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Technical Evaluation of Proposed Ukrainian Central Radioactive Waste Processing Facility

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Summary

This technical report is a comprehensive evaluation of the proposal by the Ukrainian State Committee on Nuclear Power Utilization (Goskomatom) to create a central facility for radioactive waste (not spent fuel) processing. The central facility, as proposed by Goskomatom, is intended to process liquid and solid radioactive wastes generated from all of the Ukrainian nuclear power plants and the waste generated as a result of Chornobyl 1,2 and 3 decommissioning efforts. In addition, this report provides general information on the quantity and total activity of radioactive waste in the 30-km Zone and the Sarcophagus from the Chornobyl accident. Because of the large quantities of radioactive waste located within the 30-km Zone and the Sarcophagus and the uncertainties surrounding the exact inventories involved, it is unrealistic at this time to develop fully detailed plans for the facilities required for final long-term disposal of 30-km Zone and Sarcophagus wastes. This is a unique problem that will require more study than a short technical assessment of a proposed central facility allows. However, processing options are described that may ultimately be used in the long-term disposal of selected 30-km Zone and Sarcophagus wastes.

This report presents a compilation of referenced estimates for radioactive waste volumes resulting from operations, decommissioning, and wastes within the 30-km Zone and the Sarcophagus. These references are published reports from both Western experts and experts from Ukraine and the Former Soviet Union. A detailed report on the issues concerning the construction of a Ukrainian Central Radioactive Waste Processing Facility (CRWPF) from the Ukrainian Scientific Research and Design Institute for Industrial Technology was obtained and incorporated into this report. It should be recognized that the situation surrounding NPP decommissioning, wastes within the 30-km Zone and within the Sarcophagus itself, is a complex problem that has been subject to the social and economic forces currently playing out within Ukraine and the Former Soviet Union. Some references will tend to overestimate radioactive waste volumes and others tend to under estimate waste volumes for a number of various competing reasons. Accurate and complete knowledge of the Sarcophagus conditions have been hindered not only by purely physical restrictions, but also by bureaucratic tangles, leaving the experts involved to speculate. For these reasons, among others, reported waste volumes for continuing operations, decommissioning, and wastes within the 30-Zone and the Sarcophagus will at times diverge from other estimates by several orders of magnitude. Presenting opportunities for further detailed research where current knowledge is not complete.

This report outlines various processing options, their associated costs and construction schedules, which can be applied to solving the operating and decommissioning radioactive waste management problems in Ukraine. The costs and schedules are best estimates based upon the most current U.S. industry practice and vendor information. It is recognized that the Ukrainian regulatory structure, utility structure and overall economic situation will present unique challenges

and uncertainties which may extend the schedule significantly. For example, one radioactive waste equipment vendor working in Russia reported a two year negotiating period necessary to securing a contract that will require only eleven months for completion.

Goskomatom reports there are no industries within Ukraine that currently design and build radioactive waste processing equipment. This report, for purposes of developing the cost estimates, assumes foreign vendors will design and supply the capital equipment necessary for the radioactive waste processing trains. The development of a Ukrainian infrastructure capable of safely handling and disposing of radioactive waste is important and should be developed in concert with the design of the equipment used to process the radioactive waste. Delivery of equipment alone would be inadequate if there is no infrastructure to support safe and efficient operation of the systems.

This report compares the options using a method which estimates the total present worth (in terms of cost). The total present worth includes the capital equipment costs, facilities costs and the yearly operating costs of processing and storing the wastes. The option with the lowest total present worth (least cost option) is chosen as the preferred alternative. The operating costs are generated using U.S. information for equipment and labor rates. There was no information provided on Ukrainian labor rates so Ukrainian operational costs could not be estimated. Total Ukrainian operational costs will definitely be significantly less due to the fact that the corresponding hourly average rates under Ukrainian conditions are significantly less. However, because a comparative method was used in the selection of the preferred alternative the least cost option remains the same.

The least cost option would use proven, innovative state-of-the-art, skid mounted or mobile technology to perform primary waste treatment and volume reduction at the individual waste producing sites. Advanced volume reduction techniques have been developed that allow for a reduction of waste volumes by approximately a factor of four or more depending upon the process chosen. This strategy reduces the total volumes that would have to be processed and stored at a central facility to be located at the Chornobyl site. The central facility would process the concentrated liquids and resins using solidification trains and would process the solids using supercompaction. The central facility processing trains would package the wastes in containers that meet the criteria for final disposal in a suitable near surface disposal facility. Only those wastes that meet Ukrainian established classification criteria should be disposed of in near surface disposal facilities. Those wastes with radio nuclide concentrations that exceed the classification criteria would be placed into safe interim storage until long term disposal in a geologic repository could be achieved. Proven technology for near surface disposal facilities in order of increasing cost are: shallow land disposal, below ground vaults, earth mounded concrete bunkers, and above ground vaults. Ukrainian plans and proposals for a long term geologic repository are outside the scope of this report and are not discussed.

The table below summarizes the cost estimates based upon the U.S. generic cost estimates for the processing and disposal of radioactive wastes contained in Reference [11]. These costs are also based on vendor supplied capital cost information for typical systems and components that would be used in a central radioactive waste processing facility. The least cost option was chosen based upon the total present worth including capital equipment costs, facilities costs, processing/operating costs, and storage costs. Using a conventional approach without advanced volume reduction techniques results in total costs that are significantly higher. This is because a conventional approach results in greater volumes of waste to process and store. Additional information on the details and assumptions behind the cost estimates and capital investment schedules developed independently by participating Ukrainian Institutes are contained in the body of the report.

Least Cost Option - Capital Equipment Estimate Summary, (U.S. $)

Process Description	Low Range	High Range
Single Solids Compactor System	$74,000	$295,000
Central Compactor for all NPPs and CNPP D&D waste.	$640,000	$2,560,000
Single Advanced Mobile Process/Evaporator Unit	$5,900,000	$13,300,000
Three Advanced Mobile Process/Evaporator Units	$17,700,000	$39,900,000
Single Solidification Train	$1,000,000	$6,000,000
Central Solidification Train Processing all NPPs and CNPP Operating Wastes	$1,500,000	$8,900,000
Storage Facility for all NPPs and CNPP Solidified Liquids and Resins	$9,900,000	unavailable
Storage Facility for all NPPs and CNPP Compacted Solids	$71,100,000	unavailable
Storage Facility for 3 RBMKs D&D Waste	$73,700,000	unavailable

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1.0 Introduction

The Ukrainian State Committee on Nuclear Power Utilization (Goskomatom) is proposing to create a central radioactive waste processing facility. Goskomatom has approached the U.S. Department of Energy (DOE) Office of Nuclear Energy, Science and Technology requesting cooperation on a project to create a central facility for radioactive waste processing to be located outside the site boundary at the Chernobyl Nuclear Power Plant (NPP) site. The DOE Office of Nuclear Energy, Science and Technology directed PNNL, under the International Nuclear Safety Program, to complete a technical evaluation of the Ukrainian proposal within the framework of addressing safe operation and decommissioning issues associated with the Chernobyl NPP Ref. [1]. This technical report was prepared in cooperation with Ukrainian technical experts so as to accurately reflect the best technical information available and to accurately reflect the views of Goskomatom, the Ukrainian National Academy of Sciences, participating Ukrainian Institutes, as well as PNNL technical experts.

There are eleven VVER-1000, two VVER-440 and two RBMK-1000 power plants currently operating in Ukraine. This report includes referenced estimates for the generation and current inventories of radioactive waste from the following sources: currently operating plants, decommissioning of the 3 RBMK-1000 plants at Chornobyl, decommissioning of the two VVER-440 plants, decommissioning of the eleven VVER-1000 plants, waste inventories in the 30-km Zone, and estimates for volumes of radioactive waste located inside the destroyed Chornobyl unit 4 Sarcophagus.

Not all of the referenced estimates for radioactive waste inventories within the 30-km Zone and within the unit 4 Sarcophagus are included in the evaluation of the central facility. It is certain that waste types such as: contaminated ground, vegetation, forests, cooling pond silt and high-level Sarcophagus wastes will not be processed in such a facility. It is more likely that the wastes, depending upon their category, will be either left in current storage, immobilized in situ or will be transferred from the approximately 600 to 800 interim storage trenches to long term engineered near surface disposal facilities or transferred to interim storage prior to disposal in a future deep geologic repository.

In addition, shutdown of the first VVER plant is not scheduled until 2007 and VVER decommissioning work will continue through 2025 indicating a staggered approach to siting the necessary processing capabilities may be appropriate. For this reason the central facility should be designed with the ability to expand its capability rather than designing the facility for the total decommissioning waste produced through 2025. However, the total capacity required for the near surface disposal facilities should factor in the total volume of waste that will be produced.

This evaluation does not address spent fuel or RBMK reactor graphite as these issues are being addressed through other means. This report focuses primarily on the handling and processing of what is defined in the U.S. as low-level radioactive wastes.

2.0 Volumes and Generation Rates of Radioactive Wastes

Central to the technical evaluation of the proposed radioactive waste processing facility is the ability to quantify the volumes and generation rates of the liquid and solid radioactive wastes produced by the Ukrainian NPPs. The characteristics of radioactive waste from NPP operation can be dependent upon several diverse factors which are not easily defined or standardized. This is particularly true with the Ukrainian NPPs where limited data on radioactive waste stream characteristics is available. Data on annual radioactive waste generation rates and volumes by Soviet designed reactor type was obtained from Ref. [5] and is presented in Table 1. Typical Russian storage space data presented in Table 3 was also obtained from Refs. [7 & 8]. In addition, reasonable estimates can be made and documented by drawing upon "typical" radioactive waste data that is available from operating experience of U.S. Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs) Refs. [2-4]. The U.S. "Typical" data is presented in Tables 4 and 5. The data from Refs. [5, 7 & 8] and the U.S. NPPs will be used as a basis for comparison with the Ukrainian data from Goskomatom and other Ukrainian Institutes. The data provided by Goskomatom is presented in Section 2.3. Estimates of radioactive waste volumes generated over a five year period are shown in parentheses to allow for comparison with the volumes generated since Ukrainian independence in 1991. Figures 2.1 and 2.2 provide estimated forecasts for Ukrainian liquid and solid waste volumes and storage capacities.

2.1 Radioactive Waste Information for Soviet Designed Reactors

At Russian designed NPPs, liquid waste is processed and classified as follows: evaporator bottoms, low-level sorbents, high-level sorbents and perlite (RBMK-1000 reactors only) Ref. [5]. The data on waste type, annual quantities generated and historical volumes generated from 30 years of NPP operation is presented in Table 1. Data on unprocessed liquid radioactive waste streams was not available. The classification of radioactive wastes in the former USSR is detailed in Appendix C.

The solid radioactive waste at Russian designed reactors is pre-treated at the NPP site and consists of the following steps, Ref. [5]: waste collection and sorting by contamination groups and treatment possibilities, waste transportation to a storage area or to a processing facility, incineration of solid organic waste and incorporation of the ash into cement, compaction of solid noncombustible wastes, scrap decontamination, and finally, storage in a repository. High-level wastes are planned to be packed into containers and casks and then solidified with cement. Graphite waste materials are stated as being hard to process and are apparently handled using special composites. Metal decommissioning wastes were recommended to be decontaminated and compacted.

Table 1

Annual Radioactive Waste Generation by Reactor Type and (5 Year Estimates)

Waste Category	VVER-440	VVER-1000	RBMK-1000
Evaporator Bottoms, m^3	120 - 170 (600 - 850)	220 - 300 (1100 - 1500)	1000 - 2000 (5000-10,000)
Average Salt Concentration, g/l	300 - 400	300 - 400	200 - 250
Total Salt Accumulation, ton	50 (250)	90 (450)	250 (1250)
Specific Activity, MBq/l	2	2	2
Low-level Sorbents (Resins), m^3	8 (40)	16 (80)	62 (310)
Specific Activity, MBq/kg	100	100	100
High-Level Sorbents (Resins), m^3	3.0 (15)	5.3 (26.5)	22 (110)
Specific Activity, MBq/kg	2000	2000	2000
Perlite, m^3	-	-	9 (45)
Specific Activity, MBq/kg	-	-	100
Solids, m^3	200 (1000)	300 (1500)	400 (2000)

Radioactive Waste Generated from 30 Years of Reactor Operation

Reactor Type	Bituminized Waste, m^3	Solid Waste, m^3	
VVER-440	3,900	6,000	
VVER-1000	7,500	9,000	
RBMK-1000	22,500	12,000	

Reference [6] describes radioactive waste management in Russia as follows, "The radioactive waste produced in NPPs belongs to the class of low and medium level waste (high level waste accounts for less than 1%). All types of radioactive waste are stored on the territory of the NPP. Liquid radioactive waste is stored in concentrated form after evaporation. Solid radioactive waste is not processed and is placed in special concrete structures. The amount of liquid and solid radioactive waste produced annually is approximately equal to the design values."

Reference [14] describes the radioactive waste handling process at the Zaporozhye VVER-1000 NPP as follows:

1. Radioactive wastes are transported in special shielded vehicles, from reactors to a decontamination shop located nearby, where the wastes are sorted.

2. Combustible wastes are burned in a "special furnace" at a temperature of 1,100 °C, and the off-gases are "cleaned" and monitored.

3. Metals are compacted and packed in shielded carbon steel drums reducing their volume by 4 to 100 times. The drums are then lowered into "wells" inside a storage facility for radioactive wastes. These storage wells are set in concrete and covered with concrete lids 900 to 1200 mm thick, weighing from 1.0 to 4.5 tons and are periodically monitored. The three storage facilities at Zaporozhye are stated to be capable of storing all wastes produced over the plant lifetime.

It should be noted that Goskomatom made no mention of an incineration facility at Zaporozhye when questions were submitted regarding current processing capabilities at the operating NPP sites. Therefore, it is not clear that the incineration facility described by Ref. [14] is currently in an operating condition.

The organizations within the Former Soviet Union (FSU) and foreign companies involved in designing radioactive waste processing equipment for the FSU are listed in Refs. [5 & 15] they are: Research Institute for Nuclear Power Plant Operation (VNIIAES), Radon, Scientific Production Association, Design and Research Institute of Complex Power Technology (VNIPIET), Scientific Research Institute of Chemical Machine Building (SNHM), NUKEM (a German company), and Chem-Nuclear Systems (an American company). NUKEM constructed a facility at the Balakovo site with 25% of the components manufactured in Russia with plans for similar equipment to be installed at other sites within Russia. Chem-Nuclear is building a liquid radioactive waste processing system to be installed in August of 1996 on a barge in Vladivostok and has plans for similar facilities for the Russian Northern fleet as well as the Black Sea fleet.

Reference [5 & 18] provide data on the expected amounts of solid wastes that will be generated during reactor disassembly and decommissioning. In addition to the primary decommissioning wastes shown in Table 2, secondary wastes generated as a result of decommissioning activities is estimated as 10 to 15% of that shown in Table 1 for radioactive waste generated from 30 years of operation. It has been noted that these referenced estimates provided by Russian organizations are not as comprehensive and detailed as typical western estimates such as those contained in Reference [28].

