CHEMICAL SEPARATION PLANTS IN RUSSIA:

WHY FURTHER OPERATIONS SHOULD BE DEFERRED

by

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I.   INTRODUCTION.

Chemical separation facilities - also referred to as reprocessing plants - are used to chemically separate out the plutonium and unused uranium from the highly radioactive fission products and other wastes in the irradiated fuel elements or removed from nuclear reactors.[1] The separation of the plutonium from fission products and uranium represents an essential step in the production of plutonium for nuclear weapons. Since plutonium can also be used a nuclear reactor fuel, reprocessing plants are also used to recover plutonium and uranium from the spent fuel of nuclear power plants and other civil reactors for subsequent recycling into fresh nuclear fuel.

As a consequence of bilateral and unilateral actions by the United States and the Commonwealth of independent States, large surpluses of weapon-grade plutonium will be created in the United States and Russia over the coming decade. Large surpluses of reactor-grade plutonium are projected to accumulate in France, United Kingdom, Japan and Russia as a consequence of ongoing reprocessing of spent power reactor fuel.

In this paper we examine the relationships among (a) further reductions in the stockpiles of nuclear weapons, (b) the stockpiles of separated military and civil plutonium, and (c) the continued operation of the chemical separation plants. We will argue that all chemical separation plants, both military and civil, should be shut down, at least until the military and civil plutonium surpluses are substantially eliminated. We begin by reviewing the current status of plutonium production and stockpiling in the United States and Russia.

II.   STATUS OF PLUTONIUM PRODUCTION, SEPARATION, AND STOCKPILING IN THE UNITED STATES AND RUSSIA.

A.   United States.

The United States ceased production of plutonium for weapons in 1988, when the last of its 14 plutonium production reactors - nine at the Hanford Reservation and five at the Savannah River Site (SRS) - was shut down. (The United States ceased production of highly-enriched uranium (HEU) for weapons in 1964, when the facility for conversion of HEU hexafloride to HEU metal at the Y-12 plant in Oak Ridge was shut down.) The U.S. Department of Energy (USDOE) has canceled plans to construct a new tritium production reactor at SRS, announcing that it had sufficient tritium for weapons through 2010.

The PUREX chemical separation plant at the Hanford Reservation (as well as its predecessor facilities, the Redox plant) which separated plutonium produced at the Hanford production reactors has been shut down. The Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL), which processed naval and research reactor fuel, has been shut down. The USDOE had announced that the F- and H-area chemical separation plants at SRS will be phased out of operation in five years after processing remaining inventories

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[1] In plutonium production reactors that utilize highly enriched uranium fuel, the plutonium is produced in separate natural, or depleted, uranium target elements. The target and fuel elements are processed separately.

of fuel and target materials from past operations of the SRS production reactors. Limited processing is planned at the "HB-line" at SRS to recover Pu-238 for space reactors.

The United States has approximately 100 metric tons (MT) of weapon-grade plutonium in weapons and available for weapons.

Since 1972 there have been no operating commercial reprocessing plants in the United States. The Nuclear Fuel Services (NFS) plant operated from 1966 to December 1971, but was shut down to expand its reprocessing capability from 200 to 750 metric tons of heavy metal per year (MTHM/y). This facility was plagued by technical problems, adverse publicity, and financial difficulties. Cleanup of groundwater contamination and remaining waste of the NFS site is now expected to cost nearly $900.[2] In September 1976 NFS notified the U.S. Nuclear Regulatory Commission (USNRC) that they were abandoning plans to reprocess fuel because of economic reasons. A second reprocessing plant, the 300 MTHM/y Midwest Fuel Recovery Plant near Morris, Illinois was constructed but never operated because of design and technical problems. A third plant, the 1200 MTHM/y Allied General Nuclear Services (AGNS) plant at Barnwell, South Carolina was canceled during construction after President Ford refused to subsidize its completion and after the Carter administration asked the USNRC not to grant AGNS an operating licence.

In 1976, in his final months in office, President Ford announced that "avoidance of proliferation must take precedence over economic interest and that reprocessing should be deferred until there is sound reason to conclude that the world community can effectively overcome the risks of proliferation." In April 1977 President Carter declared that commercial reprocessing would be deferred indefinitely, and requested that no further commercial spent fuel reprocessing would be licensed by the USNRC due to the risk of proliferation of nuclear weapons represented by this technology. This effectively put an end to civil reprocessing in the United States. President Reagan reversed the Carter policy and encouraged commercial fuel reprocessing, but there was no longer commercial interest due to the fact the reprocessing and recycling of plutonium was more costly than operating power reactors on a once through cycle.

