800-4500 μR/hour), 504 (3100 μR/hour), A-1 and A-1Sh (2070μR/hour) and 165 (2000 μR/hour). As regards the valleys formed by the streams from the other tunnels, the radiation background varies from natural (tunnel 143) to 1800 μR/hour (tunnel Z-6), the average being 50-500 μR/hour.

The highest $^{137}$Cs activities are found in samples of soil and alluvium from the valleys formed by the streams from tunnels Z-6 (1630 kBq/kg), 104 and 105 (1440 kBq/kg), 609 (950 kBq/kg) and 165 (610 kBq/kg). It is the contamination with this radionuclide which produces the high radiation levels in these valleys.

The specific $^{90}$Sr activity of the soil lies in the range 1.5-112 kBq/kg. The highest values are found in the case of soil from the valley of the right-hand tributary of the Kara-Bulak, where tunnels 504 (62 kBq/kg) and 506 (122 kBq/kg) are located, and from the valley formed by the streams from tunnels A-1 and A-1Sh (90 kBq/kg). The $^{90}$Sr concentration is highest in the streams from tunnels 504, 104 and 177. Compared with the water, the bottom sediment is enriched in $^{137}$Cs relative to $^{90}$Sr, which is due to the higher sorbability of caesium.

The specific activity of the plutonium in silt and soil samples from the investigated valleys is basically less than that of the $^{90}$Sr and $^{137}$Cs. However, some samples have specific activities in excess of the permissible level and must be regarded as radioactive waste. About 80% of the measured samples from the investigated valleys are classifiable as radioactive waste by virtue of their combined plutonium and $^{137}$Cs concentrations.

Thus, owing to the level of contamination with radionuclides and to the radiation background, the investigated valleys must be classified as restricted zones from which, for health reasons, members of the public must be excluded.

The main natural streams flowing out from the Degelen Mountains are the Uzun-Bulak, the Kara-Bulak and the Baitles. Beyond the peripheral road, the specific activity of the radionuclides in the bottom sediment and the earth is several orders of magnitude less, and these materials are no longer classified as radioactive waste. The surface waters of the Degelen Mountains transport $^{90}$Sr, $^{137}$Cs and $^{239\text{-}240}$Pu only short distances (10-15 km), not beyond the peripheral road, owing to the high radionuclide sorption capacity of the rocks.

It would seem that, at present, the main threat to the environment outside the Degelen Mountain region comes from streams containing tritium at above the established norms.

Thus, during the ten years since the end of testing the radiation situation in the Degelen Mountain region of the former Semipalatinsk test site has improved somewhat thanks to the decay of short-lived radionuclides and to decontamination activities connected with the sealing of tunnels. Otherwise it has remained unchanged, and in a number of places, including the "Test field" and part of the territory adjacent to lake Shagan, intervention measures are called for.

After implementation of the Programme for Demilitarization of the Semipalatinsk Test Site, the problem of the Degelen Mountains appeared in a completely different light. At present, these mountains (an experimental zone) are the only experimental zone where the radiation situation has a tendency to change-not because of radioactive decay, but because of migration processes.

As water is the principal agent causing radionuclide migration from the central zones of the underground nuclear blasts, over many years the streams flowing from tunnels have carried radionuclides remaining from nuclear blasts into the surroundings. At present, those radionuclides are tritium, $^{90}$Sr, $^{137}$Cs and plutonium. During spring floods, the radionuclides have spread along the valleys and been taken up by soil and silt through sorption. Thus, not only the portal rock areas of tunnels have been contaminated, but also the valleys of some streams. Consequently, following the work done in the Degelen Mountain region it is necessary to establish a health exclusion zone there, until decontamination operations have been carried out. Such operations must be preceded by the establishment of a detailed inventory of the contaminated areas for all radionuclides, including uranium. It is necessary to take the decision regarding decontamination on the basis of existing international standards. For those contaminated areas which will not be decontaminated, it is necessary to introduce use restrictions, and for that purpose there is already a need to formulate provisional land use standards.

It will be necessary to develop such standards on the basis of the appropriate population dose limits, taking into account the levels of contamination of the three media. In addition, it is necessary to carry out radiation studies on all used test boreholes at the Balapan and Sary-Uzen test locations in order to assess how contaminated they are.

## 3. RADIOECOLOGICAL "PASSPORT" OF THE FORMER NUCLEAR TEST SITE

As the territory of the former Semipalatinsk test site is earmarked-and some parts are already being used-for various economic activities (mineral extraction, agriculture, scientific research etc.), a radioecological "passport" of the territory must be established. In this connection, it is necessary to finally resolve the question of the administrative boundaries of the territory, which falls within the responsibility of the National Nuclear Centre of the Republic of Kazakhstan. As indicated above, the former test site includes parts of the provinces of Semipalatinsk, Pavlodar and Karaganda.

