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OVERVIEW OF CONTAMINATION FROM U.S. AND RUSSIAN NUCLEAR COMPLEXES

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OVERVIEW OF CONTAMINATION FROM U.S. AND RUSSIAN NUCLEAR COMPLEXES

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1. Introduction

Over the last 50 years, Russia and the United States have developed the largest nuclear weapons complexes in the world. In doing so, they have also created the world's largest inventories of radioactive materials. Although parts of these inventories have decayed to insignificant levels (stored in engineered systems such as tanks, or placed into a waste form such as glass), significant amounts have been released to the environment. In both countries, the primary contaminated areas are located at or near facilities that reprocessed fuel from weapons materials production reactors. In the United States, these locations are the Hanford, Savannah River, and Oak Ridge sites. In Russia, the corresponding sites are Mayak (near the city of Ozersk, formerly Chelyabinsk-65), Tomsk-7 (now called Seversk), and Krasnoyarsk-26 (now called Zheleznogorsk), all of which are located in western Siberia.

Reprocessing of spent nuclear fuel generates waste streams from low to high radioactivity levels as a result of dissolving the fuel and extracting uranium and plutonium to make new fuel or for defense purposes. Contamination of the environment from reprocessing operations, due to off-normal events or planned discharges, has led to the majority of contamination in both of our countries. The contamination at the three Russian production reactor and fuel reprocessing sites dwarfs all other contamination problems in Russia, as well as anywhere else in the world. Probably the primary example of this is the extent of radioactive waste disposal by injection into wells at depths from 300 to 1,000 meters at the Tomsk-7, Krasnoyarsk-26, and Dimitrovgrad sites. Currently, it is believed that up to 1.6 billion curies exist underground at the Tomsk-7 and Krasnoyarsk-26 sites, and waste injection is still ongoing. This is in addition to the several hundred million curies that have been discharged to surface waters at the Mayak and Tomsk-7 sites. Investigations are now being started to understand contaminant migration and potential human and environmental impacts from well-injection disposal activities.

This paper briefly compares the United States and Russian weapons complexes and provides a perspective on the releases of radioactivity to the environment in both countries. Fortunately, the technologies, data, models, and scientific experience that have been gained over the last 50 years are being shared between the U.S. Department of Energy (DOE) and Ministry of Atomic Energy of the Russian Federation (MINATOM), which constitutes a new environmental partnership between the two countries.

2. Overview of Russian and U.S. Nuclear Weapons Complexes

Russia continues to focus on the closed nuclear fuel cycle, with reprocessing of commercial reactor spent fuel ongoing at Mayak, and reprocessing of spent fuel from dual-purpose reactors operating at Tomsk-7 and Krasnoyarsk-26. Figures 1 and 2 provide a comparison between the general components and locations of the Russian and United States weapons complexes, showing the production reactor and reprocessing sites, which account for the majority of radioactive materials released to the environment. An obvious distinction between the two countries is that the United States has not operated a production reactor or reprocessing plant since 1988.[1] Pending establishment of

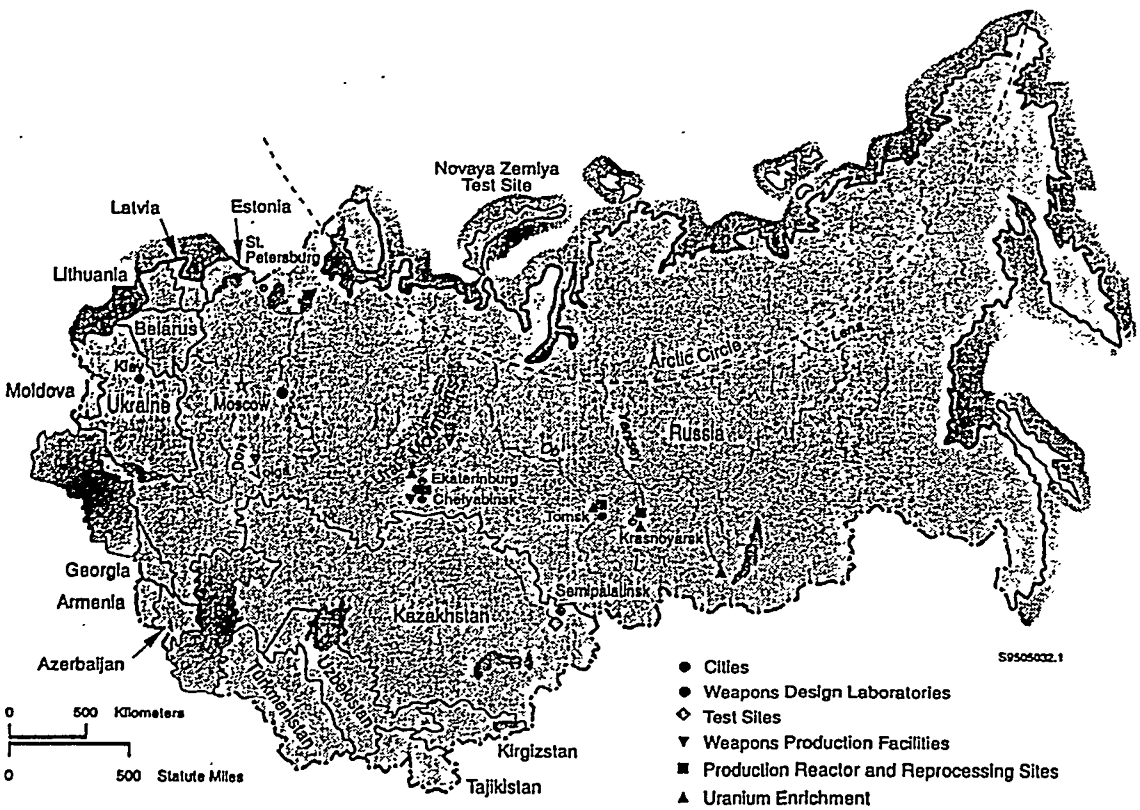

Figure 1. Russian weapons complex.

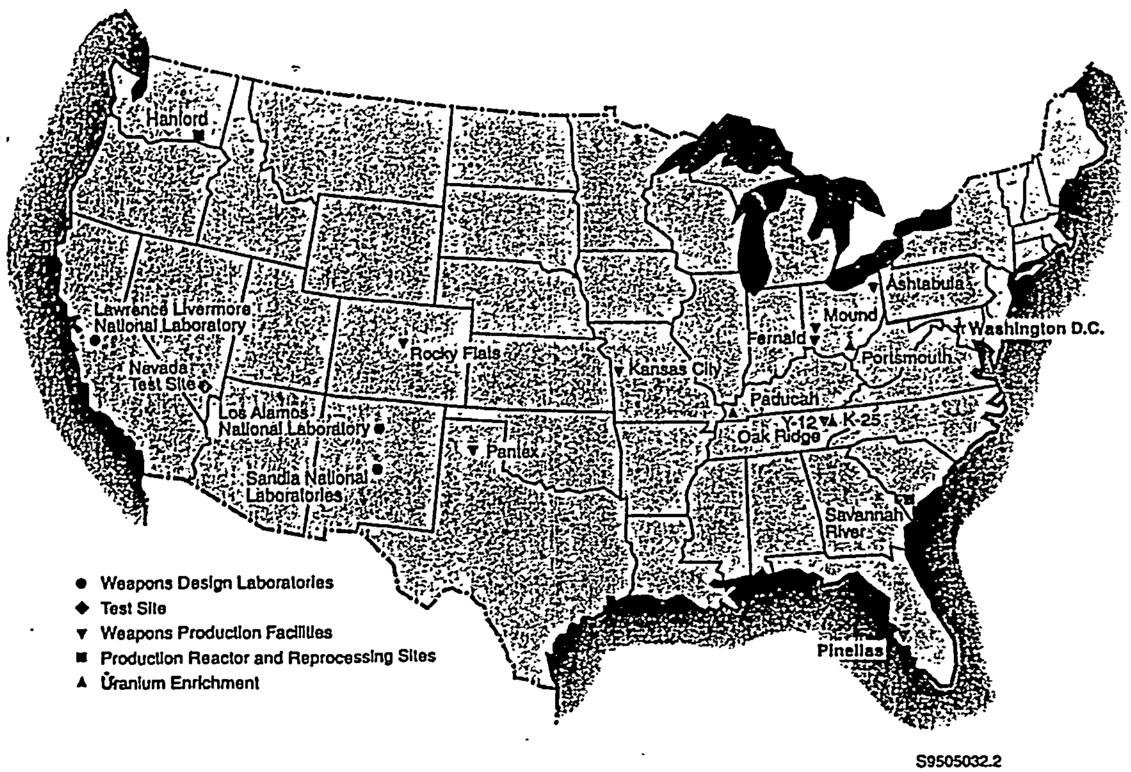

Figure 2. United States weapons complex.