On December 8, 1992, the U.S. Department of Defense (USDOD) notified the Department of State that authorization for export of spent fuel assemblies from the Shoreham nuclear plant in New York to the Cogema reprocessing plant in France would be "inimical to the common defense and security of the United States," because it would seriously undermine U.S. non-proliferation policy, particularly as it relates to the Korean Peninsula. It is the policy of the United States that the proliferation risks from both reprocessing and enrichment on the Korean Peninsula are unacceptable. The USDOD also noted that approval of the Shoreham application would foreclose more economic and proliferation resistant storage options which are available for spent reactor fuel.

B.   Russia

There are at least three large chemical separation facilities currently in operation in Russia, at Chelyabinsk-65, Tomsk-7 and Krasnoyarsk-26. The sites are also the locations of the

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[2] USDOE, "Environment, Safety & Health Needs of the USDOE," DOE/EH - 0079, December 1988, V. 2, p. 229.

plutonium production reactors of the nuclear weapons program. The chemical separation plants are described more fully below.

RT-1 Radiochemical Plant at Chelyabinsk-65: Chemical separation of plutonium for weapons began at Chelyabinsk-65 in 1949, shortly after the first production reactor went on line. The principal chemical separation plant that is still operating, now designated RT-1, started processing spent fuel from the five plutonium production reactors in 1956. We can estimate the capacity of the chemical separation plant from the production reactors it serviced. We estimate the combined capacity of the five graphite moderated plutonium production reactors was 6565 megawatts (thermal) (Mw_t). Using the Hanford B-Reactor as a model, at a burnup of 500 megawatt (thermal) days per metric ton (Mwd/MT), the reactors could produce 0.86 grams of plutonium per Mwd (g Pu/Mwd) of weapon-grade plutonium (4.6% Pu-240). Operating at a capacity factor of 60 percent, the five reactors could produce annually some 1.2 MT of plutonium from 2900 MTHM/y of natural uranium fuel.[3]

In 1976 RT-1 was modified to process spent fuel from naval propulsion reactors, and in 1977, shifted from processing military production reactor fuel, to processing spent fuel from naval (both submarine and civil icebreaker) reactors (which apparently occurred first), test reactors, and the older model light-water moderated and cooled power reactors (VVER-210s, -230s, and -440s).[4] It is the only fuel reprocessing plant in Russia used for power and naval reactor fuel reprocessing.

In 1989 it was reported that over the plants 10-year "civilian" lifetime, throughput has averaged 200 MTHM/y.[5] And in the same year Evgeniy Mikerin, the ministry official responsible for plutonium production and separation, said the Soviet stockpile of plutonium recovered by RT-1 amounted to "around 20 tons."[6] One MT of VVER fuel (with an initial enrichment of 3.6%) after a burnup to 30,000 Mwd/MT, contains about 8.75 kg of plutonium.[7] If we assume RT-1 has processed mostly VVER fuel it would have recovered 17.5 MT of plutonium from 2,000 MTHM (200 MTHM/y for 10 y). If we assume naval reactors are similar to VVER, but operate at an average initial enrichment of 10% U-235, then for burnups from 30,000 to 50,000 Mwd/MT, some

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[3] U.S. military chemical separation plants operated at a 50 percent capacity factor. If this also applies to the Russian plants, then RT-1, when it was processing natural uranium metal fuel from the production reactors, would have had a rated capacity of about 6000 MTHM/y.

[4] Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22; Oleg Bukharin, "Soviet reprocessing and waste-management strategies," DRAFT, November 5, 1991. Production reactor fuel is uranium metal. Because VVER fuel, and presumably naval fuel, is in the form of uranium oxide pellets in zirconium alloy (or stainless steel) fuel rods, a second "head-end" was added to the plant to chop the rods and dissolve the UO_2 fuel.

[5] "Soviet Union Postpones Completion of Siberian Reprocessing Plant," *Nuclear Fuel*, October 16, 1989, pp. 1-2.

[6] Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22.

[7] For 30,000 Mwd/MT burnup, we estimate 8.75 kg of plutonium (1.42% Pu-238, 64.24% Pu-239, 20.11% Pu-240, 11.28% Pu-241, and 2.95% Pu-242) (See Table 1, column 3). These figures apply to equilibrium cores. The initial core and the first refueling would be charged with lower enriched fuel.

5.8 to 8.7 kg of plutonium would be produced per MTHM. Thus, it is difficult to estimate what fraction of the spent fuel processed at RT-1 was VVER fuel and what fraction was naval fuel.