Table 2

Solid Wastes Generated from Reactor Decommissioning

Reactor Type	Concrete, tons	Scrap, tons	Equipment, tons
VVER-440	9,000	500	4,000
VVER-1000	12,000	900	6,000
RBMK-1000	36,000	2,500	15,000

Reference [18] provides detailed estimates for disassembly of the equipment for an RBMK-1000 reactor. This data was generated to support a decommissioning study for the Kursk NPP in Russia. The estimate for metallic equipment wastes from disassembly of a single unit was reported at approximately 20,752 tons. This total was also broken down into the following categories:

High-Level (Group III)	1.5 tons
Medium & Intermediate-Level (Group II)	2,576.5 tons
Low-Level (Group I)	9,528.0 tons
No Thorough Decontamination Required	8,646.0 tons
Total	20,752 tons

Reference [18] indicated that the volume of waste that did not require thorough decontamination would be free released and recycled leaving 12,106.0 tons of equipment as radioactive wastes.

Reference [18] also provided additional estimates for wastes produced during decommissioning of a VVER-440 reactor. This data was generated to support a decommissioning study for the Novovoronezh NPP in Russia. The estimate for equipment waste from disassembly of a single unit for long-term observed observation was reported at approximately 22,280 tons. The total solid wastes generated as a result of disassembly of equipment and structures for a dual unit VVER-440 plant during the third phase of decommissioning were reported as follows:

1. Metallic Wastes

Equipment from Primary Loop	3,370 tons
Metallic Equipment and Structural Elements	6,000 tons
Non-Radioactive Equipment	35,000 tons

2. Non-Metallic Wastes

Radioactive Solid Wastes (plaster, concrete, etc.)	6,500 tons
Non-Radioactive Solid Wastes	12,000 - 16,000 tons
Total Radioactive (Two VVER-440s)	15,870 tons
Total Non-Radioactive (Two VVER-440s)	47,000 - 51,000 tons

The quantity of solidified liquid radioactive waste accumulated during 30 years of operation of a VVER-440 design were reported by Reference [18] to be 5,200 m^3 per unit. The quantity of solid radioactive waste accumulated during 30 years of operation were reported by Reference [18] to be 6,000 m^3 per unit. The quantity of solidified liquid and solid radioactive wastes produced during decommissioning were estimated at 10% of the quantities formed during operation.

It should be noted and in fact is highly recognized that the estimates for the amounts of radioactive waste generated during decommissioning vary considerably, ranging for a typical NPP from as low as 3000 tons in some countries to the maximum of 53,500 tons for the RBMK-1000. The decommissioning strategy and the methods that will be used to segregate the fraction of material that will be released for restricted or unrestricted use have a large impact on the estimates.

Data on available radioactive waste storage capacities for Russian designed NPPs was obtained from Refs. [7 & 8]. The data on radioactive waste storage capacity was normalized to m^3 per MWe installed capacity for purposes of comparison with the Ukrainian data.

Table 3

Storage Capacities for Radioactive Waste at Russian Designed NPPs

NPP Facility	Storage Type	Capacity, m^3 and Used Capacity (%)	Normalized Capacity, m^3/MWe
Kola Site[(a)] 4 VVER-440s 1760 MWe	Two Liquid Storage Blocks	7326 (77%)	4.2
	Two Solid Storage Blocks	7475 (27%)	4.2
	Solid Low-Level Waste	12,060 (30%)	6.8
Kalinin Site[(b)] 2 VVER-1000s 2000 MWe	Liquid Storage LLW & ILW	3617 (94%)	1.8
	Solid Storage LLW & ILW	5000 (13%)	2.5
Balakovo Site[(b)] 4 VVER-1000s 4000 MWe	Liquid Storage LLW & ILW	3797 (79%)	0.9
	Solid Storage LLW & ILW	6000 (30%)	1.5
Smolensk Site[(b)] 3 RBMK-1000s 3000 MWe	Liquid Storage LLW & ILW	11,746 (63%)	3.9
	Solid Storage LLW & ILW	19,697 (33%)	6.6

(a) Ref. [7] - 1994 data
(b) Ref. [8] - 1992 data

2.2 Typical Radioactive Waste Information for Western Plants Including U.S. PWRs and BWRs

Reference [3] reports the radioactive waste volumes and generation rates in values that were taken from operating data and normalized to one GW(e) installed power. Using this information, projections can be made of the annual radioactive waste generation rates and the total volumes generated over an extended period. The principal waste streams for a U.S. PWR and BWR are presented in Table 4 in normalized values. In addition, for 1000 MWe PWRs and BWRs Table 4 provides values for annual and 5 years of operation. Note that in the U.S. high-level waste is defined as spent fuel and wastes from fuel reprocessing, therefore, all waste categories in Table 4 are defined as Low-Level waste.

Table 4

U.S. Normalized Radioactive Waste Generation Rates

Waste Category	PWR Normalized Rate m^3/MWe - yr	BWR Normalized Rate m^3/MWe - yr
Low-Level Evaporator Bottoms	3.459×10^{-1}	2.343×10^{-1}
Low-Level Spent Resins	2.257×10^{-2}	5.190×10^{-2}
Low-Level Filter Cartridges	6.408×10^{-3}	-
Low-Level Filter Sludge	8.163×10^{-4}	3.829×10^{-1}
Low-Level Compactable Trash	3.913×10^{-1}	6.422×10^{-1}
Low-Level Noncompactable Trash	4.930×10^{-2}	9.340×10^{-2}

Annual Radioactive Waste Generation by Reactor Type and (5 year Estimates)

Waste Category	PWR 1000 MWe, m^3	BWR 1000 MWe, m^3
Low-Level Evaporator Bottoms	345.9 (1729.5)	234.3 (1171.5)
Low-Level Spent Resins	22.6 (112.8)	51.9 (259.5)
Low-Level Filter Cartridges	6.4 (32.04)	-
Low-Level Filter Sludge	0.8 (4.1)	382.9 (1914.5)
Low-Level Compactable Trash	391.3 (1956.5)	642.2 (3211.0)
Low-Level Noncompactable Trash	49.3 (246.5)	93.4 (467.0)

Radioactive Waste Generated during Operating Lifetime

Reactor Type	Operating LLW, m^3	Decommissioning LLW, m^3
PWR 1000 MWe	26,000	15,200
BWR 1000 MWe	48,000	16,300

The probable quantities of unprocessed liquid radioactive waste for representative U.S. BWR and PWR plants are found in Ref. [9]. These quantities of unprocessed wastes are considered representative of the inputs to a U.S. NPP radioactive waste processing system. The details for each individual NPP radioactive waste stream are important for assigning one of several possible processing methods or treatment combinations. There are no standard processes or treatment methods in the U.S. Commercial vendors in the U.S. are capable of competitively supplying a number of different proprietary processes that can be applied to similar waste stream inputs. However, a basic process that is representative of the functional process steps can be developed and evaluated against the Ukrainian proposal. The functional process steps must be capable of processing the expected average daily inputs and the inputs from a conservatively chosen design basis event. Table 5 presents a summary of the total unprocessed waste inputs for the expected average daily input and the input from a conservatively chosen design basis event Ref. [9].

Table 5

Total Unprocessed Liquid Radioactive Waste Inputs for U.S. NPPs

Reactor Type	Expected Generation Rate, gal/day	Design Basis Event Max Generation Rate, gal/day
BWR 1000 MWe	38,340	165,160 for 1 day
PWR 1000 MWe	44,090	61,200

In the U.S., the Nuclear Regulatory Commission (NRC) under Reference [19] sets forth the regulations for classification of radioactive waste for near surface disposal. Reference [19] describes the two considerations involved in the classification of radioactive waste. First, consideration is given to the concentration of long-lived radio nuclides whose potential hazards persist long after precautions such as institutional controls, waste forms, and deeper disposal have ceased to be effective. Second, consideration is given to the concentration of shorter-lived radio nuclides for which requirements on institutional controls, waste form and disposal method are effective. Waste is classified using specific radio nuclide concentration limitations into Class A, B, and C waste. If the concentration exceeds the values listed below the wastes are not generally acceptable for near-surface disposal in the U.S., Ref. [19].

Radio nuclide	Concentration Ci/m^3
Long Lived Radio nuclides:	
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220

Radio nuclide	Concentration Ci/m^3
Long Lived Radio nuclides: cont.	
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half lives > 5 yrs.	100(1)
Pu-241	3,500(1)
Cm-242	20,000(1)
Short Lived Radio nuclides:	
Total of all nuclides with half lives < 5 yrs.	700(2)
H-3	40(2)
Co-60	700(2)
Ni-63	700
Ni-63 in activated metal	7000
Sr-90	7000
Cs-137	4600

Notes:
(1) units are nanocuries per gram.
(2) This is a Class A limit, there are no concentration limits on these radio nuclides for near surface disposal. Practical considerations such as dose rate at the package surface and handling restrictions will limit the concentration of these radio nuclides.

Additional requirements and special considerations for Class A, B and C waste such as stability, institutional controls and characteristics are contained in Reference [19] and for purposes of brevity will not be addressed here.

2.3 Radioactive Waste Information Presented by Ukrainian Institutes

In the process of evaluating the Ukrainian proposal to build a central radioactive waste processing facility, detailed questions (see Appendix D) were submitted to Victor D. Chebrov, Chairman of Goskomatom and C. Faschevsky, Director Ukrainian Central Radioactive Waste Processing Facility. Goskomatom also coordinated its efforts with the Ukrainian Scientific Research and Design Institute for Industrial Technology and the Ukrainian National Academy of Sciences.

2.3.1 Radioactive Waste Information Presented by Goskomatom

Initial responses to the questions PNNL submitted are contained in Ref. [16]; a Letter from Goskomatom to PNNL. The letter contained the following information:

1. At the present time, the work related to creation of the Central Radioactive Waste Processing Facility (CRWPF) are in a stage of agreement on feasibility studies for site selection and performance of construction works.

2. The Ministry of Environmental Protection and Nuclear Safety is the regulatory body in Ukraine responsible for obtaining permits (licenses) to build and operate the CRWPF, as well as to transport radioactive waste. The regulatory document are the Laws of Ukraine entitled, "On using Nuclear Power and Radiation Safety" and "On Radioactive Waste Treatment."

3. In accordance with the general scheme of development of a radioactive waste processing industry in Ukraine, issued by Goskomatom, it is suggested that liquid radioactive waste from all Nuclear Power Plants in Ukraine would be transported to the CRWPF. Liquid radioactive waste can be transported only after preliminary processing at an evaporator, bituminization, or cementation installation, where liquid waste is transferred to a solid crystal matrix and placed into 200 liter drums, the drums are then loaded into special containers for transport to the CRWPF.

4. During decommissioning of the Chernobyl NPP all kinds of radioactive waste will be generated out of which only low-level and intermediate-level radioactive waste (both liquids and solids) will be processed.

5. Liquid radioactive wastes are classified as:

    Low-Level (specific activity < $1\mathrm{x}10^{-5}$ Ci/l, (370 kBq/l));
    Intermediate-Level (specific activity $1\mathrm{x}10^{-5}$ to 1 Ci/l, (370 kBq/l to 37 GBq/l));
    High-Level (specific activity > 1 Ci/l (> 37 GGq/l)).

6. For each category, the annual volume of liquid radioactive waste produced is:

Low-Level and Intermediate-Level	2,044 m^3 per year;
High-Level	100 m^3 per year.

7. The capacity of the tanks for liquid waste storage (m^3) are:

Table 6

Ukrainian Liquid Waste Storage Tank Capacities m^3		
NPP Site	Evaporator Bottoms	Ion-Exchange Resins
Chernobyl	28,000	15,000
Rivne	6,150	1,580
South Ukraine	4,115	400
Khmelnitsky	800	200
Zaporozhye	4,600	400

8. Currently, Zaporozhye and Khmelnitsky NPPs have evaporator facilities with a 500 l/hour capacity.

9. Solid radioactive wastes are classified as follows:

Table 7

Ukrainian Solid Waste Classifications			
Classification	Radiation dose at 10 cm from the surface, mr/hr	Beta Specific Activity Ci/kg	Alpha Specific Activity Ci/kg
Low-Level	0.03 - 30	2×10^{-6} - 1×10^{-4}	2×10^{-7} - 1×10^{-5}
Intermediate-Level	30 - 1,000	1×10^{-4} - 1×10^{-1}	1×10^{-5} - 1×10^{-2}
High-Level	> 1000	$> 1 \times 10^{-1}$	$> 1 \times 10^{-2}$

2.3.2 Radioactive Waste Information Presented by Ukrainian Scientific Research and Design Institute for Industrial Technology

The final responses to the questions submitted by PNNL are contained in Reference [27]. These responses were prepared by the Ukrainian Scientific Research and Design Institute for Industrial Technology at the request of Goskomatom. The responses to the questions are as follows:

Response to Question 1:

The following reports were produced at the instruction of Goskomatom: "Concept for Ukrainian Radioactive Waste Handling" - 1993; "General Schedule for the Development of the Ukrainian Radioactive Waste Handling Industry" - 1993. The basis for these documents was Decree No. 44/93-RP of the President of Ukraine of April 14, 1993. A "Feasibility Study for Development of a Ukrainian Central Radioactive Waste Processing Facility" is planned for 1996.

Response to Question 2:

The following classes of licenses are issued for activities associated with the use of nuclear power under the "Ukrainian Law on the Use of Atomic Energy and Radiation Safety" (Article 28): (1) licenses for design, construction, extraction, production, manufacturing, purchase, sales, ownership, commissioning, operation, use, transport, decommissioning and conservation of any ionizing radiation source at a nuclear facility; (2) a license for surveying for site selection for a nuclear facility or an installation designated fro radioactive waste handling. The same document (Article 29) stipulates the terms and procedure for issuing permits relating to use of nuclear power; (3) Requirements for radioactive waste handling are also stipulated by another document entitled "Ukrainian Law on Handling of Ukrainian Radioactive Waste."

Response to Question 3:

It is not anticipated that liquid radioactive waste will be transported from nuclear power plants to the CRWPF. Treatment of the liquid radioactive waste will include the following: a sedimentation tank; mechanical processing; treatment employing activated charcoal; a waste evaporator and radio nuclide treatment employing resins (ion exchange treatments).

Response to Question 4:

It is anticipated that the CRWPF will handle treatment of the full range of nuclear power plant waste with low and medium level radioactivity. The volume anticipated during decommissioning of the Chornobyl Nuclear Power has not been determined.