alternative energy sources, the Russians plan to continue to operate their dual-purpose reactors to supply power and heat to the site and local populations.

All activities associated with the nuclear fuel cycle and the use of radioactive materials generate some type of radioactive waste material. Most, however, produce low-level and some intermediate-level waste, while the reprocessing of spent nuclear fuel is the key activity that produces high-level waste. Most of the volume of radioactive materials produced in the nuclear fuel cycle are low-level waste, such as that generated by uranium mining and processing, while the high-level liquid wastes generated during the dissolution of spent nuclear fuel and the subsequent separation of uranium and plutonium contain by far the largest amount of radioactivity in terms of curies. Thus the discharge of only small volumes of high-level wastes into the environment can have severe environmental and human health effects. Figure 3 shows a simplified drawing of the nuclear fuel cycle and the generation of radioactive wastes.

3. Environmental Releases of Radioactivity

For the front end of the nuclear fuel cycle, uranium mining and milling operations have had the largest environmental impact. These activities have resulted in the largest volumes of waste materials generated and left essentially unprotected in the environment.

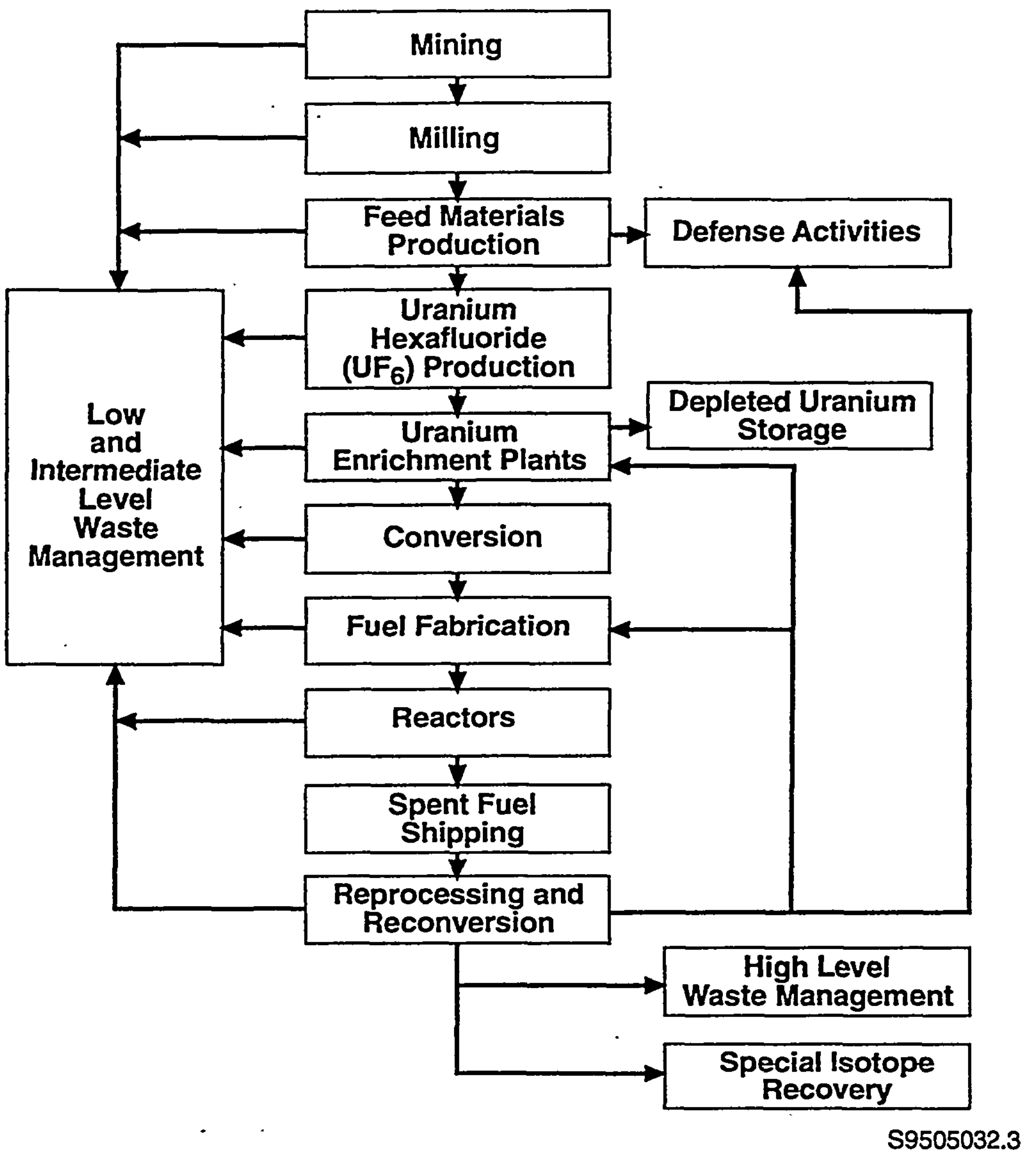

Figure 3. Waste generation in the nuclear fuel cycle.

As of 1990, the former Soviet Union (FSU) had accumulated approximately 5 x 10^9 tons of mill tailings. The Russians expect to cover their mill tailings, probably with a 1.5 meter clay top covered with grass by the year 2000.[2] The total contaminated area from uranium mining and milling operations in the FSU is estimated at 600 km^2 [3] while the radioactive inventory of tailings piles is estimated to be 600,000 curies.[4] The radioactive inventory in U.S. uranium mill tailings piles equals 500,000 curies.[1] Uranium mill tailings in the U.S. are subject to an extensive effort to remediate contaminated mill tailings sites via the DOE Uranium Mill Tailings Remedial Action Program (UMTRA). Of the total of 24 sites being addressed by UMTRA, having a total of approximately 4 km^2 of contaminated tailings site area,[5] 13 have been completed as of December 1994. As of 1986, the Environmental Protection Agency issued its final rules for ^{222}Ra emissions from tailings piles. Mill owners have 6 years to phase out the use of large existing tailings piles. New tailings piles must be smaller than 40 acres with no more than 10 acres uncovered at any one time.[6] One method used to remediate U.S. tailings piles is removal of the tailings materials and placement into a new multi-barrier engineered repository. The repository is designed to reduce radon emissions, prevent the infiltration of water, and provide a erosion-resistant cover that lasts up to 1,000 years.