An ecological 'passport" is a technical standards document containing data about the use of natural resources by a specific entity and the influence of that entity on the natural environment. The data consist of a system of indicators reflecting the level of resource use by the entity and the extent of its impact on the environment.

At present it is difficult to predict when the entire territory of the former Semipalatinsk test site will be free of zones restricted for health reasons or even whether that will be in the foreseeable future. Consequently, it is already necessary, drawing on the available experimental data about the radioactive contamination of the territory and on the experience of developing and introducing modern ecological standards for quality control regarding the ecological aspects of the industrial activities, to produce a set of legal standards documents relating to the development and introduction of modern ecological standards for quality control of the ecological activities within the territory of the former Semipalatinsk test site.

During the ten years since the closure of the test site, a start has been made with new activities-for example, the extraction of coal, fluorite's and gold-which will have an environmental impact over and about that of the radiation legacy. Hence, in establishing the ecological "passport" one must also take into account factors such as the territory's status, which will determine who controls industrial operations and environmental activities at the former test site-the National Nuclear Centre of the Republic of Kazakhstan or the individual companies engaged in the exploitation of deposits. On that will depend the area of responsibility covered by the ecological "passport".

The ecological "passport" of the former test site will have to contain-inter alia-general information about the site, its geographical co-ordinates, its administrative status, the population distribution throughout the territory, and the zones and structures representing a radiation hazard. Particular care will have to be taken in describing these areas and structures. Also, it will be necessary to include information about all the economic (mainly agricultural) activities taking place within the territory.

Establishment of the ecological "passport" must be preceded by a comprehensive assessment of the impact of the nuclear test site on environment and population in the region of the site. Here it is necessary to have a complete description of the degree of radioactive contamination of the environmental features at the locations where nuclear tests were carried out, including details of all the experimental areas and especially of the contaminated ones where health exclusion zones have been established pending decontamination and restoration.

It is necessary to document the presence or absence of radiation effects on the flora and fauna, to count the fauna species and the numbers of individuals belonging to each species, and to count the species of plants growing within the extensive territory of the former test site.

The "passport" must contain a physico-geographical description, including geomorphological conditions, orography, hydroclimatic conditions (climate, hydrography) and radiohydrogeological situation of the test site and the adjacent regions, biogenic conditions (topography, soil, vegetation), wildlife, fauna monitoring.

The "passport" must also indicate ways of preserving and exploiting the fauna. The basis aim of the exploitation of nature must here be mutually advantageous development of the existing anthropogenic factor and the preservation of natural ecosystems. The preservation of wild animals and their habitats must not be based solely on restrictions and prohibitions. This issue must be approached in an integrated manner, account being taken of the socio-economic situation and with the development of a general nature preservation strategy that should derive from an analysis of the ecological functions of the different areas to be protected.

The establishment of protected areas can be based on two fundamental approaches:

(1)declaring the entire former test site to be a special protected territory, but with provision for the possibility of conducting scientific investigations at any location;

(2)creating a network of specially protected areas of varying status, with the possibility of conducting scientific investigations in those areas.

For the preservation and rational exploitation of the wildlife at the former test site, it is above all necessary to:

- determine and confirm the areas which are to receive special protection;
- carry out counts of the particularly valuable wildlife species;
- establish a rapid-reaction group for the protection of ecosystems.

Questions of monitoring of the radiation situation at the former test site must also be reflected in the "passport". Immediate monitoring is undoubtedly necessary in the Degelen Mountain region as the situation there-in contrast to elsewhere-is unstable. That is due to the constant influx of radionuclides in the water from tunnels, especially during the spring floods. For the Degelen Mountains, therefore, it is necessary to make a rough forecast of the radionuclide migration, for which purpose it is necessary to calculate the volume of radioactive rock material in the central underground nuclear explosion zones and the overall amounts of radionuclides in that material.

The radionuclide migration at the Balapan test field and at other sites where detonations took place in vertical boreholes will be less pronounced than that in the Degelen Mountains owing to fact that less water is present there and the rates of underground water movement are lower. Consequently, in our opinion, it is necessary to monitor the underground water there, but to a lesser extent, and at the initial stage it will be possible to use the existing observation boreholes and to monitor first for tritium. According to our information, even the migration of tritium is insignificant in this region and its dispersion halo extends to no more than 0.5-1 km from the outermost boreholes.

Lastly, one must not forget the artificial reservoir-lake Shagan. It will be necessary to look at the behaviour of radionuclides during the period of spring floods.

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