Response to Question 5:

The capital investment schedule for establishment of the CRWPF is presented in the following table:

Table 8

CRWPF Equipment/Facilities	Quantity Required, Units	Total Cost U.S.
1. Containers/Casks:		
- Compaction Containers	7700	$116,000.00
- Ash Containers	50	$750.00
- Transport Containers	50	$50,000.00
- Radioactive Waste Storage Casks	1000	$1,100,000.00
- Returnable Containers	2280	$34,000.00
2. Special Vehicles	20	$240,000.00
3. Special Purpose Railway Cars	10	$100,000.00
4. Compacted Radioactive Waste Drying Unit	1	$500,000.00
5. Radioactive Waste Combustion Unit	1	$4,000,000.00
6. Compactor	1	$400,000.00
7. Mobile Oil Treatment and Regeneration Unit	1	$400,000.00
8. Molten Salt Treatment and Processing Unit	1	$400,000.00
9. Ionite Processing Unit	1	$400,000.00
10. Facility for Equipment and Container/Cask Testing	1	$400,000.00
11. Temporary Surface Storage Facility for Radioactive Waste from Nuclear Power Plants	1	$30,000.00
12. Metallic Radioactive Waste Processing Unit	1	$16,000,000.00
13. Cementation Unit	1	$500,000.00
14. Unit for Fabrication of Rebar Concrete Casks for Radioactive Waste Storage	1	$500,000.00

Table 8

CRWPF Equipment/Facilities	Quantity Required, Units	Total Cost U.S.
15. Radioactive Waste Fragmentation Unit	1	$500,000.00
16. Auxiliary Equipment	1	$500,000.00
17. Storage Facility for Conditioned Radioactive Waste	1	$30,000,000.00
18. Accounting, Monitoring, Communications and Physical Security System	1	$1,500,000.00
19. Laboratory Equipment	1	$4,000,000.00
TOTAL:	-	$61,670,750.00
Scientific Research, Survey Costs (10% of Total)	-	$6,167,000.00
Other Costs	-	$13,200,000.00
TOTAL:	-	$81,037,750.00

Response to Question 6:

The Ukrainian classification for liquid radioactive wastes were listed and are identical to those provided in item 5 of the initial response. Liquid radwaste is stored separately depending on type and origins: (1) evaporator bottoms with salt concentration under 500 g/l (from the evaporators) is stored in evaporator bottom vessels; (2) slurries and filtrant media are stored in filtrant media storage vessels. Floor drain water is stored in floor drain tanks.

Table 9

Quantity of Liquid Radwaste by Nuclear Power Plant, m^3

Power Plant	Type of Radwaste		
	Evaporator Bottoms	Water Containing Ion-Exchange Resins and Filtrant Media	Radioactive Lubricants and Oils
KNPP	686	100	no data
RNPP	5000	250	60
ZNPP	4600	385	no data
SUNPP	2814	398	no data
CNPP	10186	4837	no data

The Zaporozhye and Khemelnitskiy Nuclear Power Plants contain units for converting evaporator bottoms into molten salt with a salt concentration of up to 1600 g/l. At the Rivne Nuclear Power Plant, this unit was developed by the Ukrainian Scientific Research and Design Institute for Industrial Technology and will be placed into service in 1997. The quantity of molten salt in 200 liter barrels at the ZNPP and KNPP is 4200 m^3 and 1100 m^3 respectively.

The annual volume of liquid radwaste for nuclear power plants employing VVER-1000 reactors is:

(1)	Evaporator Bottoms	86 m^3/yr
(2)	Ion exchange resins and filtrant media	15 m^3/yr

The following vessels are available for storing liquid radwaste at nuclear power plants:

At the Zaporozhye Nuclear Power Plant:

(1) The available volume for storage of evaporator bottoms and filtrant media as well as deposits is 4800 m^3 (the capacity of each vessel ranges from 100 to 750 m^3).

(2) The capacity for storage of floor drains: six 200 m^3 capacity floor drain vessels for a total of 1200 m^3; four 40 m^3 laundry control vessels for a total of 160 m^3; two 40 m^3 vessels for storing contaminated water from the laundry for injection to the evaporators for a total of 80 m^3. The total capacity for the storage of floor drains is then 1440 m^3.

At the Khemelnitskiy Nuclear Power Plant:

(1) As of May 1, 1995 the plant contained five vessels with a capacity of 800 m^3 and is assembling three vessels for the second series units with a capacity of 700 m^3 each.

At the Rivne Nuclear Power Plant:

(1) Total storage capacity for liquid radwaste is 6150 m^3 for storage of evaporator bottoms.
(2) Total vessel storage space for ion-exchange resins and sorbents is 1580 m^3.

At the South Ukraine Nuclear Power Plant:

(1) Total vessel capacity for storage of molten salt is 4,114 m^3.
(2) Total storage capacity for ion-exchange resins and sorbents is 400 m^3.

At the Chornobyl Nuclear Power Plant:

(1) Total vessel capacity for storage of evaporator bottoms is 28000 m^3.
(2) Total vessel storage for ion-exchange resins and sorbents is 15000 m^3.

All nuclear power plants have evaporators to produce evaporator bottoms.

The Ukrainian classifications for solid radioactive wastes by dose rate and activity were provided and are consistent with those provided in the initial response, see Table 7. Solid radioactive waste is divided into the following classifications based on physical composition and characteristics: combustible/noncombustible; metallic/nonmetallic; compactable/noncompactable and stored in special vessels and in reactor containment.

Table 10

Composition of Solid Radioactive Waste
(Example from Zaporozhye Nuclear Power Plant)

Type of Waste	Composition %
Special Clothing	26.6
Plastics	9.31
Thermal Insulation	13.3
Paper	3.33
Rubber	1.33
Filters	3.59
Wood	2.68
Metal	14.52
Concrete (dry)	0.67
Glass	0.67
Sorbents	0.665
Other	23.34

Solid radioactive waste is stored based on its components and radioactivity in the appropriate cells of solid radwaste storage facilities:

(1) thermal insulation;
(2) metal;
(3) ion-exchange resin;
(4) fine aggregate concrete following reconstruction;
(5) removable filters;
(6) ash;
(7) paper;
(8) contaminated tools;
(9) other waste.

Table 11

Volume of Solid Radwaste by Nuclear Power Plant and Design Storage Capacity, m^3

Power Plant	Accumulated Solid Radwaste	Design Capacity
RNPP	3000	10905
KNPP	1163	45544(1)
SUNPP	8697	14500
ZNPP	10531	17000
CNPP	3019	15900
Sarcophagus	790000	-

Note (1) This design capacity may be in error as KNPP is a single unit plant.

All solid radwaste at the Khemelnitskiy, South Ukraine and Chornobyl Nuclear Power Plants are not conditioned, but rather are stored "in bulk" without containers in solid radwaste storage facilities. Solid radwaste (compressed) is additionally compressed into 200 liter drums at the Zaporozhye Nuclear Power Plant. Only combustible solid radwaste is compacted and packaged at the Rivne Nuclear Power Plant.

Response to Question 7:

The response to Question 7 is addressed in Section 3.1 which covers the design information for the proposed central facility.

Response to Question 8:

The isotope composition of solid radwaste and ash samples from the Zaporozhye Nuclear Power Plant is presented in Table 12.

Table 12

Solid Radwaste Samples from the Reactor Hall of Unit No. 4, Zaporozhye Nuclear Power Plant

Type of Waste	Total Activity Ci/kg	Isotope Composition and Specific Activity, Ci/kg				
		C^{134}	C^{137}	Co^{58}	Mn^{54}	Co^{60}
Thermal Insulation	$5.1x10^{-10}$ (1)	$4.4x10^{-11}$	$5x10^{-11}$	-	$6.7x10^{-11}$	$6x10^{-11}$
Rags-Clothing	$4.8x10^{-7}$	$2.5x10^{-8}$	-	$2x10^{-7}$	$1x10^{-7}$	$1.8x10^{-7}$
Concrete	$3.1x10^{-10}$ (1)	-	$9.7x10^{-11}$	-	$7.2x10^{-11}$	$1.4x10^{-10}$

Isotope Composition and Specific Activity of Ash Residue

Date of Analysis	Total Activity Ci/kg	Isotope Composition and Specific Activity, Ci/kg				
		C^{134}	C^{137}	Co^{58}	Mn^{54}	Co^{60}
04/16/88	$2.6x10^{-9}$ (1)	$4.5x10^{-10}$	$1.3x10^{-9}$	$3.8x10^{-11}$	$3.9x10^{-10}$	$3.1x10^{-10}$
04/24/89	$1.4x10^{-8}$	$1.3x10^{-10}$	$3.6x10^{-10}$	$5.1x10^{-10}$	$1.7x10^{-8}$	$1.1x10^{-8}$
02/09/90	$1.3x10^{-9}$ (1)	-	$8.6x10^{-11}$	-	$3.2x10^{-10}$	$9.7x10^{-10}$

NOTE (1) PNNL recognizes that the total activity levels reported are very low (below those typically found in the human body) and may not be of significant concern.

Response to Question 9:

Class 1 and 2 waste will be processed at the CWRPF (see response to question 7).

Response to Question 10:

All equipment which will be periodically decontaminated is to be fabricated from corrosion-resistant material.

Response to Question 11:

Monitoring and analysis links currently in use at the operating nuclear power plants will be used. This issue will be discussed in greater detail during the development of the feasibility study for the

CWRPF.

2.3.3 Radioactive Waste Information Provided by the Ukrainian Ministry of Environmental Safety

Reference [17] is a 1994 status report on nuclear and radiation safety in Ukraine issued by the Ukrainian Ministry of Environmental Protection and Nuclear Safety and their Nuclear Regulatory Administration. The status report broadly outlined and described the radioactive waste handling situation in Ukraine as follows:

> *The Ukraine Cabinet of Ministers has designated Goskomatom as the agency responsible for organizing the safe handling of radioactive wastes in industry and for collecting, processing, and storing them until the radioactive wastes are shipped for burial. The management and handling of radioactive wastes during long-term storage and burial is under the jurisdiction of the Ukraine Ministry for Mitigating the Consequences of the Chornobyl Disaster.*
>
> *The following general problems were described:*
>
> - *lack of a well developed regulatory base,*
> - *lack of a radioactive waste accounting and control system,*
> - *lack of a well developed national scientific and industrial base,*
> - *lack of a national plan for the long-term handling of radioactive wastes,*
> - *lack of a sufficient number of qualified specialists.*
>
> *Because the problem of final burial of radioactive wastes in Ukraine has not yet been solved, an approach has been adopted which provides for long-term storage of radioactive wastes in specially monitored storage facilities. A large group of scientists and specialists from Ukrainian Academy of Sciences, institutes, ministries, and agencies has been formed to study the storage and burial of radioactive wastes. The preliminary results have been positive, and several sites whose geological structure is suitable for radioactive waste burial have been identified.*
>
> *Ukraine now has six main radioactive waste storage points which operate as special subdivisions of the Radon State Association; these were built as far back as 1959-1962. The sites are located at Kharkov, Odessa, Lvov, Dnepropetrovsk (being rebuilt), Kiev (shutdown) and Donetsk (mothballed). All of these special facilities must be fundamentally rebuilt, equipped with modern process equipment, and brought into compliance with current requirements, regulations and standards. In not a single instance does radwaste facility documentation contain a section on "Radiation Monitoring." Documentation for the first units at radwaste burial sites has not been*

assembled, and there are no receipt control reports.

The problem of radioactive waste handling at the Eastern Mining and Ore Processing Enterprises (Zheltye Vody) is acute. It has accumulated a large amount of gangue (waste rock) containing radioactive isotopes or uranium, thorium, and radium. There is also a large amount of liquid radioactive wastes from enrichment and hydro metallurgical manufacturing and underground leaching sites. The approximate total activity concentrated at these sites, which are located in densely populated regions of Ukraine, is about 140,000 curies.

Handling radioactive wastes created as a result of the Chornobyl disaster is a serious problem. A large portion of these wastes have been buried in temporary storage facilities which are in complete non-compliance with current requirements, standards, and regulations. Registered temporary Chornobyl radioactive waste localization and burial sites have a total radioactive waste activity of about 300,000 curies.

Nuclear power stations are among the main producers of radioactive waste in Ukraine. In 1994 nuclear power plants with VVER reactors accumulated about 47,000 cubic meters of radioactive wastes, half of which are liquid.

Not a single Ukrainian nuclear power plant has solved the problems of processing liquid radioactive wastes and safe long-term storage of the solidified product. Bituminization units installed at the South Ukraine and Rovno Nuclear Power Plants capable of yielding a product with acceptable characteristics are not currently in operation. The reason for this at the South Ukraine plant is the lack of bitumen of the required quality; at Rovno, the fact that construction of a storage facility which meets the requirements for safe long-term storage of solidified product is incomplete. Deep concentration plants (evaporators) in operation at Zaporozhye and Khmelnitsky do not solve the problem, because the characteristics of the product are such that it is doubtful whether it can be buried or transported without very expensive preventative measures for which the engineering and technology have not been developed. The problem is not being resolved because Ukraine does not produce its own casks for solidified radioactive wastes and the service life guarantee on casks bought in Russia is limited. It is simply being put off for a few years. In addition, the problem of large-sized wastes, as well as waste such as low-activity fuels and contaminated thermal insulation, must be solved. The lack of technologies and equipment for processing them result in larger amounts of radioactive waste requiring storage than might otherwise be anticipated.

The main problems in handling radioactive waste at Ukraine's nuclear power plants are:

- *they exceed design and regulatory requirements for recoverable liquid radwaste* *(a major source of liquid radioactive wastes at nuclear power plants),*

- *liquid radioactive waste solidifiers are primitive, inadequate in number, or entirely lacking,*
- *safe handling of large-sized waste formed during outages, post-accident remediation, or retrofitting and modernization is not dealt with in nuclear power plant designs,*
- *Ukraine does not have special design and engineering organizations or manufactures of equipment for nuclear power plants.*

The handling of radioactive wastes in industry, agriculture, science, and medicine causes serious concern. Because there is no closed system of accountancy and state registration of ionizing radiation sources, radioactive wastes may be created that are not recorded and, in the best case, disposed of at ordinary municipal dumps.

If the draft General System for Developing the Radioactive Waste Handling Industry (now being revised by Goskomatom) is adopted, we do have prospects for solving these problems.

2.4 Wastes Located Within 30-km Zone and the Unit 4 Sarcophagus

The types and quantities of radioactive waste in the 30-km Zone around the Chornobyl NPP site and within the destroyed unit 4 Sarcophagus are for obvious reasons difficult to quantify. However, research has been conducted and estimates have been made. For example, in Reference [20] the type, quantity and activity of radioactive waste formed in the 30-km Zone are estimated as follows:

Waste Type	Quantity, Metric Tons	Total Activity, Ci
Vegetation	1.0×10^9	150,000
Structural Materials	3.5×10^5	60,000
Contaminated Ground	2.0×10^8	40,000
Garbage	3.0×10^5	20,000
Scrap Metal	4.0×10^5	15,000
Forest (woods)	3.0×10^5	10,000
Silt	2.0×10^6	5,000
Contaminated Buildings	3.0×10^6	3,500
Contaminated Water	5.0×10^7	100
Total	1.2×10^9	303,600

Several engineered disposal sites were built within the 30-km Zone, but a significant portion of the waste is disposed of in approximately 600 to 800 temporary storage trenches with no waterproof barriers. The volume of radioactive waste stored in the destroyed unit 4 Sarcophagus is estimated to be 100 times larger than the total volume of waste stored in the interim storage facilities (PVLROs) and disposal facilities (PZROs). The total volume stored in the PZROs and the PVLROs is approximately 1.1 x 10^9 m^3. Therefore, this estimate for total volume of radioactive waste stored in the destroyed unit 4 sarcophagus would be approximately 110 x 10^9 m^3, Ref. [21]. This reference must be verified against other references; 110 x 10^9 m^3 is a cube with sides approximately 3 miles in length, which is unlikely, the Sarcophagus is not that large. Reference [23] indicates there is approximately 1.0 x 10^6 m^3 of radioactive waste with a total activity of 380,000 Ci stored in the temporary trenches, which exceed 800 in number.