As far as releases from reactor operations are concerned, the major event which increased the public awareness of radioactive contamination in the FSU was the accident in April 1986 at Ukraine's Chernobyl Unit #4 reactor. While causing significant environmental contamination and human health effects, the amounts of radioactivity currently in the environment from Chernobyl are in fact much smaller than that which has been discharged to the environment at Russian production reactor and spent fuel reprocessing sites. Of the estimated 80 million curies released by the Chernobyl accident,[7] decay correction calculations show that the activity remaining equals about 1.7 million curies.[1]

Most recently, world attention has been focused on Russian contamination of Arctic and Pacific oceans and seas by discharges of radioactive wastes from operation of nuclear reactors on submarines and icebreakers. In this case, the majority of the radioactivity appears to be confined to somewhat robust containment systems, including submarine reactor compartments that have been filled with furfurol. Less robust are numerous containers and barrels, which fortunately appear to contain much smaller amounts of radioactivity. Figure 4 shows the discharge areas in the Kara Sea,[8,9], and Figure 5 shows the discharge areas in the Barents Sea.[10] Figure 6 depicts the radioactive waste discharge areas resulting from Pacific Fleet activities.[11] Tables 1 and 2 list the solid radioactive wastes in the Kara and Barents seas,[9] and Table 3 provides similar information for the Pacific discharge sites.[11]

Although the original estimate of total activity discharged was about 2.5 million curies (Yablokov March 23,1993), the current activity remaining in the Kara Sea is estimated to be about 140,000 curies as indicated in Tables 1 and 2.[12] All of the discharges from the Northern and Pacific fleets taken together, including the loss of a ^{90}Sr source off Sakhalin Island, still constitute less than 0.5% of the current radioactivity in Lake Karachai at the Mayak site alone.

The largest environmental releases of radioactivity by far for both countries are derived from reprocessing. This activity entails the dissolution of spent nuclear fuel and the subsequent separation of plutonium and uranium. Early radioactive waste reservoirs. management of reprocessing wastes included discharging of wastes to rivers, lakes and

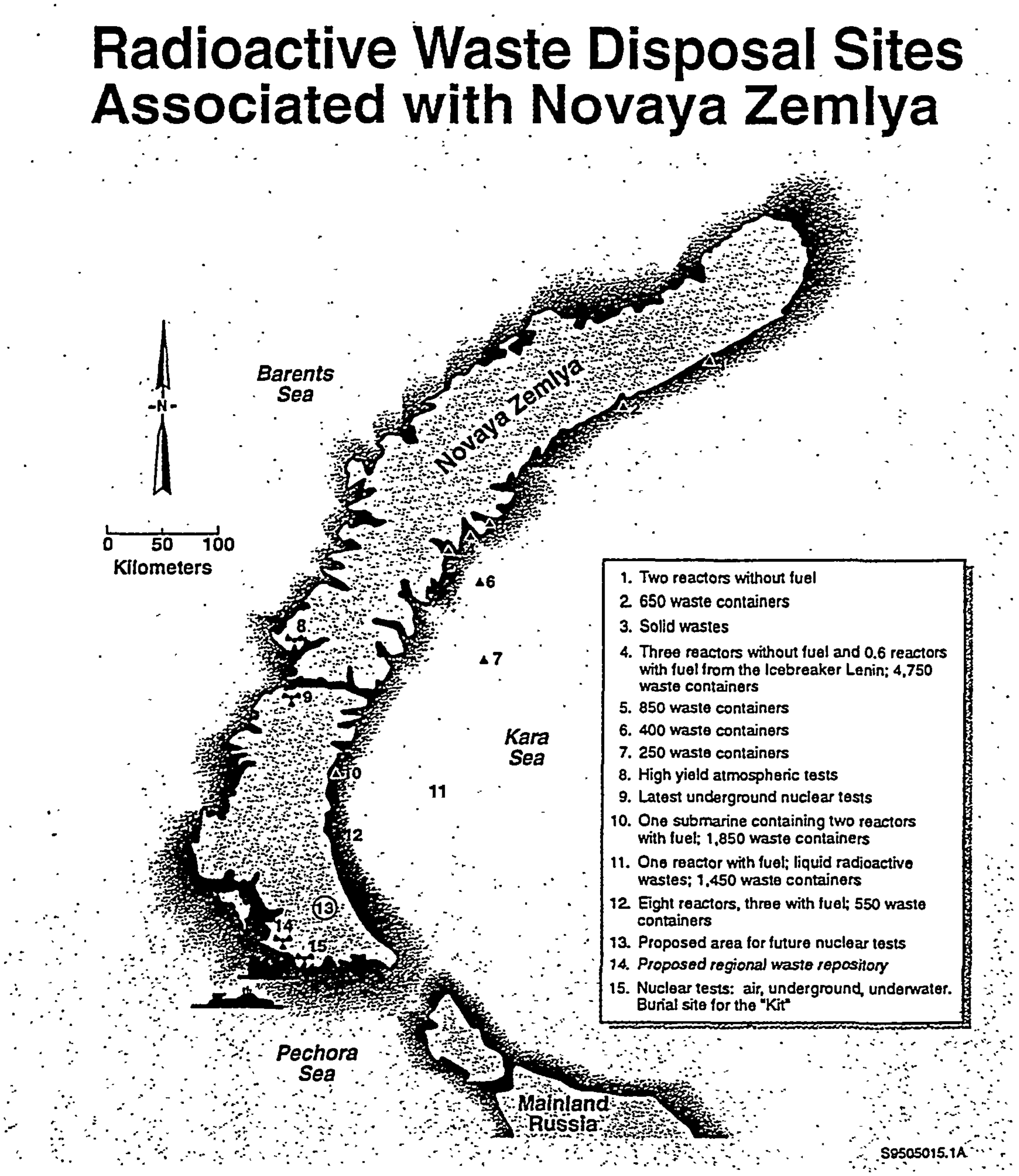

Figure 4. Russian radioactive waste discharge areas in the Kara Sea.