By the end of 1991 the stockpile of separated civil plutonium at Chelyabinsk-65 was reported to be about 25 MT.[8] In 1992 it was reported to be about 30 MT, some 10 MT more than reported in 1989. These estimates imply that RT-1 has been recovering about 3 MT of plutonium annually for the last three years. In 1992 Mikerin is quoted as having said, "Currently, it reprocesses 200-250 [metric] tons/year."[9] This suggests the plutonium production rate during the past year has been closer to 2 MT/y. The RT-1 reprocessing plant capacity for this enriched uranium fuel is now given as 500 MTHM/y.[10] If one assumes the plant is in operation only about 50% of the time, this capacity is consistent with a throughput of about 250 MTHM/y.

Tomsk-7 Chemical Separation Plant: The chemical separation facility, or facilities (there may be more than one), may date from the late-1950s when the first of five production reactors went on line. We estimate the combined capacity of the five graphite moderated plutonium production reactors (only two are still operating) was about 10,000 Mw_t. Again, using as a model the Hanford B-Reactor operating at a burnup of 500 Mwd/MT and a capacity factor of 60 percent, we estimate the combined output of the five reactors was 1.9 MT of plutonium (equivalent) annually from 4400 MTHM/y of natural uranium fuel.

In 1977 the Soviets initiated a program of civilian fuel reprocessing and shifted the Chelyabinsk-65 separation plant operations from military to civilian operations. As a result, the Tomsk separation plant began receiving by rail the military production reactor fuel from Chelyabinsk-65 for processing.[11] This would have added an additional 1000-1500 MTHM/y requirement. Presumably these shipments have ceased now that the production reactors at Chelyabinsk-65 are no longer operating. Current plans are to continue to process the fuel from the two remaining (after 1992) production reactors at Tomsk-7.[12]

Chemical Separation at Krasnoyarsk-26: There are three production reactors (only one now operating) at Krasnoyarsk-26, with a combined capacity estimated to be 6000 Mw_t, comparable to the capacity at Chelyabinsk-65. When all three reactors were operating they were capable of producing about 1 MT of plutonium annually from 2600 MTHM of natural uranium fuel. Assuming a 50% capacity factor, we estimate that the chemical separation plant at Krasnoyarsk-26 has a capacity of about 5000 MTHM/y.

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[8] Oleg Bukharin, "Soviet reprocessing and waste-management strategies,"DRAFT, November 5, 1991.

[9] Oleg Bukharin, notes taken at meeting with Evgeniy Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

[10] Oleg Bukharin, notes taken at meeting with Evgeniy Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992. "Soviet Union Postpones Completion of Siberian Reprocessing Plant," *Nuclear Fuel*, October 16, 1989, pp. 1-2, reports RT-1 capacity as 400 MTHM/y. Oleg Bukharin, "Soviet reprocessing and waste-management strategies,"DRAFT, November 5, 1991, reports the capacity as 600 MTHM/y, or 300-900 fuel assemblies/y.

[11] Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22.

[12] Oleg Bukharin, notes taken at meeting with Evgeniy Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

III. THE NATIONAL SECURITY IMPLICATIONS OF CONTINUED PLUTONIUM PRODUCTION AND SEPARATION IN RUSSIA.

It is a widely held view within the arms control community that a pacing item in a country's effort to acquire nuclear weapons is the availability of the fissile material for weapons. As the United States and Russia dismantle their enormous stockpiles of nuclear weapons, the military establishments in each country will carefully weigh the other's capability to rapidly rebuild its arsenal, in assessing how much of the fissile material from weapons should be turned over for civil use. As indicated above the United States has halted plutonium production for weapons and civil plutonium separation, and is phasing out military plutonium separation; while Russia continues produce plutonium for weapons and separate plutonium for civil and military purposes in facilities that are operated by the Ministry of Atomic Energy (Minatom), the ministry responsible for weapons production.

As long as this asymmetry in plutonium production and separation exists, the United States will be reluctant to dismantle the plutonium pits removed from its dismantled weapons, much less to make the plutonium available for civil purposes. In turn, medium nuclear powers, such as China, are likely to be unwilling to dismantle their nuclear weapon stockpiles as long as Russia retains its large weapon-grade plutonium production and separation capability intact and as long as the United States retains its plutonium pits intact.

Thus, in order not to impede further warhead retirements beyond current commitments it is desirable that Russia cease its chemical separation activities.

IV. ECONOMIC IMPLICATIONS OF CHEMICAL SEPARATION IN RUSSIA.

Minatom maintains that economic data related to chemical separation of plutonium in Russia is classified. If these data were correct and available they would probably show that the cost of using MOX fuel, fabricated from the separated plutonium at Chelyabinsk-65,[13] in civil power reactors, is greater than using low-enriched uranium (LEU) fuel. In the West it is clear from the open literature that reprocessing and plutonium recycle are uneconomical.