The Sarcophagus itself was constructed as a temporary structure in only seven months using, depending upon the reference, between 300,000 to 720,000 tons of concrete and 7,000 tons of steel Refs. [22 & 26]. The Sarcophagus is seen as a provisional barrier pending the identification and completion of a solution for elimination of the destroyed reactor and the safe disposal of the high level radioactive material stored within. The estimates of Reference [23], a 1996 status report, place the total quantity of fuel and fuel containing masses within the Sarcophagus at approximately 180 tons with an activity of approximately 20 x 10^6 Ci. Before the accident Unit 4 had approximately 190.3 tons of irradiated fuel in the core, 19.5 tons of spent fuel in the spent fuel storage facility and 2.3 tons of fresh fuel (20 fresh fuel assemblies in the Central Hall, Ref. [26]). In addition, there are large quantities of destroyed core internals, reactor graphite, contaminated structural elements, and approximately 3,000 to 3,500 m^3 of water. References [24 & 25] summarize the forms of the 180 tons of irradiated fuel within and around the Sarcophagus as follows: "(1) Fragments of active core, most of which was hurled to the upper levels of the Central Hall and are covered by the material dispersed from Helicopters in 1986. (Estimates place the material dropped from Helicopters at over 5,000 tons consisting of: 2400 tons of lead, 1800 tons of sand and clay, 800 tons of dolomite, and 40 tons of boron carbide.) Information about the fuel in the Central Hall is limited. (2) Finely dispersed fuel dust and hot fuel particles which measure from fractions of microns to hundreds of microns. These particles are practically everywhere in the Sarcophagus and in the soil in the vicinity of the plant and further afield. The total amount of fuel in this form is estimated roughly at 10 tons. (This number is only considered very approximate.) (3) Solid lava-like fuel-containing masses which were formed during the active phase of the accident by high temperature interaction of the fuel with the structural materials in the plant. There is considerable information about the lava in the lower regions - its location and physio-chemical features, but not about the total quantity which is estimated to be in the range of 70-150 tons. (4) Soluble forms of plutonium, americium and uranium, which is found in water about 1 mg/liter. (5) About 0.5 to 1 ton of the fuel remains on the ground around the Sarcophagus, under a layer of concrete and gravel." Some estimates place the total amount of radioactive waste in and around the Sarcophagus that will eventually have to be managed at approximately 350,000 tons.

Reference [23] describes and estimates the volume of operations related waste accumulated at the CNNP site as follows: solid wastes more than 40,000 m^3, liquid waste approximately 25,000 m^3, and approximately 14,000 spent cassettes stored at the spent fuel storage site. As a result of continuing operation of the remaining two units 2,000 m^3 of solid wastes and 870 m^3 of liquid wastes are released annually Ref. [23].

Figure 2.1 Forecasts for Ukrainian Liquid Waste Volumes and Storage Capacities

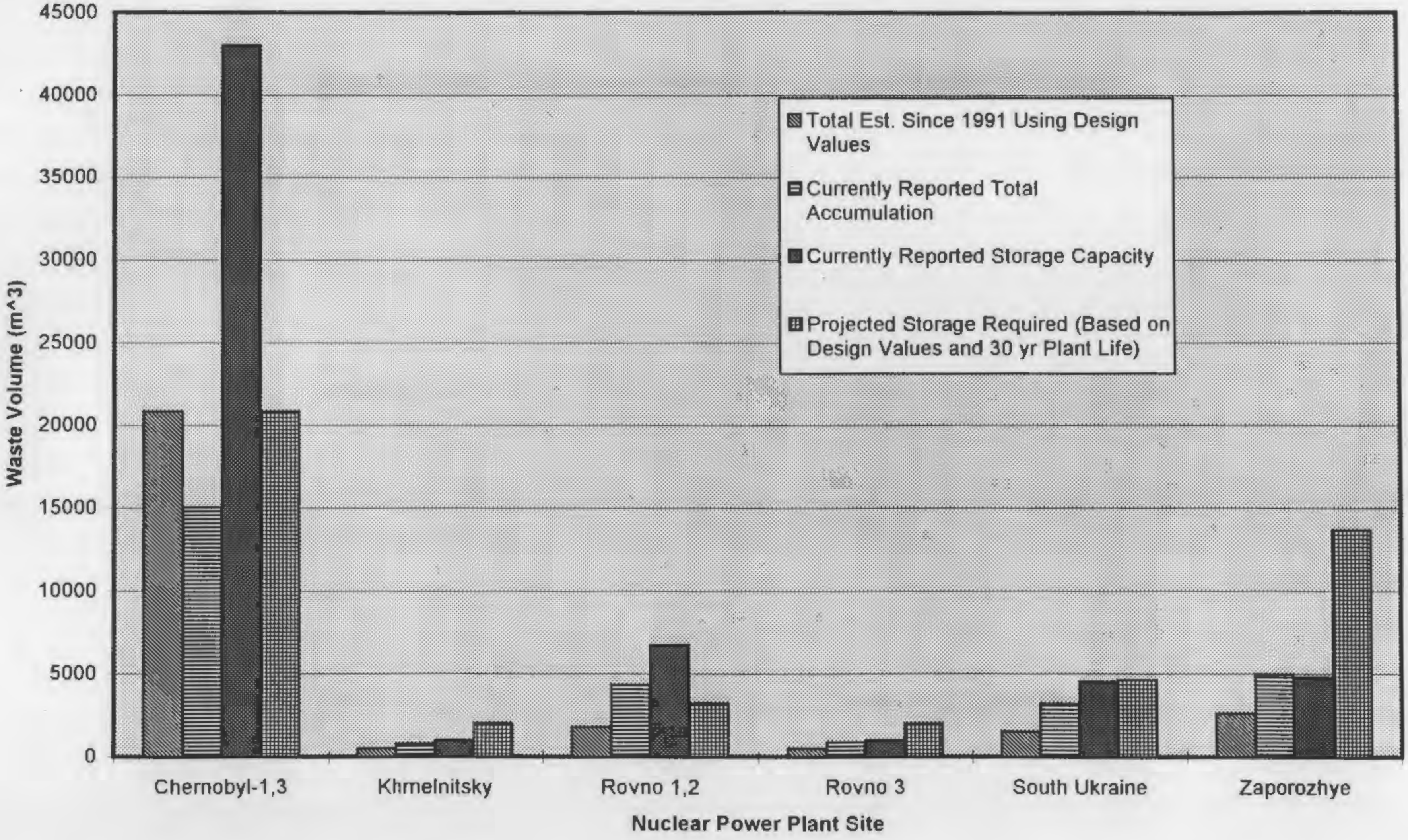
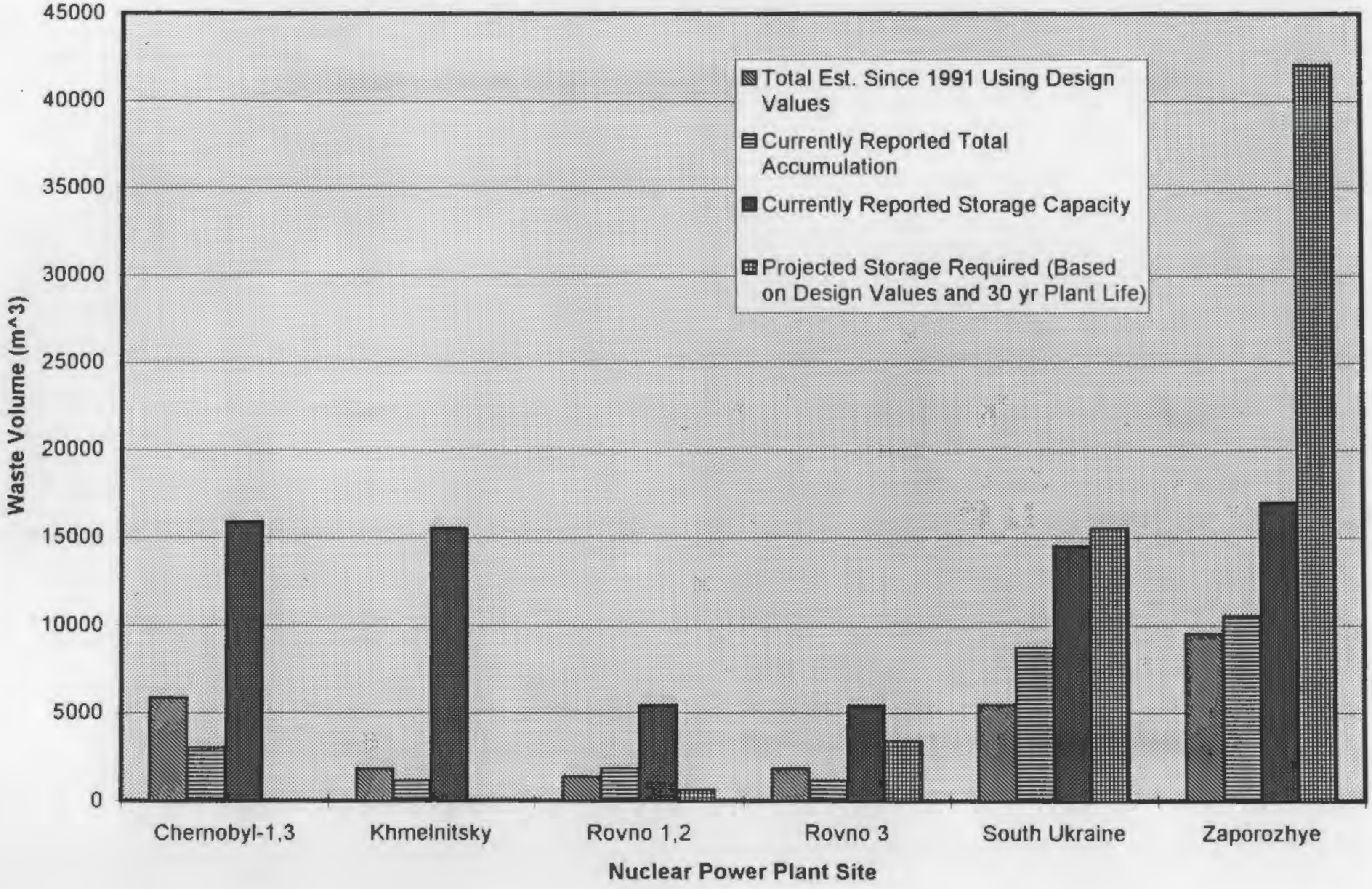
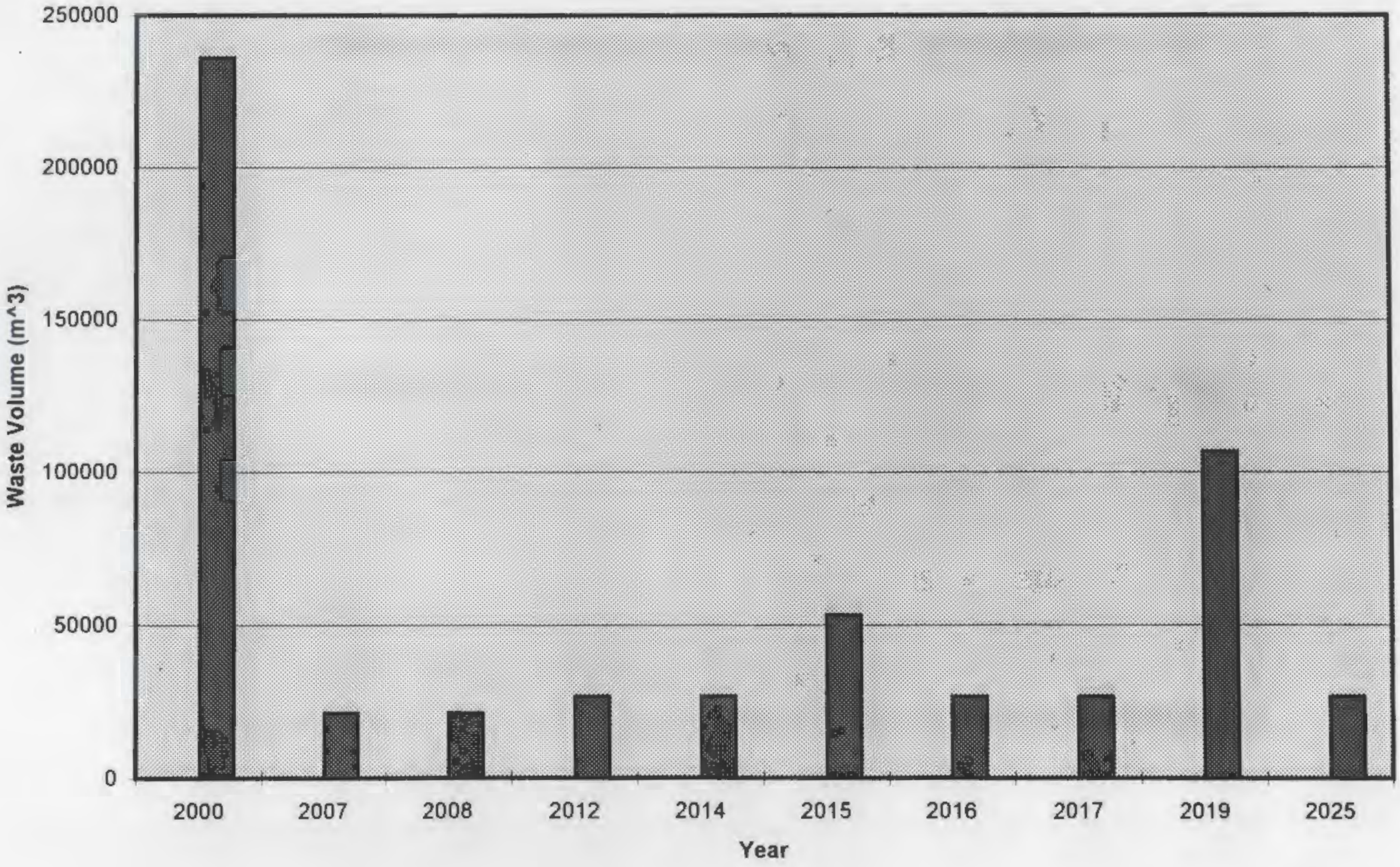