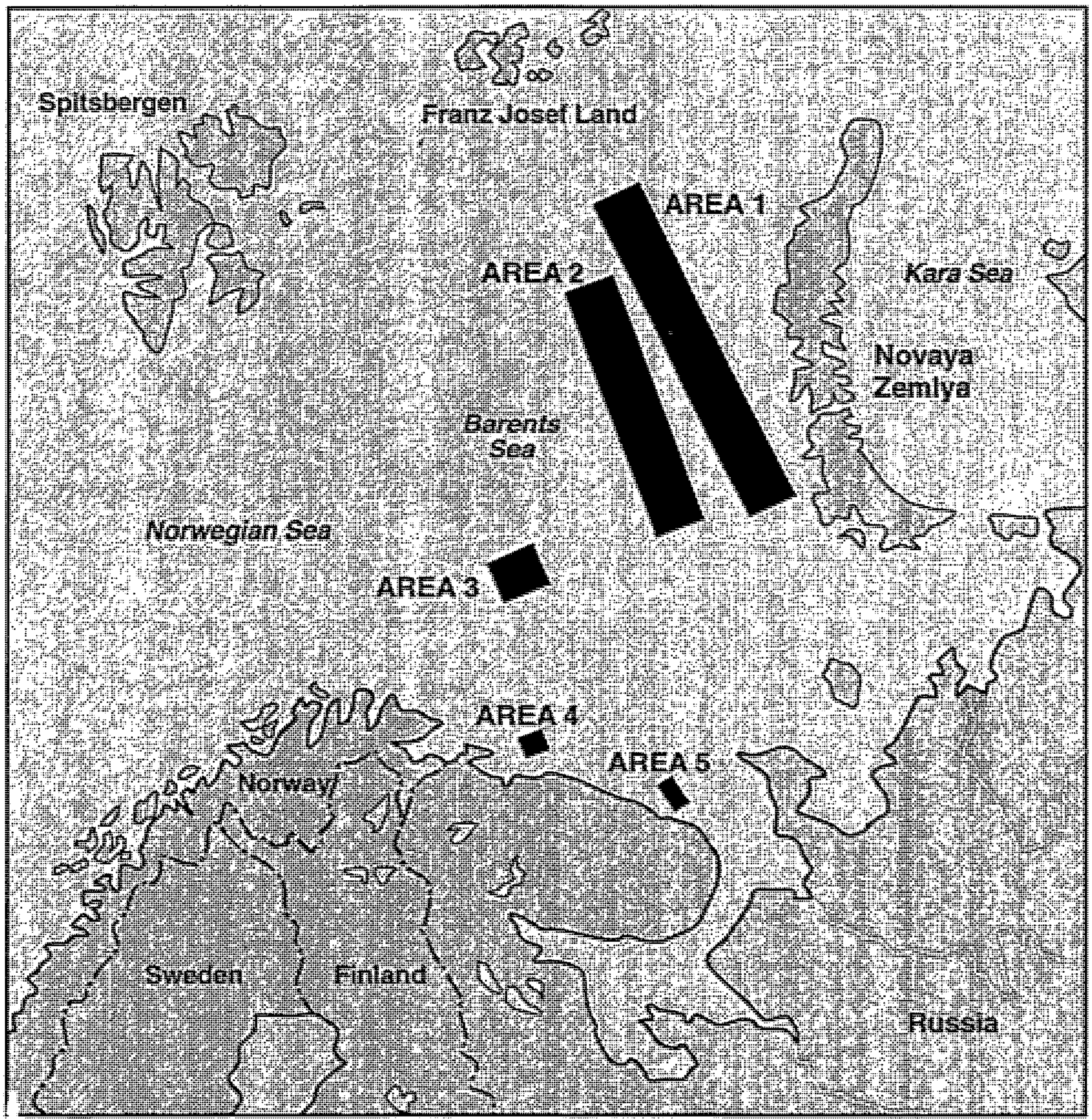

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Figure 5. Russian radioactive waste discharge areas in the Barents Sea.

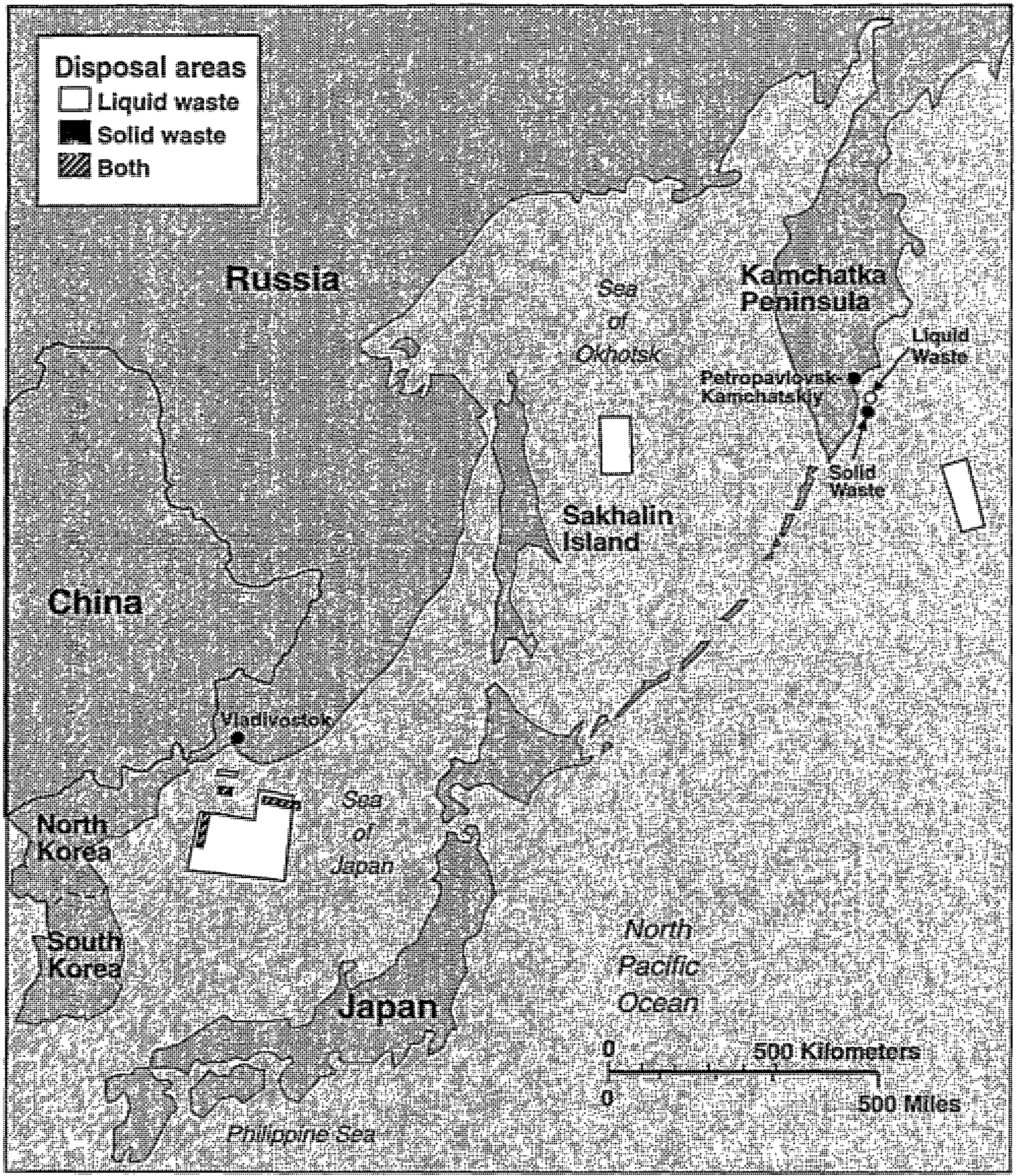

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Figure 6. Russian radioactive waste discharge areas in the Pacific Region.

TABLE 1. Information on the Russian naval reactors discharged to Novaya Zemlya Fjords and the Kara Sea

							Total Activity TBq (kCi)		
			Number of Reactors				White Book [b]	Further Studies	
Site	Year of Dumping	Factory Number	Without Spent Nuclear Fuel	Containing Spent Nuclear Fuel	Dumping Depth[a] (m)	Type of Solid Waste Form	At the Time of Dumping	At the Time of Dumping	1993/1994
Abrosimov Fjord	1965	(No.285)	1	1	20 (10-15)	Reactor compartment	30,000 (807)	11,600 (314)	634 (17.7)
		(No. 901)	-	2	20 (10-15)	Reactor compartment	15,000 (400)	2,950 (79.6)	727 19.7
		(No. 254)[c]	2	-	20 (10-15)	Reactor compartment	500 (14)	93.2 2.52	9.46 (0.256)
	1966	(No. 260)	2	-	20	Reactor compartment	500 (14)	43.7 (1.18)	5.05 (0.137)
Tsivolka Fjord	1967	(OK-150)	3	0.6[d]	50	3 Reactor compartments with a box containing fuel on top	5,500 (150)	19,500 (530)	2,200 (59.5)
Novaya Zemlya Depression	1972	(No. 421)	-	1	300	Reactor in metal container with led shell[e]	30,000 (800)	1,050 (28.3)	293 (7.91)
Stepovoy Fjord	1981	(No. 601)	-	2	50 (30)	Submarine	7,400 (200)	1,360 (36.8)	614 (16.6)
Techeniye Fjord	1988	(No. 538)	2	-	35-40	Reactor in metal container with lead shell	500 (14)	5.59 (0.152)	5.05 (0.137)
Totals			10	6.6			89,400 (2,400)	36,600 (993)	4,490 (122)

(a) Depths from the White Book, those in brackets from Norwegian-Russian Cruise data.