Minatom maintains that its cost of LEU production is the lowest in the world, largely because of its reliance on gas centrifuge uranium enrichment technology, and low energy and labor costs.[14] Therefore, even if reprocessing and MOX fabrication costs are less in Russia than in the West, this does not imply that the cost of MOX relative to LEU is lower. And in any event Russia's reprocessing costs should be increased to include a program of material accounting and control and decent environmental controls, both of which should but do not presently exist. But it is unnecessary to resolve whether reprocessing and MOX use can compete with LEU. The huge surpluses of separated plutonium that presently exist and that are projected in both the civil and weapons programs make further reprocessing uneconomical.

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[13] Mixed-oxide (MOX) fuel as a mixture of separated plutonium-oxide (PuO_2) and uranium-oxide (UO_2).

[14] This argument has been set forth by Minatom in a lawsuit in the United States, where U.S. uranium producers alleged that Russia was dumping LEU on the market.

Over the next decade Russia will recover and stockpile some 60 to 100 MT of weapon-grade plutonium and some 500 MT of HEU from dismantled weapons. This plutonium is about 35 times less radioactive (See Table 1). In terms of penetrating gamma-rays from the Am-241, built up from the decay of Pu-241 during storage, the weapon-grade plutonium is about 50 times less radioactive than the plutonium from VVERs.[15] Consequently, it will be cheaper to fabricate MOX fuel from weapon-grade plutonium than from the reactor-grade plutonium separated and stored at Chelyabinsk-65. Moreover, MOX, whether fabricated from reactor-grade plutonium or weapon-grade plutonium, cannot compete economically with the huge stocks of HEU from weapons that can be blended down into LEU. Consequently, in a market economy, the cheapest and first product to use as a fuel would be the HEU after blending it into LEU, then the separated weapon-grade plutonium, and finally the separated reactor-grade plutonium; and in any case it appears to be less expensive (and it appears to be safer) to bury the separated plutonium as a waste, rather than use it as a fuel. Thus, it makes no sense economically to continue to separate either weapon-grade or reactor-grade plutonium until these existing stocks are substantially depleted.

V.   ENVIRONMENTAL IMPLICATIONS OF CHEMICAL SEPARATION IN RUSSIA.

As noted above Russia continues to reprocess VVER and naval reactor spent fuel at Chelyabinsk-65, even though there is no economic incentive to do so. The output of the chemical separation plant is on the order of 3 MT of plutonium annually. We do not know what fraction of the separated plutonium is from naval fuel, and what fraction is from VVER fuel. Nevertheless, we can approximate the annual fission product and actinide output at Chelyabinsk-65 by assuming all the plutonium is from VVER spent fuel.

There are two dual purpose reactors still operating at Tomsk-7, and one at Krasnoyarsk-26; each producing weapon-grade plutonium, steam for district heating, and electricity. These large graphite moderated reactors are assumed to have reactor characteristics similar to the Hanford plutonium production reactors in the United States. Two of the Russian reactors has about 2700 channels each, and we assume the third is about the same size. Since all three are dual purpose reactors, we assume produces less than one Kw/channel. We assume each operates at about 2000 Mw$_t$ at a capacity factor of about 0.6.

Based on the above assumptions, we have estimated (as shown in Table 2), the atmospheric radioactive releases, the activity in the high-level radioactive waste, and the plutonium and uranium recovered at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 respectively.[16]

As can be seen from Table 2, assuming that Kr-85 is not captured, there are large releases of this isotope to the atmosphere at each site: about 2 million curies annually at Chelyabinsk-26, and about 300 thousand curies at Tomsk-7. There are also large quantities of liquid high-level wastes: some 100 million curies annually of the long-lived Sr-90 + Y-90m and Cs-137 + Ba-137m,

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[15] In both cases we have assumed the plutonium has aged 10 years since separation, i.e., in storage (or in weapons).

[16] Additional assumptions used in these estimates are given in the Table 2, Notes, following the table.

combined at Chelyabinsk-26; about 10 million curies at Tomsk-7, and about 5 million curies at Krasnoyarsk-26. Historically, a significant fraction of the Cs-137 produced at Chelyabinsk-65 was dumped directly into Lake Karachay. We are told this practice continues today, but we do not know what fraction of the Cs-137 is still disposed in this manner.

At Tomsk-7 over 100 million curies of liquid high-level radioactive waste are being injected directly into deep geological formations, and presumably the same practice is employed at Krasnoyarsk-26 as well. At Oak Ridge in the United States intermediate-level radioactive waste was disposed of in this manner for several years; but this practice was discontinued decades ago because of the higher risks associated with this method of disposal.