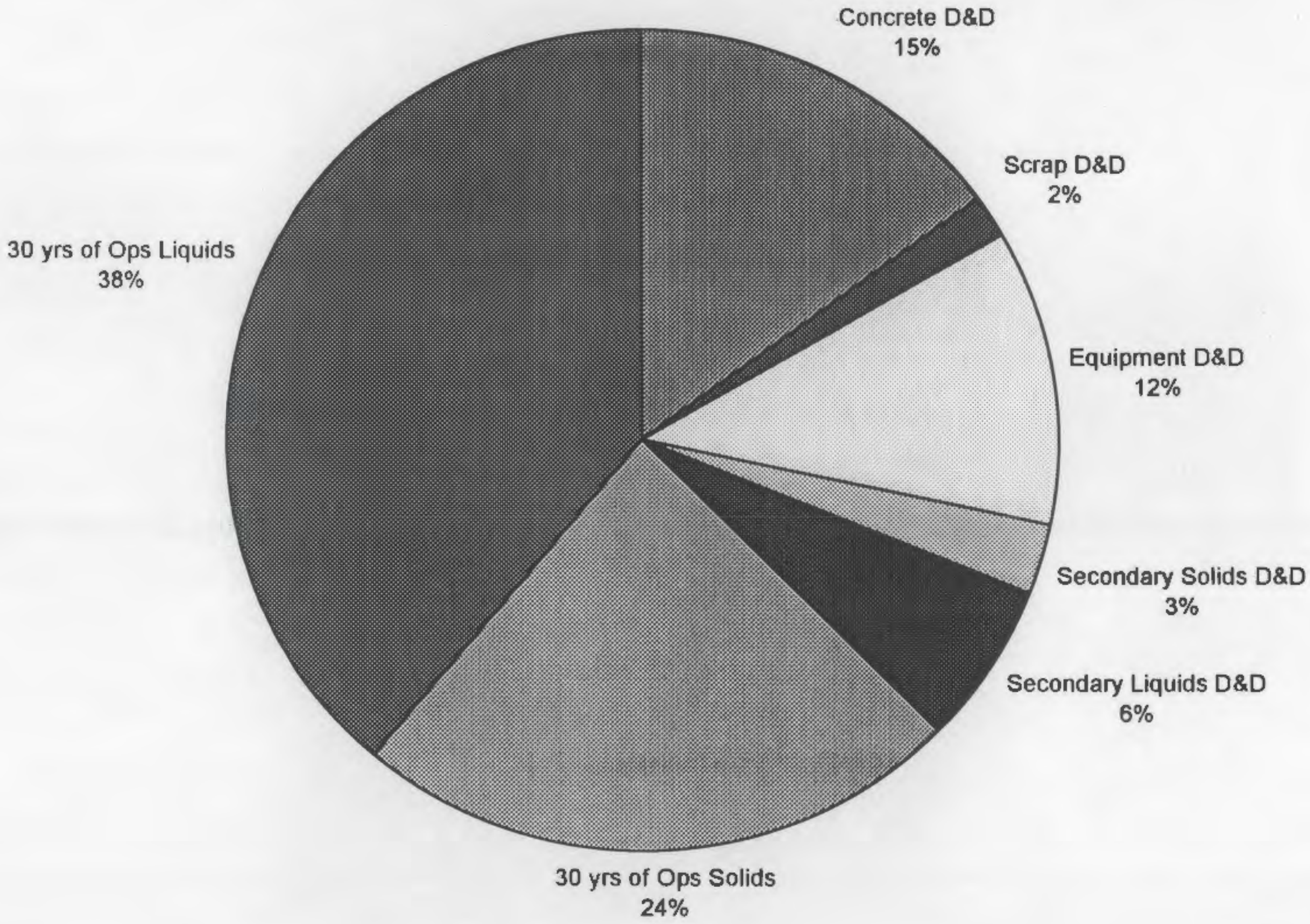
Figure 2.2 Forecasts for Ukrainian Solid Waste Volumes and Storage Capacities





Estimated 30 yr Operations and Decommissioning Total Waste Volumes by Year of Plant Shutdown

Distribution of Waste Forms, Totals for All Ukrainian NPPs, Not Including the Sarcophagus or 30 km Zone Wastes



3.0 Options Available for Solution of Ukrainian Radioactive Waste Problem

There are several options available for radioactive waste processing for the Ukrainian NPPs. Goskomatom along with other organizations, including the Ukrainian Scientific Research and Design Institute for Industrial Technology and the Ukrainian Academy of Sciences, have proceeded with a conceptual model for Ukrainian radioactive waste management. General information on the proposed Ukrainian approach was outlined in Ref. [10] which states,

> "*The radioactive waste of NPP's is stored at special storage facilities on the site. During the design of NPP's, little attention was paid to radwaste treatment. This is why radwaste management in Ukraine is among the priority issues of Goskomatom of Ukraine. Together with the Ukrainian Academy of Sciences, Goskomatom finalized in 1993 the development of the Concept for Ukrainian Radwaste Management and the General Scheme of the Development of Radwaste Management in Ukraine. The final stage of the process will be the development of the National Programme on Establishing the Radwaste Management Industry, in which the responsible executives and the scopes and sources of financing are to be defined. New Technologies for radwaste processing and new containers for long term storage of wastes of all types have been developed.*
>
> *It has been decided to establish and develop a centralized radwaste processing facility. This will enable us to carry out centralized processing activities and reliable storage of the radwastes of all NPPs at one site, which would eliminate the need to reprocess the waste at each NPP.*
>
> *Technological developments by Ukrainian scientists together with the design and manufacturing experience of Russian industrial installations, as well as possible participation of foreign firms should make it possible for us to solve the radwaste processing problem within the next four to five years, provided the work is properly organized.*"

The Ukrainian Ministry for Chornobyl Affairs in Reference [23] described a scientific and technological center for radioactive wastes complex management that has been set up in Zhovti Vody (Dnipropetrovsk region) for the purpose of implementing decontamination and recovery projects. This center focuses on the decontamination of settlements but has also designed and built burial sites for the wastes generated during decontamination efforts.

Detailed technical information on the proposed centralized radioactive waste processing facility was requested from Goskomatom and is discussed in Section 2.3 and below in Section 3.1. It is recommended that existing levels of initial processing occurring at the plant sites continue and that potential upgrades to initial on-site processing be considered. The central processing facility should not be designed to handle the unprocessed liquid radioactive waste streams from all of the Ukrainian NPPs. The total generation rate of unprocessed liquid radioactive wastes was estimated in Appendix A at 2275 m^3/day (601,000 gal/day). Handling this quantity of unprocessed waste at a central facility would be difficult considering the logistics of transport, storage, number of process trains required and necessary process rates.

The options chosen for initial processing at the plant sites and final processing at the central facility will impact the overall economics. The main techniques for treatment of the unprocessed wastes at the plant site consist of: ion-exchange treatment, filtration treatments, evaporation, chemical precipitation to produce a sludge, separation systems, reverse osmosis, molten metal technologies and incineration. All of the above treatments are applied to low and intermediate level radioactive wastes and the results are concentrates such as resins, evaporator bottoms, powders and sludge, etc. These can then be processed at the central facility using treatment methods that may consist of: additional volume reduction, incineration, and solidification in concrete or bitumen which is then packaged for storage and disposal. Solid radioactive wastes from the NPPs can be transported to the central facility to be processed using compaction, super-compaction, segregation (combustible and non-combustible), incineration of combustibles, solidification of ash, and final packaging for storage and disposal.

Cost estimates are taken from Refs. [2,3,4 and 11] and from vendor supplied information. The cost estimates come from several references which are based upon different years. Therefore, all cost estimates have been adjusted to 1996 dollars using an assumed interest rate of 5.0 % that combines the real discount rate and inflation rate from the estimates basis year.

The options presented below are compared using the present worth (in terms of costs) of the initial capital equipment investment and the yearly costs of operating the facilities to process and store the waste. It should be noted that total radioactive waste management costs are driven largely by the yearly processing and storage costs. Therefore, a higher initial capital cost required to install equipment that can significantly reduce the volume of wastes to be processed can reduce the overall costs associated with the life of the facility. In comparing the alternative options this analysis considered only the total present worth (in terms of costs) to select the preferred alternative. There may be other economic drivers and limitations that will impact the decision to select a preferred alternative, these items can be discussed individually when appropriate.

3.1 Ukrainian Design Information for Proposed Central Facility

In response to queries for design information on the proposed central facility Goskomatom, through a report completed by the Ukrainian Scientific Research and Design Institute for Industrial Technology Ref. [27], provided the following information:

The following is planned for implementation at the Central Radioactive Waste Processing Facility:

(1) extraction of molten salt, dried ionites, slurry and drum residue;
(2) extraction of borates from the molten salt;
(3) remelting of contaminated metal;
(4) thermochemical processing of spent sorbents and ion-exchange resins dried at the nuclear power plant;
(5) processing of combustible solid radwaste;
(6) drying of solid radwaste prior to compaction;
(7) compaction of pressed solid radwaste in drums;
(8) conversion of solid radwaste into insoluble forms (after preliminary conditioning) through bituminization, cementation or vitrification;
(9) storage of insoluble matrices containing solid radwaste in concrete casks.

The capacity of the processing units and storage capacity shall be determined during the feasibility analysis for development of the CRWPF, taking into account the annual production level of solid radwaste at nuclear power plants and waste from decommissioning of nuclear power plants. All equipment at the CRWPF shall be resistant to radiation, decontaminated solvents and shall have biological shielding, remote control capability; include dust and gas filtering systems and shall be licensed by Minekobezopastnost agencies. Class 1 and 2 radioactive waste will be processed at the CRWPF. The CRWPF will include automatic monitoring systems for monitoring the site radiation environment as well as environmental monitoring systems for the surrounding areas. The equipment and pipelines will be reliable and operationally safe throughout their designed service life. All equipment which will be periodically decontaminated is to be fabricated from corrosion-resistance material.

3.1.1 Ukrainian Cost Estimates for the Goskomatom Proposal

Goskomatom in its initial letter to DOE Ref. [1] estimated a total cost of $40 million dollars to construct the facility with roughly half going to capital equipment costs and half going to labor. PNNL requested details on the assumptions that went into this cost estimate. The final response to the PNNL request, in regard to capital equipment costs, were provided in Ref. [27]. The capital equipment costs provided by Ref. [27] are presented in Table 8 of this report. Total capital equipment costs were estimated by Ref. [27] to be $61.6 million dollars.

3.2 Liquid Waste Management Systems Options

Liquid waste management systems consist of tanks for collection, followed by processing using one or more unit operations such as: filters, ion exchanger, separators and evaporators to achieve the necessary cleanup and volume reduction. The processing stage can be combined in several different ways to handle the different feed streams. Because the details of the proposed central radioactive waste processing facility are not finalized, an evaluation of options for combined operations and their necessary capabilities will be conducted instead. Different combinations of the operations are generated to offer options available for solution of the Ukrainian liquid radioactive waste problem. The options presented below are compared using the total present worth (in terms of total costs) of the initial capital equipment investment plus the yearly costs of operating the facilities over a 20 year lifetime and finally long term storage of the final waste form.

3.2.1 Option 1 Description and Costs

This option assumes that the existing liquid radioactive waste processing trains at the Ukrainian NPPs will be operated as designed and the concentrates: evaporator bottoms and resins will be transported to the central facility for further processing. Processing at the central facility follows the processes described for solid waste management options and includes concentration, solidification, packaging and storage prior to final disposal. The costs for this option are discussed under Section 3.3 Solid Waste Management System Options (Option 1).

3.2.2 Option 2 Description and Costs

This option upgrades the existing liquid radioactive waste processing trains at the Ukrainian NPPs using advanced volume reduction methods. Advanced volume reduction techniques have been developed that allow for reduction of waste volumes by approximately a factor of four or more depending upon the process chosen. These technologies are supplied by U.S. Vendors who currently have proven facilities in operation at U.S. Plants. This option reduces the volume of concentrates and resins and therefore the costs of further processing and disposal required at a central facility. The costs for this option include the capital cost of installing the mobile processing units at the individual plant sites and the cost of processing the reduced volumes of solid waste delivered to the central facility.

The per-unit capital equipment costs for a single advanced process/evaporator system supporting a single plant are estimated at $5,900,000 to $13,300,000. These estimates came from a recently completed U.S. vendor project in Valdivostok and Refs. [3 and 11] where process/evaporator systems supporting a single unit are given. The total capital equipment costs are higher when factoring in the number of Ukrainian NPPs (15 plants) and the centralized solidification system capable of handling the concentrated liquids and resins produced. However, cost savings could be realized by designing mobile units that service one NPP site (with 3,4, or 6 NPPs). In addition, the costs for a single mobile unit may be suitable to a multi-phased staggered approach where those plants with the severest process and storage problems are solved first. Increasing the above per unit cost estimate by a factor of 3 ($18 to $40 million) provides a total cost estimate that would be reasonable to support distributed operations, and still results in a total present worth (in terms of total costs) that is lower than Option 1. Advanced process/evaporator units have a wide range of potential configurations and options including: ion-exchanger, separators, dryers, crystallizer, etc. causing the large range in cost estimates.

The yearly processing cost estimate for a mobile process/evaporator solution with a centralized solidification system is $4,425,000 based upon the processing costs per cubic meter found in Ref. [11].

The capital equipment cost estimates for a centralized solids compactor system capable of processing the total estimated generation rates and volumes are in the range of $640,000 to $2,560,000. These estimates come from Refs. [3 and 11] where a compactor system supporting a single unit are estimated at $74,000 to $295,000. The individual unit estimates were adjusted to account for the required capacity to service 15 Ukrainian power plants and the decommissioning waste from three RBMK-1000s at Chernobyl.

The yearly processing cost estimate for a centralized solids compactor system for the operating NPPs is $8,570,000 based upon the processing costs per cubic meter found in Ref. [11]. The yearly processing cost estimate for a centralized solids compactor system for the Chornobyl decommissioning waste is $9,050,000 based upon the processing costs per cubic meter found in Ref. [11].

When evaluating the total present worth (in terms of total costs) for Option 2 it becomes clear that Option 2 is the preferred alternative in terms of minimizing total costs. Option 2 has a lower present worth (total cost), due to the fact that the yearly processing and storage costs are much lower for Option 2 (there is a smaller volume of concentrated waste to process and store). The total present worth is lower even though the initial total capital equipment costs are higher.