(b) Fission products as in the White Book [10]; activation products estimated on the basis of the White Book as follows: total content of activation products in reactors without spent nuclear fuel not more than 100 kCi (3700 TBq), 50 kCi of which was in 3 reactors of OK-150. Thus remaining 7 reactors contained not more than 7kCi each.

(c) Either 254 or 260.

(d) The SNF was not contained in the naval reactor, but in a reinforced concrete and metal shell.

(e) Probably no furfural.

TABLE 2. Summary data on low- and intermediate-level solid radioactive waste discharged to the Kara and Barents seas from Russian sources

Area	Activities in Curies	Number of Discharges	Years	Remarks
Sedov Fjord	3,410	8	1982-1984	1,108 C, 104 LO
Novaya Zemlya Trench	3,320	22	1967-1991	3,174+? C, 9 LO, 8 V
Tsivolka Fjord	2,684	8	1964-1978	1,600+? C, 6 LO, 1 V
Oga Fjord	2,027	8	1968-1983	472+? C, 4 LO, 1 V
Techniye Fjord	1,845	3	1982-1988	146+? C, 18 LO, 1 V
Stepovoy Fjord	1,280	5	1968-1975	5 LO
Abrosimov Fjord	661	7	1966-1981	8+? C, 7 LO, 4 V
Blagopoluchiya Fjord	235	1	1972	1 LO
Off Kolguyev Island	40	1	1978	1 V

Key to Remarks: C-containers; LO-large objects; V-vessels.

TABLE 3. Characteristics of Russian wastes discharged in the Pacific Region

Region	Sea	Distance from Coast, Miles	Depth, m	Period of Discharge	Type of Radioactive Waste Discharged	
					Liquid, Ci	Solid, Ci
9	Japan	120	3,300-3,400	1974-1993	10,840	3,234
8	Kamchatka	25	2,000-2,600	1969-1992	-	2,993
6	Japan	50	1,900-3,300	1967-1990	-	969
10	Japan	120	2,900-3,300	1974-1984	536	721
7	Kamchatka	20	1,400-1,500	1962-1992	361	-
5	Japan	25	1,100-1,500	1962-1993	117	-
1	Japan	90	3,000-3,400	Not Used		
2	Japan	160	2,800-3,400	Not Used		
3	Okhotsk	160	1,200-1,300	Not Used		
4	Kamchatka	160	4,700-5,300	Not Used		
	Total Curies				11,854	7,917

In the case of Russia, this was followed by extensive injection of these wastes into underground rock formations. These practices have led to significantly larger releases to the environment in Russia in comparison to those in the U.S. The total amount of radioactivity released to the environment [i.e., not contained in any type of engineered barrier system] by both countries nuclear fuel cycles, roughly 1.7 billion curies in current activity, is small (<1%) by comparison to the 440 billion curies of ^{40}K + ^{87}Rb in the world's oceans.[13] However, as opposed to the dispersed nature of this large amount of naturally occurring radioactivity, the 1.7 billion curies is concentrated in small areas, thus offering the potential for substantial environmental and human health impact.

In the U.S., the main releases of radioactive materials to the environment occurred at the Hanford, Savannah River, and Oak Ridge sites. The amounts of the releases in current activity, as well as that contained in U.S. uranium mill tailings piles, are given in Table 4.[1]

TABLE 4. United States environmental contamination from nuclear materials production

Location	Estimated Current Activity of Radioactivity Released, Curies	Type of Discharge
Oak Ridge Site	1,000,000	Injection of wastes underground
Savannah River Site	900,000	Liquid discharges to streams and seepage basins
Hanford Site	700,000	Liquid discharges to soils and surface ponds

The largest radioactive waste releases in Russia have occurred in western Siberia as a result of discharging radioactive waste streams, resulting from the reprocessing of spent fuel from plutonium production reactors, to the environment. Beginning in the late 1940s, wastes were released to surface water systems at the Mayak site. The underground disposal of radioactive wastes via well injection, starting in the 1960s, has introduced radioactivity into the environment, significantly so for Russia at its Tomsk-7 and Krasnoyarsk-26 sites. In the United States, about 3 million curies has been released to the environment, while in Russia our understanding is that approximately 1.7 billion curies have been released, in current activity.

Several activities that have resulted in the have release of radioactivity to the environment are outside of the nuclear fuel cycle, and will not be discussed in this paper. The largest by far of these is from weapons testing activities, and in the case of the FSU, an extensive program involving the use of peaceful nuclear explosions for earth moving, storage cavity formation, and oil and mineral recovery. Other activities that have resulted in some contamination arise from the use of radioisotopes in medicine, research, and industry. Summaries of information available on these topics are available.[14,15,16] Due to the less well-known nature and size of the contamination at Russia's production reactor and reprocessing sites, the remainder of this paper will focus its attention on the Mayak, Tomsk-7, and Krasnoyarsk-26 sites.

3.1. THE MAYAK SITE

The Mayak Production Association, or Mayak, is located about 70 km north of the city of Chelyabinsk in Russia. It is the site of the first production reactor complex built in Russia, and has been significantly contaminated by direct discharges of radioactive wastes to the environment for over 40 years.[17] Mayak is the only facility for VVER-440, fast-reactor, and naval spent fuel reprocessing and has the largest facility for producing radioisotopes. The nuclear site is now referred to as Mayak. The city housing the Mayak workers, formerly called Chelyabinsk-65, has been renamed Ozersk.[18]