In addition, at all three sites there are the usual streams of intermediate-level and low-level liquid wastes effluent, radioactive solid wastes, an occupational radiation exposures associated with chemical separation plants.

Today, emissions from chemical separation plants represent the largest source of radioactive pollution from routine operations of the nuclear fuel cycle. In the past, the mismanagement of nuclear waste from chemical separation plants in Russia has resulted in catastrophic releases of radioactive materials to the environment. Clearly, it make no senses to continue these harmful activities in Russia given that there is no national security or economic benefit to do so.

These radioactive pollutants are virtually always mixed with a large amount of non-radioactive chemical wastes. Unfortunately, little information is available on these non-radioactive wastes from Russian chemical separations facilities. Because most Russia chemical separations facilities involve the same basic PUREX process used in the U.S., information on U.S. chemical separations facilities' wastes can be used to extrapolate the types and quantities of wastes produced by Russian facilities. These wastes can pose substantial health and environmental risks by themselves. However, mixed with radioactive wastes in typical chemical separations effluents, these wastes increase the risks from the radioactive materials through chemical and biological interactions.

There are three general categories of non-radioactive wastes generated by chemical separations processes. First, acid wastes are generated during the process of dissolving the spent fuel.[17] Nitric acid (HNO_3) is used most commonly, but other types of acid may be used (see Table 3).[18] The corrosiveness of these acids (pH usually less than 1.0) creates serious waste management problems, and often causes leaks in underground transfer pipes, which results in groundwater contamination. These acids may also hasten the reaction rates of other chemicals in the waste resulting in the generation of explosive gases, such as hydrogen. Moreover, high acidity

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[17] Acids are generated primarily from the first cycle rafinnate wastes.

[18] e.g., sulfuric acid H_2SO_4 is usually cheaper, but requires greater quantities, and the sulfur may threaten the integrity of the resulting glassified waste from vitrification.

(low pH) in the discharged waste greatly increases the mobility, especially in colloidal forms, of radioactive materials such as plutonium.[19]

A second class of non-radioactive chemicals in the waste includes a wide variety of chelating and complexing agents, which are added to the waste to reduce its reactivity or cause physical separation into supernatant and sludge (see Table 3). One of these agents - cyanide (CN) - may form toxic gases in an acidic environment, creating severe risks to workers. These problems of worker exposures and the threat of explosion has been identified by the USDOE at the Hanford Reservation. Other chelating agents are extremely persistent or may form hazardous breakdown products.

A third class of non-radioactive wastes includes a wide variety of organic solvents such as kerosene, trichloroethylene (TCE), and tributylphosphate (see Table 3). These contaminants are derived from the second and third extraction cycle in the chemical separations process. Many of these solvents, such as carbon tetrachloride, are known to present substantial carcinogenic risks.[20] In addition, dense non-aqueous phase solvents (e.g., TCE) create intractable cleanup problems because they can contaminate large areas of ground water while eluding detection or extraction in aquiclude pockets.

At the Hanford Reservation, approximately 100 square miles of ground water in the "200-Area" has been contaminated with organic solvents and radioactive contamination from reprocessing effluents. At INEL, more than 30 square miles of the Snake River aquifer has been contaminated. This contamination has occurred despite the fact that high level radioactive waste has generally always been stored in underground steel tanks. Only "low level" radioactive wastes have been disposed of in open trenches or "cribs" in the U.S., depending on local hydrogeology. Ground water contamination at Russian reprocessing sites can be expected to be more severe because of traditionally less strict control of high level liquid wastes.

More than 40 years of military reprocessing in the U.S. has produced 399,000 cubic meters (105 million gallons) of high-level waste,[21] and a far larger quantity of low-level liquid radioactive waste.[22] The twin "Canyon" chemical separations plants at Savannah River -- F and H -- have generated approximately 132,000 cubic meters (35 million gallons) of high-level waste.[23] Operation of the F-and H-Canyon produces approximately 1.16 million and 1.5 million gallons,

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[19] Mahara, Y. and H. Matsuzuru, "Mobile and Immobile Plutonium in a Groundwater Environment," Water Resources, 23(1): 43-50, 1989. Also See, generally, McCarthy, J.F. and J.M. Zachara, "Subsurface Transport of Contaminants," Environmental Science and Technology, 23(5): 496-502, May 1989.

[20] WHO/IARC, "IARC Monographs on the Evaluation of Carcinogenic Risks to Humans," Supplement No.7, 1987.

[21] DOE/OCRWM, "Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 7, October 1991.

[22] In addition, operation of a reprocessing facility for civilian spent fuel at a site near West Valley, New York from 1966-1972, produced 1,230 cubic meters (325,000 gallons, which comprises 0.3 percent of the HLW by volume, and 2.6 percent of the HLW by curie content.