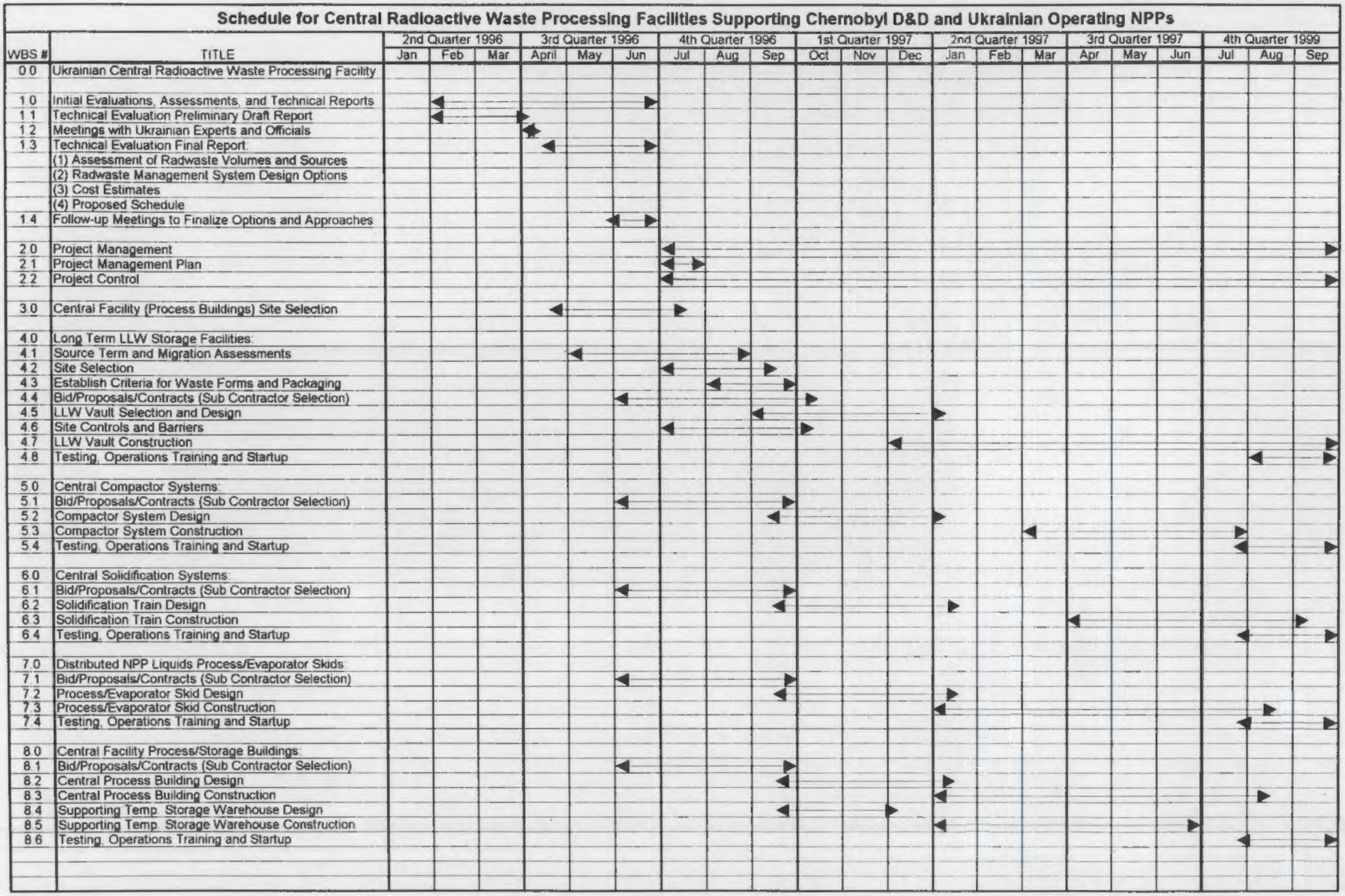
Table 13

Least Cost Option #2 - Capital Equipment Estimate Summary

Process Description	Low Range	High Range
Single Solids Compactor System	74,000	295,000
Central Compactor for all NPPs and CNPP D&D waste.	640,000	2,560,000
Single Advanced Mobile Process/Evaporator Unit	5,900,000	13,300,000
Three Advanced Mobile Process/Evaporator Units	17,700,000	39,900,000
Single Solidification Train	1,000,000	6,000,000
Central Solidification Train Processing all NPPs and CNPP Operating Wastes	1,500,000	8,900,000
Storage Facility for all NPPs and CNPP Solidified Liquids and Resins	9,900,000	unavailable
Storage Facility for all NPPs and CNPP Compacted Solids	71,100,000	unavailable
Storage Facility for 3 RBMKs D&D Waste	73,700,000	unavailable

An initial schedule showing a work breakdown structure for the major components of the central processing and storage facilities follows. This schedule is preliminary and is presented to provide a general overview of the major items that would have to completed for such a project. It is not intended to be comprehensive but rather a starting point for consideration and discussion among the participating Institutes and Organizations.

Schedule for Central Radioactive Waste Processing Facilities Supporting Chernobyl D&D and Ukrainian Operating NPPs



WBS #	TITLE
0.0	Ukrainian Central Radioactive Waste Processing Facility
1.0	Initial Evaluations, Assessments, and Technical Reports
1.1	Technical Evaluation Preliminary Draft Report
1.2	Meetings with Ukrainian Experts and Officials
1.3	Technical Evaluation Final Report:
	(1) Assessment of Radwaste Volumes and Sources
	(2) Radwaste Management System Design Options
	(3) Cost Estimates
	(4) Proposed Schedule
1.4	Follow-up Meetings to Finalize Options and Approaches
2.0	Project Management
2.1	Project Management Plan
2.2	Project Control
3.0	Central Facility (Process Buildings) Site Selection
4.0	Long Term LLW Storage Facilities:
4.1	Source Term and Migration Assessments
4.2	Site Selection
4.3	Establish Criteria for Waste Forms and Packaging
4.4	Bid/Proposals/Contracts (Sub Contractor Selection)
4.5	LLW Vault Selection and Design
4.6	Site Controls and Barriers
4.7	LLW Vault Construction
4.8	Testing, Operations Training and Startup
5.0	Central Compactor Systems:
5.1	Bid/Proposals/Contracts (Sub Contractor Selection)
5.2	Compactor System Design
5.3	Compactor System Construction
5.4	Testing, Operations Training and Startup
6.0	Central Solidification Systems:
6.1	Bid/Proposals/Contracts (Sub Contractor Selection)
6.2	Solidification Train Design
6.3	Solidification Train Construction
6.4	Testing, Operations Training and Startup
7.0	Distributed NPP Liquids Process/Evaporator Skids:
7.1	Bid/Proposals/Contracts (Sub Contractor Selection)
7.2	Process/Evaporator Skid Design
7.3	Process/Evaporator Skid Construction
7.4	Testing, Operations Training and Startup
8.0	Central Facility Process/Storage Buildings:
8.1	Bid/Proposals/Contracts (Sub Contractor Selection)
8.2	Central Process Building Design
8.3	Central Process Building Construction
8.4	Supporting Temp. Storage Warehouse Design
8.5	Supporting Temp. Storage Warehouse Construction
8.6	Testing, Operations Training and Startup

3.3 Solid Waste Management Systems Options

The types of solid waste generated at a NPP can be classified into four main groups: concentrated liquids (slurries such as evaporator bottoms), wet solids (resins and sorbents), dry solids (ash or dry resins) and contaminated trash (anti-contamination clothing, plastic, concrete, wood etc.) The discharge of the NPPs liquid radioactive waste systems and the solids can be processed at the central facility using treatment methods that may consist of segregation, additional volume reduction (such as incineration, compaction or super-compaction), solidification of liquids, wet solids and ash in concrete or bitumen followed by final packaging of the solids for storage and disposal.

The steps for solid waste management consist of waste collection, waste pretreatment and volume reduction, solidification and mixing, and final package container handling storage and disposal. All of the solid waste options include the capital and operating costs associated with a compactor system to process the contaminated trash that is not solidified.

3.3.1 Option 1 Description and Costs

This is the conventional option where the solid wastes generated (concentrated liquids, resins or dry solids) are solidified in cement or other binding agents. Cement is often used in the U.S. because of its relatively low cost and stability, bitumen is used primarily in Europe. However, mixing of the waste stream with the solidification agent increases the volume of waste to be disposed. The volume increase ratio for solidification of concentrated liquids and ion-exchange resins is approximately 1.4.

The capital equipment cost estimates for a centralized solidification system capable of handling the total estimated generation rates and volumes are in the range of $8,550,000 to $51,340,000. These estimates came from recently completed individual utility projects and Ref. [3] where solidification systems supporting a single unit are estimated at $990,000 to $5,900,000. The individual unit estimates were adjusted to account for the required capacity to service 15 Ukrainian power plants. Solidification units have a wide range of potential configurations including: in-line mixing, in-container mixing, batch, continuous, automatic drum stacking, etc. leading to the large range in cost estimates.

The yearly processing cost estimate for a centralized solidification system is $9,300,000 based upon the processing costs per cubic meter found in Ref. [11]. The capital cost estimate for storage space for the operating NPP only is $93,000,000 based upon the storage costs per cubic meter found in Ref. [11].

The capital equipment cost estimates for a centralized solids compactor system capable of processing the total estimated generation rates and volumes are in the range of $640,000 to

$2,560,000. These estimates come from Refs. [3 and 11] where a compactor system supporting a single unit are estimated at $74,000 to $295,000. The individual unit estimates were adjusted to account for the required capacity to service 15 Ukrainian power plants and the decommissioning waste from three RBMK-1000s at Chernobyl.

The yearly processing cost estimate for a centralized solids compactor system for the operating NPPs is $8,570,000 based upon the processing costs per cubic meter found in Ref. [11]. The yearly processing cost estimate for a centralized solids compactor system for the Chornobyl decommissioning waste is $9,050,000 based upon the processing costs per cubic meter found in Ref. [11].

When evaluating the total present worth (in terms of total costs) for Option 1 it becomes clear that Option 2 is the preferred alternative in terms of minimizing total costs. Option 2 has a lower present worth (total cost), due to the fact that the yearly processing and storage costs are much higher for Option 1 (there is a greater volume of waste to process and store). This is true even though the initial capital equipment costs are higher for Option 2.

3.3.2 Option 2 Description and Costs

See the above discussion under Section 3.2 Liquid Waste Management Systems Options (Option 2).

3.3.3 Option 3 Description and Costs

Option 3 is the use of incineration technology at the central facility to process the resins, sludge, and combustible trash (often 50% to 80% of the total dry solids generated). Because this option cannot process evaporator bottoms (concentrated liquids), without the use of a dryer system, a solidification train is required to process the concentrated liquids. The solidification train is also required to solidify the resulting ash. In addition, a compactor system is required to compact the non-combustible trash and salts. Incineration systems are relatively expensive compared to the other available technologies with total system capital costs from Refs. [3 and 11] ranging from $13 to $115 million dollars. Because of the high costs of incineration systems, which are due primarily to the high initial capital cost and the high costs of operation, including scrubbing and filtering the exhaust gasses, only the capital costs are evaluated. Incineration systems, although commercially available, are not routinely used at commercial nuclear reactors and their use for the Ukrainian nuclear reactors is not recommended because of the high costs and technical concerns involved.

In addition to the high costs of incineration, other technical concerns also limit the viability of an incineration system. Incineration of intermediate level and above wastes would require shielding of the incinerator itself with provisions for remote operation throughout the process, limiting incineration to low-level wastes only. Segregation would be required to eliminate objects from the waste stream that are unsuitable for combustion such as: PVCs, high rubber content items, large metal objects, and explosion hazards. The feasibility of incinerating ion exchange resins is not well established and there are uncertainties in the areas of volume reduction effectiveness, corrosive attack, emissions generated, system complexity, long term effects and overall economics. For these reasons, an incineration system for general use is not recommended for the Ukrainian central radioactive waste processing facility. However, incineration systems can be developed for special processes if the economics prove viable and a specific need for an incineration system is identified.

3.4 Options for Storage Facility and Central Shielded Process Building

The storage facility and central process buildings should be designed, and constructed in conformance with acceptable standards and regulations. These standards and regulations can be summarized with one general and three specific performance objectives for any storage and radioactive waste process facility Ref. [3]. These performance objectives summarize those that have been established for U.S. facilities. Given that the proposed storage and process facility is to be located in Ukraine, near the destroyed unit at Chernobyl, all of these performance objectives may or may not be directly applicable.

The general performance objective addresses the site-specific barrier system that must be designed for long term safe storage performance through:

(1) detailed engineering design of the proposed structure;
(2) developed operational procedures;
(3) criteria for the waste forms and packaging to be stored;
(4) consideration and use of the natural characteristics of the site; and
(5) established controls for site land use.

The three specific performance objectives include:

(1) protection of the ground water (requires consideration of local geology and hydrology);
(2) protection against any inadvertent intruder (requires consideration of local natural resources, population distribution, and existing land use patterns); and
(3) provisions to ensure safety during operation of the storage facility (requires consideration of ALARA, waste routing, waste packaging and operator/administrative controls).

There are many design provisions that must be considered to meet the above performance objectives. Design provisions include but are not limited to: ensuring structural stability; the use of curbs and drains to contain spills; proper material selection; precluding release pathways;

collecting drainage; proper shielding configurations; fire protection; and corrosion allowances.

The storage facility options include:

(1) Temporary Storage in Warehouse Structures
(2) Shallow Land Burial (Earth Mounded Bunkers and Trenches)
(3) Shallow Land Burial (Earth Mounded Concrete Bunkers)
(4) Above Ground Vaults
(5) Below Ground Vaults
(6) Mined Cavities (New mined cavities would be overly expensive but existing dry limestone or salt mines might be feasible. Coal mines are prohibited due to corrosive and potentially explosive environments.)

Many different materials have been used to construct storage vaults and no constraints should be placed on material selection or shape of the storage vaults as long as the performance objectives can be met.

The structure costs per m^2 for storage facilities and for shielded buildings and warehouses for a central process facility are taken from Refs. [3 and 11].

Structure or Facility	Typical Cost Range per m^2
Radioactive Waste Storage Facility	\$4,900 - \$10,600 /m^2
Central Process Building (shielded)	\$4,900 - \$8,200 /m^2
Warehouse (shielded)	\$850 - \$1,700 /m^2

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Appendix A: Computer Models used in this Evaluation (Radstat1.xls and Ukrcalc1.mcd)

Ukrainian Rad Waste Data

	A	B	C	D	E	F	G
1	Description of Waste		Volumes of Radioactive Wastes Generated during Operations				
2	Type and Storage						
3	Capacity	Chernobyl-1,3	Khmelnitsky	Rovno 1,2	Rovno 3	South Ukraine	Zaporozhye
4		2 RBMKs	1 VVER-1000	2 VVER-440s	1 VVER-1000	3 VVER-1000s	6 VVER-1000s
5							
6	Evap Bottoms m^3/yr	4000	86	340	86	258	516
7	LL Resin m^3/yr	124	10	16	10	30	60
8	HL Resin m^3/yr	44	5.3	6	5.3	15.9	31.8
9	Tot Conc. Liquid m^3/yr	4168	101.3	362	101.3	303.9	607.8
10	Total Since 1991 m^3	20840	507	1810	507	1520	2634
11	Reported Liquids Accumulation	15023	786	4350	900	3212	4985
12	Total Calc Since Start Up	66688	810	5249	912	3109	4761
13							
14	Solids m^3/yr	818	300	200	300	900	1800
15	Salts m^3/yr	358	65	72	65	195	390
16	Total Solids m^3/yr	1176	365	272	365	1095	2190
17	Total Since 1991 m^3	5880	1825	1360	1825	5475	9490
18	Reported Solids Accumulation	3019	1163	1837	1163	8697	10531
19	Total Calc Since Start Up	18816	2920	3944	3285	11202	17155
20							
21	Liquid Storage						
22	Installed Storage Capacity m^3	43000	1000	6730	1000	4514	4800
23	% used	48%	79%	65%	90%	71%	104%
24	Projected Storage Req. m^3	20840	2015	3231	2027	4615	13658
25							
26	Solid Storage						
27	Installed Storage Capacity m^3	15900	15544	5452	5452	14500	17000
28	% used	19%	7%	34%	21%	60%	62%
29	Projected Storage Req. m^3	0	0	601	3376	15517	42076
30							
31							
32	Total Conc. Liquid all NPPs	5644					
33	Total Solids all NPPs m^3/yr	5463					
34	Total all NPPs m^3/yr	11107		This is the unprocessed total volume per year m^3/yr (design)			
35							
36							