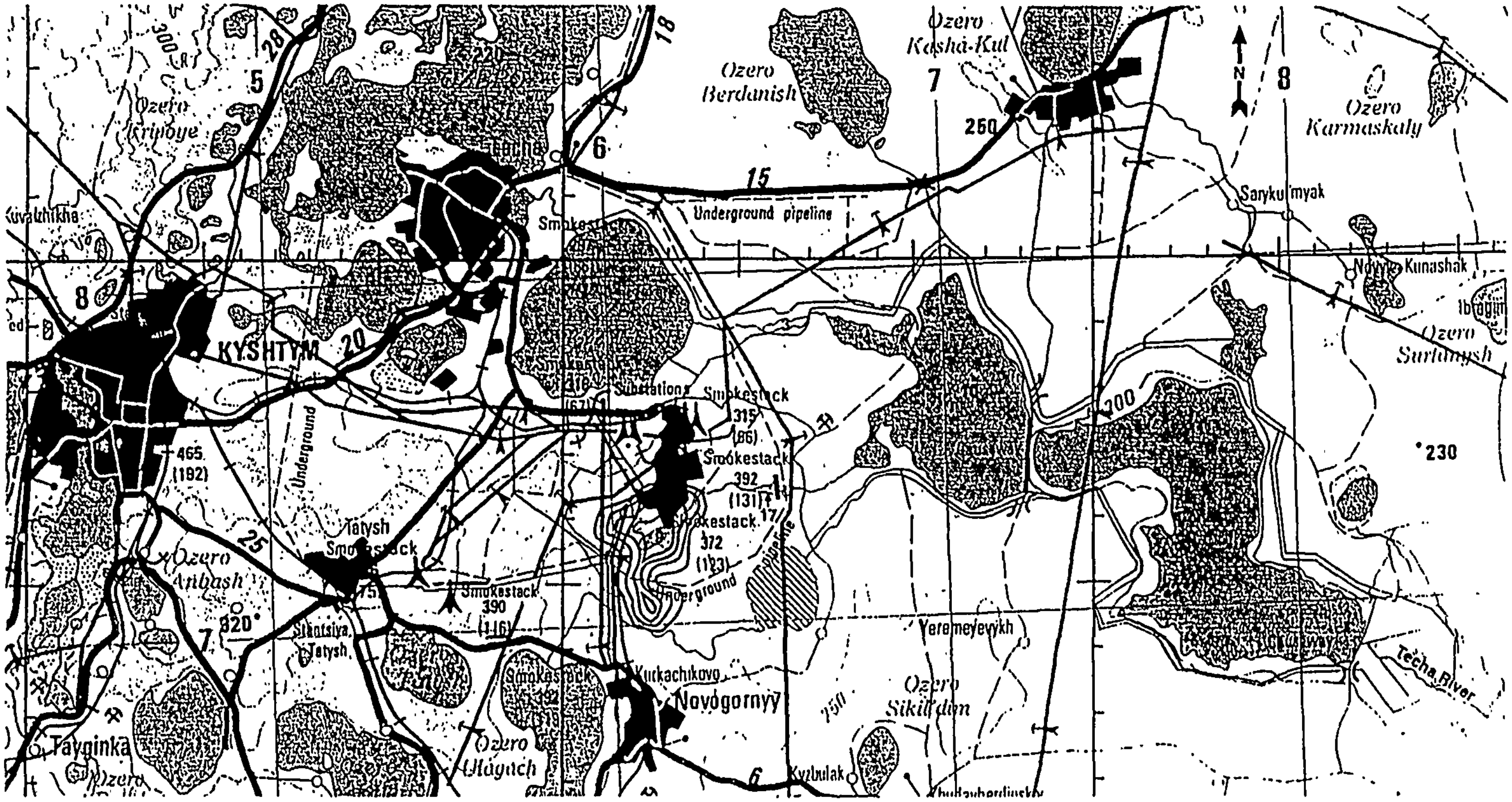
As of 1991, about 800 million curies [17] liquid high-level waste (HLW) was stored in more than 60 tanks at Mayak.[19] The tanks are stainless steel placed in reinforced concrete "shells" with a metal liner. Some of these wastes likely have been removed and solidified at the vitrification facility located at Mayak, as part of an active program addressing the treatment and solidification of sludges and precipitates in their storage tanks.[20] One of the major waste management accomplishments at Mayak is the effort to solidify these high-level liquid waste solutions using the vitrification process. Mayak, in concert with several research institutes, began a program to develop vitrification of HLW in 1967. The first ceramic melter with a feed solution capacity of 500 L/hour was operational in 1986.[21] Following the shutdown of this melter in 1987 because of electrode problems, a modified second ceramic melter began operation in June 1991.[20] As of the fall of 1994, this second melter had solidified about 220 million curies into phosphate-based glass, roughly equal to the entire high-level waste tank inventory at the Hanford site.[22] Russia is now continuing its research on second generation high-level waste solidification systems-primarily through the development of induction heated melters to produce synthetic minerals species that can be tailored to specific wastes streams and hopefully offering higher durability than glass waste forms.

While a large portion of the radioactive wastes at the Mayak site has been stored in tanks, a series of releases to the environment has contaminated the site and the surrounding area. Figure 7 shows a map of the contaminated reservoirs associated with Mayak.[23] The mid-1993 status of the contaminated areas at the Mayak site was as follows:[24]

- 120 million curies in Lake Karachai (Reservoir #9 in Figure 7). Lake Karachai also has generated a contaminated underground plume having a volume of 5 million m^3, and radionuclides are penetrating into uncontaminated water-bearing zones.

- 2 million curies of low-level radioactive waste in 380 million m^3 of water located in the man-made reservoir system.

- 10 million curies contained in 500,000 tons of solid radioactive waste in burial grounds.



Contamination Plumes from Lake Karachai, Reservoir #9

Scale
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Figure 7. Map of Mayak contaminated reservoirs.

- About 2 million curies, including tritium, in Lake Staroe Boloto (Reservoir #17), into which liquid wastes continue to be discharged.[25,23,26]

- Contamination from ^{90}Sr as a result of the 1957 HLW tank explosion: ~1,000 km^2 at a contamination density above 1 Ci/km^2. Some parts of the Mayak site and sanitary-protective zone are contaminated up to some "ten and hundreds" of Ci/km^2.

In addition to these discharges, cooling waters from the once-through cooled reactors were discharged into some of the reservoirs surrounding the Mayak site, such as Lakes Kyzyltash and Tatysh (Reservoir #6).[27] As a result of these releases, about 500,000 people have received an "elevated radiation dose," and about 18,000 have been relocated.[25,23,26] There have been four contamination events which will be briefly discussed that define environmental contamination at Mayak:

- direct discharges to the Techa River starting in 1949 and essentially ending in 1956

- discharges to Lake Karachai starting in 1951 and continuing at a low level today

- wind-borne contamination from the dried shores of Lake Karachai due to a drought in 1967

- explosion of a HLW tank in 1957.

3.2. TECHA RIVER AND RESERVOIR CONTAMINATION

The contamination of the Techa River, artificial reservoirs, and the Asanov Marsh area located downstream from Reservoir #11 is associated with the direct discharge of high-level and other waste streams to the Techa River, primarily from 1949 to 1952. During this period, 76 million m^3 of liquid wastes were discharged, with a total beta activity of 2.75 million curies.[25] About 124,000 people who lived near the Techa River were exposed to radiation, of which 28,100 who lived along the bank received the highest doses.[28] In 1951, the Russians started to build a cascade of reservoirs along the Techa River to prevent radionuclide migration from the most contaminated upper floodlands of the river and to store low-level radioactive wastes. Table 5 details the contamination characteristics of the waste storage basins at Mayak.[27,16] The reservoirs are very much of concern today, as contamination is seeping from them which can then migrate downstream to the Ob river.

3.3. LAKE KARACHAI

Radioactive waste discharges to Lake Karachai (Reservoir #9, Figure 7), a small natural lake near the Mayak reprocessing area, began in 1951, corresponding to the stoppage of large discharges of radioactive waste to the Techa River. The Russians have not accurately measured the total activity in the lake: 120 million curies is their best estimate of the current activity, of which 80 million curies are estimated to be from ^{137}Cs

TABLE 5. Contamination Characteristics of the Mayak Site Reservoirs

	Concentration of Radionuclides in Solution, Ci/liter				Concentration of Radionuclides in Sediments, Ci/kg		Total Curie Content		
Reservoir Number	^{90}Sr	^{137}Cs	Tritium[(a)]	Sum of Alpha Emitters	^{90}Sr	^{137}Cs	In Solution Ci	In Sediments Ci	Total Ci
9[(b)]	1.7×10^{-3}	1.2×10^{-2}	5.3×10^{-5}	5.7×10^{-6}	0.3	1.4	8.4×10^{6}	$1.1. \times 10^{8}$	1.2×10^{8}
17	7.0×10^{-4}	4.0×10^{-6}	1.0×10^{-4}	1.2×10^{-5}	1.2×10^{-1}	3.3×10^{-2}	4.5×10^{4}	2.0×10^{6}	2.0×10^{6}
10	3.5×10^{-7}	8.6×10^{-9}	3.2×10^{-7}	1.0×10^{-11}	3.5×10^{-6}	1.5×10^{-4}	5.0×10^{4}	6.0×10^{3}	1.1×10^{5}
11	5.1×10^{-8}	$<2.0 \times 10^{-11}$	4.5×10^{-8}	$<2.0 \times 10^{-12}$	1.3×10^{-6}	1.3×10^{-7}	2.4×10^{4}	1.5×10^{4}	3.9×10^{4}
2	1.1×10^{-8}	4.5×10^{-9}	2.5×10^{-7}	1.2×10^{-1}	1.3×10^{-6}	3.0×10^{-5}	2.0×10^{3}	1.8×10^{4}	2.0×10^{4}
3	1.6×10^{-6}	2.0×10^{-7}	1.4×10^{-6}	3.0×10^{-10}	1.4×10^{-4}	1.0×10^{-3}	2.6×10^{3}	1.53×10^{4}	1.8×10^{4}
4	1.7×10^{-7}	7.3×10^{-8}	5.2×10^{-7}	4.5×10^{-9}	4.0×10^{-6}	6.0×10^{-5}	1.7×10^{3}	4.2×10^{3}	$\sim 6.0 \times 10^{3}$
6	3.7×10^{-10}	2.0×10^{-11}	1.0×10^{-8}	1.0×10^{-10}	3.0×10^{-7}	$<1.0 \times 10^{-12}$	2.0	3.0×10^{2}	3.0×10^{2}