[23] U.S. Department of Energy, Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 7, October 1991, p. 44.

respectively, of high-level waste per year.[24] In addition, annual operations of F- and H-Canyons generate approximately 460,000 cubic meters (121 billion gallons) per year of liquid low-level radioactive wastes, including contaminated cooling water and storm water runoff.[25] To handle the high level waste stored in tanks, USDOE has constructed a waste vitrification facility costing approximately $1 billion.[26] Discharges from the SRS canyons into "Seepage Basins" have resulted in widespread groundwater contamination.[27]

The ICPP at USDOE's INEL has produced 12,000 cubic meters (3 million gallons) of high-level waste.[28] In addition, the ICPP pumped almost 7 billion gallons of radioactive waste into an onsite underground well averaging nearly a million gallons a day between 1953 and 1974.[29] The expansion of ICPP, currently under way, would nearly double the plant's waste output to as much as two million gallons per day.[30]

Reprocessing at the Hanford Reservation, primarily at the PUREX plant, has produced approximately 253,600 cubic meters (67 million gallons) of high-level wastes.[31] PUREX generates 3 cubic meters (800 gallons) of high-level waste per MT of fuel processed.[32] Dozens of the high-level waste tanks have been found to be leaking.In addition, safety concerns have arisen about the potential for an explosion in at least one of the tanks.The construction cost for building a vitrification plant, similar to the SRS plant, to solidify the high level waste stored in underground tanks cleanup is expected to cost more than one billion dollars.Discharges from PUREX to percolation "cribs" have caused widespread groundwater contamination in the 200-East Area extending to the Columbia River.The ground water cleanup cost has not been accurately estimated.

A preferred, and more economical alternative, would be for Russia to shut down all of its chemical separation plants. The workers at these plants can be more productively engaged in the following activities:

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[24] DOE, "Environmental Survey Preliminary Report," DOE/EH/OEV-10-P, August 1987, pp. 4-24.

[25] U.S. DOE, "FEIS: Continued Operation of K-, L-, and P-Reactors, Savannah River Site," (December, 1990), DOE/EIS-0147, p. 4-39.

[26] Known as the "Defense Waste Processing Facility."

[27] DOE, "Environmental Survey Preliminary Report, Savannah River Plant," DOE/EH/OEV-10-P, August 1987, p.4-23.

[28] Integrated Data Base, p. 43. High level waste at the ICPP is reduced in volume by approximately 6 times by "calcining" before interim storage in bins.

[29] Energy Research and Development Administration, "Waste Management Operations, Idaho National Engineering Laboratory," September 1977, ERDA-1536, September 1977, p. II-89.

[30] DOE, "Environmental Assessment: Fuel Processing Restoration at the Idaho National Engineering Laboratory," DOE/EA-0306, August 1987, p. 2-14.

[31] Integrated Data Base, p. 53.

[32] U.S. Department of Energy, DEIS: Process Facility Modifications Project, DOE/EIS-011D, April 1986, 3.23.

(a) clean up the radioactive contamination at the existing facilities and sites;
(b) construct additional temporary water-basin spent fuel storage capacity where needed; and
(c) develop dry cask spent fuel storage containers, like those used in the West;

VI. SPENT FUEL STORAGE AND HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL.

Some no doubt will argue that Russia needs to continue to reprocess the spent fuel at Chelyabinsk-65, Toms-7, and Krasnoyarsk-26 because of a shortage of spent fuel storage capacity, and as a means of safely storing the high-level radioactive waste. The first argument may be true in the very short run, but even this is doubtful. There is ample water basin spent fuel storage capacity at the RT-2 facility at Krasnoyarsk-26 to last for several years. During the next few years additional pool storage capacity could be constructed if needed, and additional capacity could be realized if the older fuel elements in RT-1 were shifted to dry cask storage. In the longer term it should be more economical to store spent fuel in dry casks than to reprocess and store separated plutonium.

With regard to the second argument the United States and some other countries in the West plan to dispose of spent fuel directly in deep geologic repositories. Until the repository is built the spent fuel will be stored (and cooled) in water-filled basins, and then where additional storage space is required, in dry casks on the surface of the earth. In the United States the commercial power reactor fuel is predominantly uranium oxide (UO_2) clad in zircolloy or stainless steel rods - similar to VVER fuel. The production reactors at Tomsk-7 and Krasnoyarsk-26 use a uranium metal fuel clad in aluminum.