	A	B	C	D	E	F	G
37							
38							
39			Estimated Waste Volumes from Decommissioning and Dismantaling Activities				
40							
41							
42		For purposes of estimating volumes the following assumptions were made for material packing					
43		densities: Concrete 150 lbm/ft^3, Scrap 1.6 g/cm^3 (avg.), Equipment 0.05 lbm/in^3 (avg.).					
44	Waste Type		Metric Tons			m^3	
45		RBMK-1000	VVER-440	VVER-1000	RBMK-1000	VVER-440	VVER-1000
46	Concrete	36000	3250	12000	14942	1349	4981
47	Scrap	2500	500	900	1588	318	572
48	Equipment	12106	4685	6000	8732	3379	4328
49	30 yrs of Operations Solids				17640	7080	10950
50	30 yrs of Solidified Liquids				89314	7757	4341
51	Other Solids (10%)				1764	708	1095
52	Other Solidified Liquids (10%)				8931	776	434
53	Totals				142912	21367	26701
54							
55				Total Estimated D&D Wastes for Each NPP Site m^3			
56	Waste Type	Chernobyl 1-3	Khmelnitsky	Rovno 1,2	Rovno 3	South Ukraine	Zaporozhye
57		3 RBMKS	1 VVER-1000	2 VVER-440s	1 VVER-1000	3 VVER-1000s	6 VVER-1000s
58	Concrete	44827	4981	2698	4981	14942	29885
59	Scrap	4763	572	635	572	1715	3429
60	Equipment	26197	4328	6759	4328	12984	25967
61	30 yrs of Operations Solids	28224	10950	14160	10950	32850	65700
62	30 yrs of Solidified Liquids	100032	4341	15514	4341	13024	26049
63	Other Solids (10%)	5292	1095	1416	1095	3285	6570
64	Other Solidified Liquids (10%)	26794	434	1551	434	1302	2605
65	Totals m^3	236129	26701	42733	26701	80102	160204
66							
67	Total 30 yrs of Ops Solids	162834		Total Concrete all NPPs			102314
68	Total 30 yrs of Ops Solidified li	163302		Total Scrap all NPPs			11684
69	Total 30 yrs of Ops all NPP	326136		Total Equipment all NPPs			80562
70				Total Other Solids (10%) all NPPs			18753
71				Total Other Solidified Liquids (10%) all NPPs			33121
72	Total all NPP Ops and D&D	572570		Total D&D Waste all NPPs			246434

	A	B	C	D	E	F	G
73							
74							
75			Estimated D&D Wastes per Year of Plant Shutdown				
76		For purposes of estimating the future waste volumes, the D&D wastes are accounted for in the year a plant shuts down. Actual waste production is dependent on the D&D strategy and will occur over a several year period.					
77							
78							
79							
80	No# and Type of Plant	Year	Total Estimated 30 yr Ops and D&D Waste m^3				
81	3 RBMK-1000s	2000		236129			
82	1 VVER-440	2007		21367			
83	1 VVER-440	2008		21367			
84	1 VVER-1000	2012		26701			
85	1 VVER-1000	2014		26701			
86	2 VVER-1000s	2015		53401			
87	1 VVER-1000	2016		26701			
88	1 VVER-1000	2017		26701			
89	4 VVER-1000s	2019		106803			
90	1 VVER-1000	2025		26701			
91			Total	572570			
92							
93							
94							
95							
96							
97			Operating Waste Volumes After Completion of Processing				
98	Process Description	Chernobyl 1,3	Khmelnitsky	Rovno 1,2	Rovno 3	South Ukraine	Zaporozhye
99		2 RBMKS	1 VVER-1000	2 VVER-440s	1 VVER-1000	3 VVER-1000s	6 VVER-1000s
100	Solidification Trains:						
101	VR factor 0.7	0.7					
102	Solidified Liquids/Res m^3/yr	5954	145	517	145	434	868
103							
104		Total Solidified Liquids/Resins m^3/yr			8063		
105							
106		Total Solidified Liquids/Res. Over 20 yr Life of Facility m^3				71951	
107							
108							

	A	B	C	D	E	F	G
109	Standard Compactor:						
110	VR factor 2.3 (2.0 for Salts)	2.3	2	VR factor for Cutting and Hand Packing			0.6
111	47% of Solids are Compactible	0.47					
112	53% are Non-Compactible	0.53					
113	Compacted Solids m^3/yr	346	94	77	94	281	563
114	Non-Compacted Solids m^3/yr	723	265	177	265	795	1590
115	Totals m^3/yr	1069	359	254	359	1076	2153
116							
117		Total Processed Solids m^3/yr		5269			
118							
119		Total Processed Solids Over 20 yr Life of Facility m^3				89351	
120							
121	Super Compactor:						
122	VR factor 8.7 (2.0 for Salts)	8.7	2	VR factor for Cutting and Hand Packing			0.8
123	47% of Solids are Compactible	0.47					
124	53% are Non-Compactible	0.53					
125	Compacted Solids m^3/yr	223	49	47	49	146	292
126	Non-Compacted Solids m^3/yr	542	199	133	199	596	1193
127	Totals m^3/yr	765	247	179	247	742	1485
128							
129		Total Processed Solids m^3/yr		3666			
130							
131		Total Processed Solids Over 20 yr Life of Facility m^3				61852	
132							
133							
134	Advanced Mobile						
135	Liquid Evaporator/Solidification						
136	VR factor 6.0 (for Conc Liq.)	6					
137	VR factor 2.0 (for Resins)	2					
138	Evap/Solid Conc Liquids m^3/yr	667	14	57	14	43	86
139	Evap/Solid Resins m^3/yr	84	8	11	8	23	46
140	Totals m^3/yr	751	22	68	22	66	132
141							
142		Total Processed Liquids m^3/yr		1060			
143							
144		Total Processed Liquids Over 20 yr Life of Facility m^3				9943	

	A	B	C	D	E	F	G
145							
146	Incinerator/Solidification:						
147	VR factor 113 (for solids)	113					
148	% of combustible solids	0.8					
149	% of non-combustible solids	0.2					
150	VR factor 4.0 (for LL Resins)	4					
151	VR factor 7.5 (for Conc. Liquid)	7.5					
152							
153	Incinerated Solids m^3/yr	6	2	1	2	6	13
154	Super Comp. Solids m^3/yr	198	39	41	39	118	236
155	Incinerated LL Resins m^3/yr	31	3	4	3	8	15
156	Solidified HL Resins m^3/yr	63	8	9	8	23	45
157	Incin. Conc. Liquid m^3/yr	533	11	45	11	34	69
158	Totals m^3/yr	831	63	100	63	189	378
159							
160		Total Processed Liquids and Solids m^3/yr			1624		
161							
162		Total Processed Liquids and Solids 20 yr Life of Facility m^3				20025	
163							
164							
165							
166							
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Calculational Models for the Technical Evaluation of a Proposed Central Radioactive Waste Processing Facility to be Located in Ukraine

The purpose of these calculations are to establish a technical basis for evaluating the Ukrainian proposal for a central radioactive waste facility. The data is mainly based upon publicly available literature. In addition, specific data was obtained from the Ukrainian State Committee on Nuclear Power Utilization (GOSKOMATOM). The current volumes, generation rates, available storage and processing rates for the Ukrainian nuclear power plants and the proposed processing facility are evaluated. Also, estimates of the future radioactive waste volumes, generation rates and processing rates are evaluated. In addition, the estimated costs for a processing facility capable of handling the volumes of radioactive waste described are evaluated.

Define descriptive variables for the Ukrainian Power Plants:

N1 = 11 Number of VVER-1000 Plants Currently Operating

Cap1 = 1000 MWe

N2 = 2 Number of VVER-440 Plants Currently Operating

Cap2 = 440 MWe

N3 = 2 Number of RBMK-1000 Plants Currently Operating

Cap3 = 1000 MWe

Define Conversion Factors:

Cmg = 264.17 gal(us)/m^3 Cmf = 35.31 ft^3/m^3

Cgm = $3.785412 \cdot 10^{-3}$ m^3/gal(us) Cfm = 0.0283 m^3/ft^3

Cmy = 1.3079 yd^3/m^3

Cym = 0.7645549 m^3/yd^3

Define Radioactive Waste Generation Rates:

For the VVER-1000 Plants:

EB1 = 86 m^3/yr of Evaporator Bottoms

TS1 90 tons/yr of Total Salt

LR1 = 10 m^3/yr of Low-Level Resin Beads (Sorbents)

HR1 5.3 m^3/yr of High-Level Resin Beads (Sorbents)

SG1 300 m^3/yr of Solids

LS1 = 1800 m^3 of Liquid Storage Capacity LLW and ILW

LS1n = 1.8 m^3/MWe Normalized Liquid Storage Capacity

LS1u = 0.75 Percentage of Used Liquid Storage Capacity

SS1 = 2500 m^3 of Solid Storage Capacity LLW and ILW

SS1n = 2.5 m^3/MWe Normalized Solid Storage Capacity

SS1u = 0.50 Percentage of Used Solid Storage Capacity

UL1 = 167 m^3/day of Unprocessed Liquid Radwaste

UL1m = 232 m^3/day Unprocessed Liquid Radwaste from Maximum DBE

For the VVER-440 Plants:

EB2 = 170 m^3/yr of Evaporator Bottoms

TS2 = 50 tons/yr of Total Salt

LR2 = 8 m^3/yr of Low-Level Resin Beads (Sorbents)

HR2 = 3.0 m^3/yr of High-Level Resin Beads (Sorbents)

SG2 = 200 m^3/yr of Solids

LS2 = 1850 m^3 of Liquid Storage Capacity LLW and ILW

LS2n = 4.2 m^3/MWe Normalized Liquid Storage Capacity

LS2u = 0.75 Percentage of Used Liquid Storage Capacity

SS2 = 1850 m^3 of Solid Storage Capacity LLW and ILW

SS2n = 4.2 m^3/MWe Normalized Solid Storage Capacity

SS2u = 0.50 Percentage of Used Solid Storage Capacity

UL2 = 74 m^3/day of Unprocessed Liquid Radwaste

UL2m = 102 m^3/day Unprocessed Liquid Radwaste from Maximum DBE

For the RBMK-1000 Plants:

EB3 = 2000 m^3/yr of Evaporator Bottoms

TS3 = 250 tons/yr of Total Salt

LR3 = 62 m^3/yr of Low-Level Resin Beads (Sorbents)

HR3 = 22 m^3/yr of High-Level Resin Beads (Sorbents)

$SG3 = 400$ m^3/yr of Solids

$LS3 = 3900$ m^3 of Liquid Storage Capacity LLW and ILW

$LS3n = 3.9$ m^3/MWe Normalized Liquid Storage Capacity

$LS3u = 0.75$ Percentage of Used Liquid Storage Capacity

$SS3 = 6600$ m^3 of Solid Storage Capacity LLW and ILW

$SS3n = 6.6$ m^3/MWe Normalized Solid Storage Capacity

$SS3u = 0.50$ Percentage of Used Solid Storage Capacity

$UL3 = 145$ m^3/day of Unprocessed Liquid Radwaste

$UL3m = 625$ m^3/day Unprocessed Liquid Radwaste from Maximum DBE

Total Radwaste Generation Rates for all of the Operational Ukrainian Power Plants:

$TEB = N1 \cdot EB1 + N2 \cdot EB2 + N3 \cdot EB3$

$TEB = 5286$ m^3/yr Total Evaporator Bottoms

$TEBus = TEB \cdot Cmg$ $TEBus = 1396402.62$ gal/yr

$TTS = N1 \cdot TS1 + N2 \cdot TS2 + N3 \cdot TS3$

$TTS = 1590$ tons/yr of Total Salt

$TTSv = \frac{TTS \cdot 2200 \cdot Cfm}{87}$ Convert total tons of salt to volume in m^3/yr assuming a density of 87 lb/ft^3

$TTSv = 1137.855$ m^3/yr of dry powdered salt

$TLR = N1 \cdot LR1 + N2 \cdot LR2 + N3 \cdot LR3$

$TLR = 250$ m^3/yr Total Low-Level Resin Beads (Sorbents)

$TLRus = TLR \cdot Cmg$ $TLRus = 66042.5$ gal/yr

$THR = N1 \cdot HR1 + N2 \cdot HR2 + N3 \cdot HR3$

$THR = 108.3$ m^3/yr Total High-Level Resin Beads (Sorbents)

$THRus = THR \cdot Cmg$ $THRus = 28609.611$ gal/yr

$TSG = N1 \cdot SG1 + N2 \cdot SG2 + N3 \cdot SG3$

$TSG = 4500$ m^3/yr Total Solids

$TSGus = TSG \cdot Cmy$ $TSGus = 5885.55$ yd^3/yr

$TUL = N1 \cdot UL1 + N2 \cdot UL2 + N3 \cdot UL3$

$TUL = 2275$ m^3/day Total Unprocessed Liquid Radwaste

$TULus = TUL \cdot Cmg$ $TULus = 600986.75$ gal/day

$TULm = N1 \cdot UL1m + N2 \cdot UL2m + N3 \cdot UL3m$

$TULm = 4006$ m^3/day Total Unprocessed Liquid Radwaste from Maximum DBE

$TULmus = TULm \cdot Cmg$ $TULmus = 1058265.02$ gal/day

Calculate the total amount of waste to be generated from decommissioning of 3 RBMKs at Chernobyl:

Concrete:

$DC = \frac{3 \cdot 36000 \cdot 2200 \cdot 0.0283}{150}$ $DC = 44827.2$ m^3 of concrete with a density of 150 lb/ft^3

Scrap:

$DS = \frac{3 \cdot 2500 \cdot 1016}{1600}$ $DS = 4762.5$ m^3 of scrap with an average true density of 1.6 g/cm^3

Equipment:

$DE = \frac{3 \cdot 15000 \cdot 2200}{0.30 \cdot 6.1 \cdot 10^4}$ $DE = 5409.836$ m^3 of equipment with steel density of 0.30 lb/in^3

Other (12% of Waste Generated from 30 yrs of Operation)

$DOs = 3 \cdot 12000 \cdot 0.12$ $DOs = 4320$ m^3 of solid wastes

$DOb = 3 \cdot 22500 \cdot 0.12$ $DOb = 8100$ m^3 of bitumenized wastes

Define Capital Cost Ranges for the Options. Include Initial Equipment Capital Costs (c), Processing (p), and Storage (s) Costs: Ranges are indicated with Low (L) and High (H). Project Life is estimated at 20 years.

The combined real discount and inflation rate is assumed to be

$Ia = .05$

$n = 20$

$PA = \frac{(1 + Ia)^n - 1}{Ia \cdot (1 + Ia)^n}$ $PA = 12.462$ Uniform Series, Present Worth Factor

Option 1

This is a centralized solidification system for liquids with a compactor system to process the solids.

The estimated number of solidification system trains required to process the total Ukrainian waste stream will be used to factor up the equipment capital costs. An industry standard solidification system capacity of 3000 drums/yr or 653 m^3/yr was assumed.

$PR1 := 653$ m^3/yr

$$F1 := \frac{TEB + TLR + THR}{PR1}$$

$F1 = 8.644$

Initial Capital Costs (Low and High) in Present Dollars for a Solidification System

$C1cL := F1 \cdot 500000 \cdot (1 + Ia)^{14}$ $C1cL = 8556912.654$

$C1cH := F1 \cdot 3000000 \cdot (1 + Ia)^{14}$ $C1cH = 5.134 \cdot 10^{7}$

Annual processing costs for a solidification system given in yearly costs and converted to total present costs for n years of operation.

$$AC1p := \left[TEB \cdot Cmf \cdot 31.553 \cdot (1 + Ia)^{8}\right] + \left[TLR \cdot Cmf \cdot 31.327 \cdot (1 + Ia)^{8}\right] + \left[THR \cdot Cmf \cdot 31.327 \cdot (1 + Ia)^{8}\right]$$

$AC1p = 9286784.057$ Yearly Processing Cost

$PWC1p := PA \cdot AC1p$

$PWC1p = 1.157 \cdot 10^{8}$ Present Worth of yearly processing costs over n years

Capital cost of storage building to store the solidified waste

$$C1s := \left[Cmf \cdot 15.798 \cdot (1 + Ia)^{8}\right] \cdot n \cdot (TEB + TLR + THR)$$

$C1s = 9.304 \cdot 10^{7}$ Capital Cost of Storage Building

Initial capital costs Low and High in present dollars for a typical Compactor System (Required for all options in order to process the solid wastes and dry salts generated). The capital costs for a compactor system are increased by a factor that accounts for the total compactible material that must be processed for all of the Ukrainian NPPs and Chernobyl decommissioning. The assumed process rate is taken from a compactor designed for a single 1000 Mwe PWR which must compact approximately 400 m^3/yr. The compactible waste from Chernobyl decommissioning is assumed to occur and be processed and stored over a 20 year period. In addition the assumption is made that 47% of the solids are compactible and 53% are noncompactible.