(a) Reported as HTO.
(b) Reservoir #9, Lake Karachai, has a sum of beta emitters in solution of 1.9×10^{-2} Ci/liter, and a sum of alpha emitters in sediments of 3.9×10^{-5} ci/kg.

with ^{90}Sr making up most of the remainder.[29] In 1967, winds carried about 600 curies, primarily associated with dust from the dried exposed shoreline of Lake Karachai, up to 75 km from the site.[30]

Of primary concern is the ^{90}Sr in Lake Karachai; the strontium seems to be migrating while the cesium appears to be primarily bound to the clays at the lake bottom. Organic materials, such as solvents, have also been discharged to Lake Karachai, which contribute to the problem of contaminant migration. Mayak is still discharging low-level liquid waste to Lake Karachai to maintain the water level of the lake to prevent wind-borne releases of contamination.[29] From 1951 to 1989, 5 million m^3 of contaminated solutions entered the water-bearing strata underneath the lake. The front of the southward migrating plume of contaminated ground water, which has a ^{90}Sr concentration of 0.1 nCi/L, has advanced 2.5 km over 40 years and is approaching the Mishelyak River.[24] Figure 7 shows the contamination plumes emanating from Lake Karachai.[23]

The Russians have been filling in Lake Karachai since 1967 to minimize the release of contaminants to the environment.[31] About 5,000 hollow concrete blocks, 1 meter on a side with one side open, have been placed into the lake as of October 1991. They are intended to trap the muddy bottom deposits inside, preventing them from "squeezing" up the sides of the lake bank as the lake is gradually filled. Following emplacement of the concrete blocks, rock and soil are then used to cover them up. Lake Karachai had been reduced to about 0.20 km^2 by October 1991, down from the original size of 0.45 km^2. During a recent visit to Lake Karachai, a dose rate of 300 to 600 mr/hour at a point about 30 to 40 feet from the lake edge was observed.[20]

3.4. HIGH-LEVEL WASTE TANK ACCIDENT - 1957

Following the discharges directly to the Techa River starting in 1949, and then to Lake Karachai in 1951, the Russians began construction of waste storage tank facilities at Mayak in 1953. In 1957, one of these HLW storage tanks exploded. Of about 20 million curies contained in the tank, 2 million curies were expelled into the atmosphere and surrounding environment. The tanks, which contained HLW solutions with up to 100 g/L sodium nitrate and 80 g/L of sodium acetate, had been cooled by water. Due to inadequate capacity at the site to clean up the resulting contaminated cooling water following a pipe leak, only periodic cooling was used, which eventually led to overheating of the dried explosive salts.[32] On September 29, 1957, the waste tank exploded.[33] The radioactivity discharged into the atmosphere was spread by 25 km/hour winds.[30] Figure 8 shows a large-scale map of the contamination plumes from the 1957 HLW tank accident [34] and the wind-blown contamination plumes from Lake Karachai in 1967.[23]

3.5. TOMSK-7 SITE

Tomsk-7, the second of the Russian production reactor and reprocessing sites, is located near the city of Tomsk, and has been renamed Seversk.[18] Significant contamination

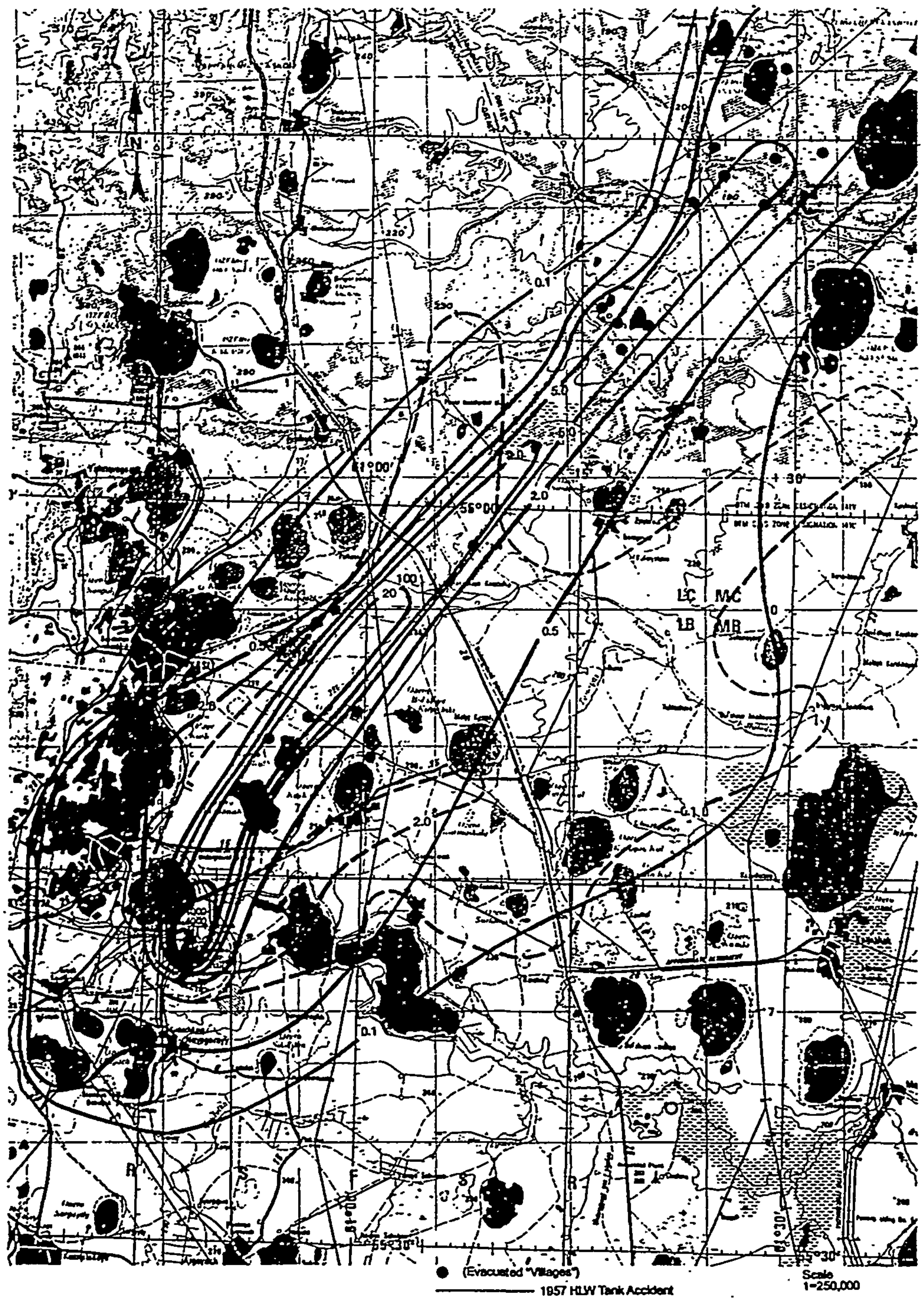

Figure 8. Map of contamination plumes from the 1957 HLW tank accident and the 1967 wind-blown contamination from Lake Karachai.