The Tomsk and Krasnoyarsk reactors should shift to higher fuel burnups for more economical operations - making them similar to the RBMK reactor fuel cycles. This would reduce their operating costs, and they would no longer be producing weapon-grade plutonium. In effect, they would become full fledged civil power reactors. Higher burnups would probably require shifting to a zircolloy (or stainless steel) clad metal fuel, similar to that used by the Hanford N-Reactor, or an oxide fuel similar to the RBMKs. Using an zircolloy (or stainless steel) clad oxide fuel would make the spent fuel compatible with the spent fuel slated for direct geological disposal in the West. Even if this last step were not taken it is hard to accept an argument that the spent fuel in Russia must be reprocessed for waste disposal, given that Minatom for years has been dumping high-level liquid radioactive waste into open reservoirs at Chelyabinsk-65, and continues to use deep well injection at Tomsk-7 and Krasnoyarsk-26.

VII. Conclusion.

In sum, it makes no sense, from the standpoint of Russia's national security, economic, environmental quality, or spent fuel management interests to continue to operate its chemical separation facilities at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26. At a minimum the further operation of these facilities should be deferred until the large stocks of separated plutonium have been used as MOX fuel. Preferably these facilities should be permanently shut down, and the alternatives of geologic disposal of spent fuel and geologic disposal of separated plutonium should be developed in Russia. The employees at the chemical separation plants should be shifted to cleanup, spent fuel storage, and waste disposal activities.

Table 1   A Comparison of the Radioactivity in One Kilogram of Weapon-Grade Plutonium Aged Ten Years With That in an Equal Weight of Plutonium Separated From VVER Fuel Also Aged Ten Years.

Plutonium	Weapon-grade Plutonium (curies)	(Reactor-Grade) Plutonium (curies)	VVER Ratio
Pu-236	0.000001991	0.00283	
Pu-238	0.4679	225.9	
Pu-239	59.05	39.87	
Pu-240	10.42	45.48	
Pu-241	151.6	7,197.	
Pu-242	0.0001713	0.1148	
Am-241	3.097	147.0	(47)
Total	224.6	7,655.	34

Table 2 Plutonium Production, High-Level Radioactive Waste Generation, and Atmospheric Radioactive Releases by the Chemical Separation Plants at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 in Russia (1992).

Isotope	Half-life (years)	Chelyab'k-65 (Curies/y)	Tomsk-7 (Curies/y)	Kras'k-26 (Curies/y)
Atmospheric Releases:				
H-3	12.26	1,800	160	77
C-14	5730	120	17	9
Kr-85	10.72	2,300,000	330,000	170,000
I-131	0.022	-	2	1
Xe-131m	0.033	-	190	95
Xe-133	0.014	-	540	270
Remaining in High-Level Waste:				
Sr-90	29.3	22,000,000	2,500,000	1,200,000
Y-90m		22,000,000	2,500,000	1,200,000
Zr-65	0.18	7,5000	43,000,000	21,000,000
Nb-95m		7,5000	43,000,000	21,000,000
Tc-99	213,000	4,500	330	160
Ru-106	1.02	24,000,000	7,800,000	3,900,000
Rh-106m		24,000,000	7,800,000	3,900,000
I-129	1.6xE07	13	0.8	0.4
Ce-144	0.78	50,000,000	58,000,000	29,000,000
Pr-144m		50,000,000	58,000,000	29,000,000
Cs-137	30.17	29,000,000	2,700,000	1,300,000
Ba-137m		29,000,000	2,700,000	1,300,000
Np-237		12	-	-
Am-241	432.2	216,800	160	81
Am-242m	141	1,800	0.085	0.043
Am-243	7,370	2,400	0.018	0.009
Am(total)		221,000	160	81
Cm-242	162.9	90,000	97	49
Cm-243	28.5	3,200	0.002	0.001
Cm-244	18.11	243,000	0.038	0.019
Cm-245	8,500	26	-	-
Cm-246	4,780	3	-	-
Cm(total)		337,000	97	49

Recovered from processed fuel elements:

	MT/y	MT/y	MT/y
Np-237	0.100	-	-
U(Total)	325.7*	1,733.*	866.4*
Pu(Total)	2.97**	0.748**0.374**	

*98.27% U-238; 1.254% U-235; 0.4499% U-236; 0.02417% U-234.
** 64.24% Pu-239; 20.11% Pu-240; 11.28% Pu-241; 2.952% Pu-242;1.427% Pu-238.
#99.33% U-238; 0.6566% U-235; 0.00919% U-236.
95.15% Pu-239; 4.605% Pu-240; 0.2376% Pu-241;
 0.004407% Pu-242; 0.002956% Pu-238.

Table 2 Notes.

The data in Table 2 was calculated using a one group burnup code and the fission product spectra for U-235 and Pu-239 fission by thermal neutrons. The fission product spectra were taken from K.A. Varteressian and Leslie Burris, "Fission-Product Spectra From Fast and Thermal Fission of ^{235}U and ^{239}Pu," Argonne National Laboratory, ANL-7678, March 1970. The following additional assumptions were made:

Chelyabinsk-26:

(a) Fuel type: VVER;
(b) Initial fuel enrichment: 3.6% U-235, 0.0337% U-234, and 96.3663% U-238;
(c) Fuel burnup: 30,000 Mwd/MT;
(d) Fuel irradiation period: 3 years;
(e) Spent fuel cooling period prior to reprocessing: 3 years;
(f) Spent fuel processed: 342.7 MTHM;
(f) Recovery: 99% of the uranium and plutonium,[33] and 85% of the neptunium;
(g) Chemical separation plant output: 3 MT of plutonium annually, less 1% losses;
(h) No capture of Krypton-85, Carbon-14, or tritium (it is all release up the stack at the chemical separation plant);

[33] Ibid; Based on "Report by the Commission for Investigation of Environmental Situation in Chelyabinsk Region." (Decree by the President of the USSR, #RP 1283, January 3, 1991). Bukharin reports that in a June 27, 1991, Evgeniy Mikerin, then head of the Department of Isotope Separation, Reprocessing and Production Technology, MAPI, told him that 99.9 percent of the plutonium is recovered and americium and curium are also extracted for further utilization.

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Tomsk-7 and Krasnoyarsk-26:

(a)   Reactor characteristics: Similar to Hanford B-Reactor;
(b)   Number of reactors operating: 2 at Tomsk-7 and 1 at Krasnoyarsk-26;
(c)   Reactor power level: 2000 Mw (thermal) each;
(d)   Average Capacity factor: 0.6 each reactor
(e)   Fuel: natural U (99.289% U-238; 0.711% U-235);
(f)   Fuel burnup: 500 Mwd/MT;
(g)   Fuel irradiation period: 62.5 days (at full power);
(h)   Spent fuel cooling period prior to reprocessing: 0.5 years;
(i)   Spent fuel processed: 1752 MTHM at Tomsk-7; 876 MTHM at Krasnoyarsk-26;
(j)   Recovery: 99% of the uranium and plutonium,[34] no neptunium;
(k)   No capture of Krypton-85, Carbon-14, or tritium (it is all release up the stack at the chemical separation plant);
(l)   Atmospheric releases of I-131, Xe-131m and Xe-133 were estimated from the Kr-85 release using the average release fractions for the Savannah River Site during the 8 year period 1971-1978.

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[34] Ibid; Based on "Report by the Commission for Investigation of Environmental Situation in Chelyabinsk Region." (Decree by the President of the USSR, #RP 1283, January 3, 1991). Bukharin reports that in a June 27, 1991, Evgeniy Mikerin, then head of the Department of Isotope Separation, Reprocessing and Production Technology, MAPI, told him that 99.9 percent of the plutonium is recovered and americium and curium are also extracted for further utilization.

Table 3   Non-radioactive Chemical Waste Constituents From Chemical Separations.

Solvent

Tri-n-butylphosphate
n-Undecane
n-Dodecane
n-Tridecane
n-Tetradecane
n-Pentadecane
n-$C_{22}H_{46}$–n$C_{34}H_{70}$
Butylbenzylphthalate
Dicotylphthalate
Unknown phthaltes

Volatile Solvents

Acetone
Methylene chloride
Chloroform

Carboxylic Acids

Docos-13en-oic acid
Hexanedioic acid
Hexadecanoic acid
Phthalic acid
Nonanedioic acid
Tetradecanoic acid
Pentanedioic acid
Octadecanoic acid
Hydroxybutanedioic acid
Butanedioic acid

Alkanes

nC_{23}-nC_{35}

Phthalate Esters

Dibutylphthalate
Dioctylphthalate

Chelating/complexing Agents

Citric acid
N-(2-Hydroxyethyl)ethylenediaminetriacetic acid (HEDTA)
Ethlyenediaminetetraacetic acid
Methane Tricarboxylic acid
Nitrilotriacetic acid (NTA)

Chelator Fragments

Ethylenediaminetriacetic acid (ED3A)
N-(2-Hydroxyethly)ethylenediamine-N'N'-diacetic acid (HEDDA)
N-(ethylene)ethylenediaminetriacetic acid (E_2DTA)
N-(2-Hydroxyethyl)iminodiacetic acid (HEIDA)
N-(2-Hydroxyethyl)-N'-(methyl)ethylenediamine-'N,N'-diacetic acid (MeHEDDA'A)
N-(methyl)ethylenediamine-N,N'-diacetic acid (MeEDD'A)
Imnodiacetic acid (IDA)