of the surrounding environment has occurred, both to surface water systems such as ponds and reservoirs, and to the underlying geologic media via well injection. A total of 8 million m^3 of wastes have been discharged into the ponds and reservoirs at Tomsk-7,[35] which are reported to contain 130 million curies of radioactive waste,[4] thus making them as contaminated as Lake Karachai at Mayak. Also, the Russians discharged up to 42,000 m^3/day of contaminated cooling water to the Tom River from several of the plutonium production reactors at Tomsk-7.[35]

The main waste management activity at Tomsk-7, however, appears to be the use of well injection to dispose of radioactive waste in underground formations chosen to isolate the wastes from the surrounding environment. This technology has been employed since 1963 at Tomsk-7, Krasnoyarsk-26, and at the Scientific Research Institute for Nuclear Reactors at Dimitrovgrad.[36] Some attempts have been made to predict the state of the waste components (chemical and radiochemical composition) as well as the properties of the geologic medium into which the wastes were placed.[37] The injection layers at Tomsk-7 are reported to be from depths of approximately 240-290 meters (low-level liquid wastes) to 310-340 meters (high-level liquid wastes) in sandy Cretaceous strata.[38] With radioactive waste injection rates of 175 m^3/hour, a total of 32 to 33 million m^3 of wastes had been disposed of by 1992 at Tomsk-7.[35] MINATOM officials have stated that the radioactive waste disposed of underground has a total radioactivity of 1 billion curies.[39]

The most recent incident at Tomsk-7 that resulted in environmental contamination occurred on April 6, 1993. A fuel reprocessing plant at Tomsk-7 was severely damaged as a result of a runaway exothermic reaction in a large process vessel. The reaction produced large amounts of flammable organic and inorganic gases and steam that pressurized and ruptured the process vessel. A release of approximately 40 curies lightly contaminated a largely forested and unpopulated area to the northeast of the site.[40]

3.6. KRASNOYARSK-26 SITE

Construction of Krasnoyarsk-26, the third Russian production reactor and reprocessing site, was begun in 1950. The site is located 40 km from the city of Krasnoyarsk [41] and has been renamed Zheleznogorsk.[18] Environmental contamination at Krasnoyarsk-26 is the result of discharges to reservoirs and injection of radioactive waste into deep underground wells. There are four reservoirs at Krasnoyarsk-26 with a reported maximum radioactivity content of 50,000 Ci. The Russians are currently "liquidating" one of the ponds by adding earth and sorbents for cesium.[29] The reservoirs, used as sedimentation ponds, are located near the Yenisey River. To minimize the risk of the reservoirs overflowing, a drain pipe siphons off excess water directly to the Yenisey.[42]

Liquid radioactive waste from the reprocessing of production reactor fuel has been pumped underground since 1963 into the Jurassic clay and aquiferous sandy strata beneath Krasnoyarsk-26, and the practice continues today. The waste has been injected in two different strata; 2.5 million m^3 of low-level wastes (at a depth of 190-225 meters) and 2.0 million m^3 of intermediate- and high-level wastes (at a depth of 380-475 meters).[38] Liquid radioactive wastes are transported via a 15-km-long pipeline to the injection facility, which consists of a dual system of injection and discharge wells. As radioactive waste is pumped in, underground stratal water is drawn off, and a system of observation wells monitors the process.[43] According to Russian scientists, the current activity of injected wastes at this site is 450 million curies, out of a total injected activity of 1 billion curies.[44]

A new installation for the underground injection of radioactive waste was planned for the west side of the Yenisey River. Tritiated liquid reprocessing wastes were planned to be injected into underground clay formations at this site, known as "Site 27," which is 10 km from a new reprocessing plant called RT-2 that is under construction. A tunnel was built under the river to transport liquid waste to the new injection facility.[45] Work stopped at Site 27 in 1989, primarily due to public and environmentalist protests.[46]

In summary, Figure 9 shows graphically the distribution of contamination from all three of the Russian production reactor sites that have just been discussed. The determination of the potential impacts to the environment and human health from these discharges to surface water systems and underground formations is believed to be one of the critical needs of waste management studies in Russia.

4. DOE-EM/Russian Program

The U.S. Department of Energy and Russia's MINATOM have agree to share environmental restoration and waste management technologies via a Memorandum of Cooperation (MOC). The best solution to environmental contamination from the weapons complexes in both countries involves working together and sharing technologies. Russia is unique in that past practices offer a once-in-a-lifetime opportunity to understand the various aspects of waste management and cleanup. The number of technology exchanges and joint projects has been growing steadily and is expected to play an important role in achieving each country's goals of cleanup and waste management at their nuclear weapons complexes.

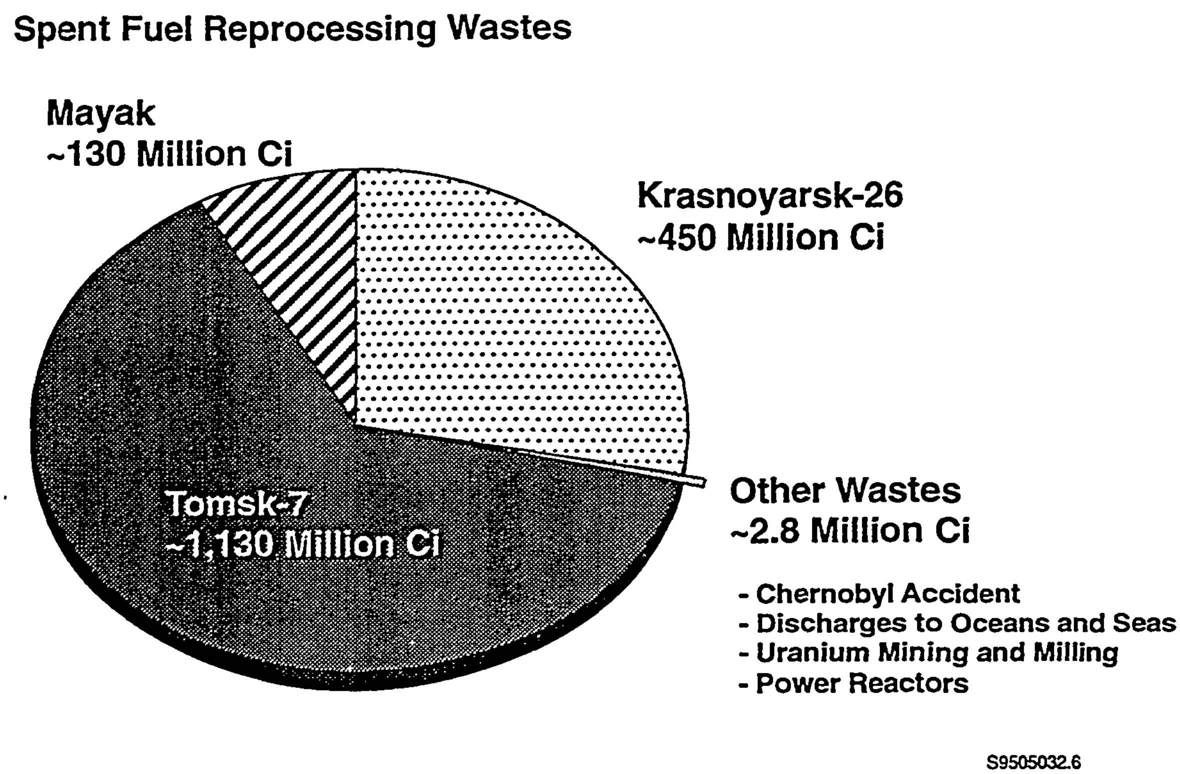

Figure 9. Distribution of Russian nuclear environmental contamination.

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