$CmpacRate := 400$ Assumed single unit compactor process rate m^3/yr

$$FC := \frac{0.47 \cdot TSG + TTSv + \frac{0.47 \cdot DS}{20} + \frac{0.47 \cdot DOs}{20}}{CmpacRate}$$

$FC = 8.666$

Capital cost of compactor system

$CccL = FC \cdot 50000 \cdot (1 + Ia)^{8}$ $\quad CccL = 640161.853$

$CccH = FC \cdot 200000 \cdot (1 + Ia)^{8}$ $\quad CccH = 2560647.413$

Assuming the dry salts will be processed in the compactor system, and the dry powder salt density is 87 lb/ft^3 (1.4 g/cm^3) and a compacted density of 168 lb/ft^3 (2.7 g/cm^3). The volumes of dry salts to be processed are then found to be:

$$VTSd = \frac{TTS \cdot 2200 \cdot Cfm}{87}$$

$VTSd = 1137.855$ m^3/yr of dry powdered salt

$$VTSc = \frac{TTS \cdot 2200 \cdot Cfm}{168}$$

$VTSc = 589.246$ m^3/yr of dry compacted salt

For the compactors the annual processing costs are given in yearly costs and converted to total present costs for n years of operation. Assume 47% of the solids are compatible and 53% are noncompactable, and all of the dry salt is compacted. The processing costs for decommissioning of 3 RBMKs are assumed to occur over 20 yrs and are calculated separately from the processing and storage costs for the operating NPPs.

$$\begin{aligned} ACcp = {} & \left(0.47 \cdot TSG \cdot Cmf \cdot 5.555 \cdot (1 + Ia)^{8}\right) + \left(0.53 \cdot TSG \cdot Cmf \cdot 62.584 \cdot (1 + Ia)^{8}\right) \ldots \\ & + \left(VTSc \cdot Cmf \cdot 5.555 \cdot (1 + Ia)^{8}\right) \end{aligned}$$

$ACcp = 8570572.525$ Yearly Processing Costs for Operating NPPs

$$\begin{aligned} ACdecomp = {} & \left(\frac{DC}{20} \cdot Cmf \cdot 62.584 \cdot (1 + Ia)^{8}\right) + \left(\frac{0.47 \cdot DS}{20} \cdot Cmf \cdot 5.555 \cdot (1 + Ia)^{8}\right) \ldots \\ & + \frac{0.53 \cdot DS}{20} \cdot Cmf \cdot 62.584 \cdot (1 + Ia)^{8} + \frac{DF}{20} \cdot Cmf \cdot 62.584 \cdot (1 + Ia)^{8} \ldots \\ & + \left(\frac{0.47 \cdot DOs}{20} \cdot Cmf \cdot 5.555 \cdot (1 + Ia)^{8} + \frac{0.53 \cdot DOs}{20} \cdot Cmf \cdot 62.584 \cdot (1 + Ia)^{8}\right) \end{aligned}$$

$ACdecomp = 9048730.436$ Yearly Processing Costs for Decommissioning Waste from 3 RBMKs

$PWCcp = PA \cdot ACcp + PA \cdot ACdecomp$

$PWCcp = 2.196 \cdot 10^{8}$ Present Worth of Yearly Processing Costs over n Years (Compactible and Non-Compactible Waste)

The capital costs for a storage building for the compactor output are estimated using the total volumes of waste to be stored including those for operating NPPs and the decommissioning waste from 3 RBMKs.

$$\begin{aligned}Ccs := {} & \left[0.47 \cdot TSG \cdot n \cdot Cmf \cdot 2.745 \cdot (1 + Ia)^{8}\right] + \left[0.53 \cdot TSG \cdot n \cdot Cmf \cdot 25.469 \cdot (1 + Ia)^{8}\right] \ldots \\ & + \left[VTSc \cdot n \cdot Cmf \cdot 2.745 \cdot (1 + Ia)^{8}\right]\end{aligned}$$

$Ccs = 7.112 \cdot 10^{7}$ Capital Cost of Storage Building for Operating NPPs

$$\begin{aligned}Cdecoms := {} & \left[DC \cdot Cmf \cdot 25.469 \cdot (1 + Ia)^{8}\right] + \left[0.47 \cdot DS \cdot Cmf \cdot 2.745 \cdot (1 + Ia)^{8}\right] \ldots \\ & + 0.53 \cdot DS \cdot Cmf \cdot 25.469 \cdot (1 + Ia)^{8} + DE \cdot Cmf \cdot 25.469 \cdot (1 + Ia)^{8} \ldots \\ & + \left[0.47 \cdot DOs \cdot Cmf \cdot 2.745 \cdot (1 + Ia)^{8}\right] + \left[0.53 \cdot DOs \cdot Cmf \cdot 25.469 \cdot (1 + Ia)^{8}\right]\end{aligned}$$

$Cdecoms = 7.376 \cdot 10^{7}$ Capital Costs of Storage Building for Decommissioning Waste from 3 RBMKs

Option 1 total present worth (in terms of lowest and highest estimated costs) to be used for option comparison:

$PWC1L := C1cL + PWC1p + C1s + CccL + PWCcp + Ccs + Cdecoms$

$PWC1L = 5.824 \cdot 10^{8}$ Low Range of Present Worth for Option 1

$PWC1H := C1cH + PWC1p + C1s + CccH + PWCcp + Ccs + Cdecoms$

$PWC1H = 6.271 \cdot 10^{8}$ High Range of Present Worth for Option 1

Option 2:

Mobile skid mounted process/evaporator units located at each site with a smaller central solidification and compactor facility to handle the reduced volume of concentrates.

The capacity of process/evaporator units varies and will have to be sized to accept the actual feed flows, but for purposes of this analysis process rates consistent with industry experience will be assumed to be in the range of 3 to 5 m^3/hr. For this analysis it will be assumed that 20% of the unprocessed liquids are processed through the evaporators, the remaining are processed through filters, demins and monitor tanks. The number of evaporators required to handle 20% of the total unprocessed liquids from all of the Ukrainian NPPs is estimated as follows:

$EvapRate := 3 \cdot 18$ Evaporator process rate m^3/day assuming 18 hours of operation per day

$$NEvap := \frac{0.20 \cdot TUL}{EvapRate}$$

$NEvap = 8.426$ The estimated number of evaporators is between 5 (at 5 m^3/hr) and 9 (at 3 m^3/hr)

Initial capital cost (low and high) for 3 skid mounted advanced volume reduction trains located at the Ukrainian NPP sites (all sites have operational evaporators).

$C2cL := 3 \cdot 4000000 \cdot (1 + Ia)^{8}$ $C2cL = 1.773 \cdot 10^{7}$

$C2cH := 3 \cdot 9000000 \cdot (1 + Ia)^{8}$ $C2cH = 3.989 \cdot 10^{7}$

This option must also include the capital cost of a smaller centralized solidification system. The volume reduction factors for typical process/evaporation systems will be used to factor down the capital costs for a smaller centralized solidification system.

$$F2 = \frac{TEB \cdot \frac{1}{6.6} + TLR \cdot \frac{1}{2} + THR \cdot \frac{1}{2}}{PR1}$$

$F2 = 1.501$

Initial Capital Costs (Low and High) in Present Dollars for a smaller Solidification System

$C2ScL = F2 \cdot 500000 \cdot (1 + Ia)^{14}$ $\quad C2ScL = 1485796.297$

$C2ScH = F2 \cdot 3000000 \cdot (1 + Ia)^{14}$ $\quad C2ScH = 8914777.78$

Annual Processing Costs Given in Yearly Costs and Converted to Total Present Costs for n years of Operation. Consistent with Ref. [11] the processing and storage costs for this option include the costs for the solidification trains.

$$AC2p = \left[TEB \cdot Cmf \cdot 14.075 \cdot (1 + Ia)^{8}\right] + (TLR + THR) \cdot \left[Cmf \cdot 29.093 \cdot (1 + Ia)^{8}\right]$$

$AC2p = 4425203.779$ Yearly Processing Cost

$PWC2p = PA \cdot AC2p$

$PWC2p = 5.515 \cdot 10^{7}$ Present Worth of yearly processing costs over n years of operation

Capital costs for storage building space for the reduced volumes from the smaller solidification system

$$C2s = \left[TEB \cdot n \cdot Cmf \cdot 1.092 \cdot (1 + Ia)^{8}\right] + (TLR + THR) \cdot n \cdot \left[Cmf \cdot 2.857 \cdot (1 + Ia)^{8}\right]$$

$C2s = 7090777.938$ Capital Cost for Storage Building Space

Option 2 total present worth (in terms of lowest and highest estimated costs) to be used for option comparison:

$PWC2L = C2cL + C2ScL + PWC2p + C2s + CccL + PWCcp + Ccs + Cdecoms$

$PWC2L = 4.465 \cdot 10^{8}$ Low Range of Present Worth for Option 2

$PWC2H = C2cH + C2ScH + PWC2p + C2s + CccH + PWCcp + Ccs + Cdecoms$

$PWC2H = 4.781 \cdot 10^{8}$ High Range of Present Worth for Option 2

Option 3:

Incineration System

Because of the high cost of incineration systems due to the high initial capital costs and the high costs of operation, including scrubbing and filtering the exhaust gases, only the capital costs are evaluated. Incineration systems although commercially available are not routinely used at commercial nuclear reactors and their use for the Ukrainian nuclear reactors is not recommended because of the high costs involved. In addition, higher specific activity results which increases the cost of processing and storage.

The capital costs (low and high) for an incineration system are factored up to handle the total combustible waste. The factor is based on an assumed incinerator capacity of 70 kg/hr processing 1300 m^3/yr of the total solids (assuming 80% are combustible), all of the low-level resins, and the Chernobyl decommissioning combustible waste:

$\mathrm{IncinRate} := 1300$

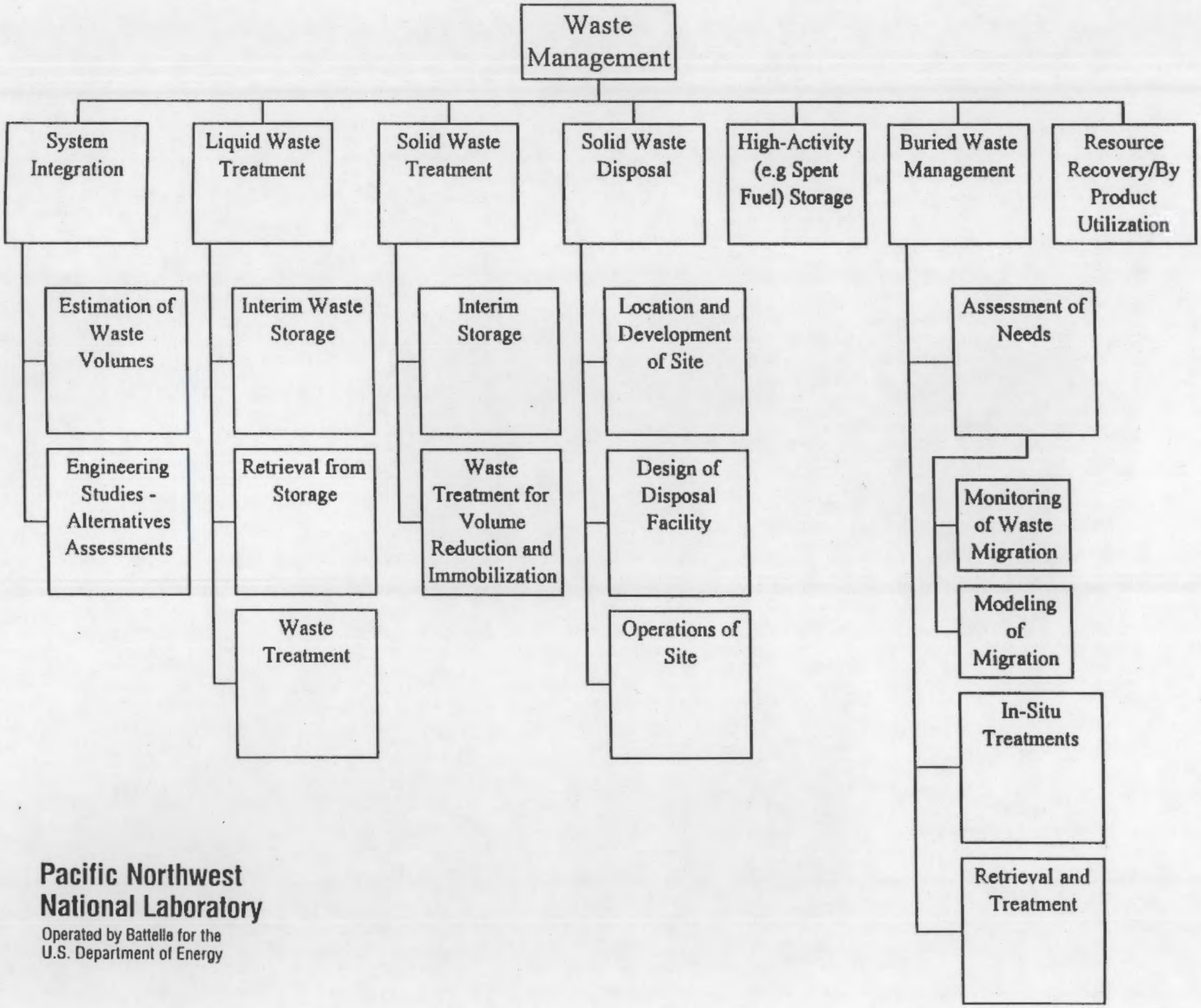
$$\mathrm{Fi} := \frac{0.80\cdot \mathrm{TSG} + \mathrm{TLR} + \dfrac{0.8\cdot \mathrm{DOs}}{20} + \dfrac{0.80\cdot \mathrm{DS}}{20}}{\mathrm{IncinRate}}$$

$\mathrm{Fi} = 3.241$

$\mathrm{C3cL} := \mathrm{Fi}\cdot 2.0\cdot 10^{6}\cdot (1 + \mathrm{Ia})^{14}$ $\quad$ $\mathrm{C3cL} = 1.283\cdot 10^{7}$

$\mathrm{C3cH} := \mathrm{Fi}\cdot 24\cdot 10^{6}\cdot (1 + \mathrm{Ia})^{8}$ $\quad$ $\mathrm{C3cH} = 1.149\cdot 10^{8}$

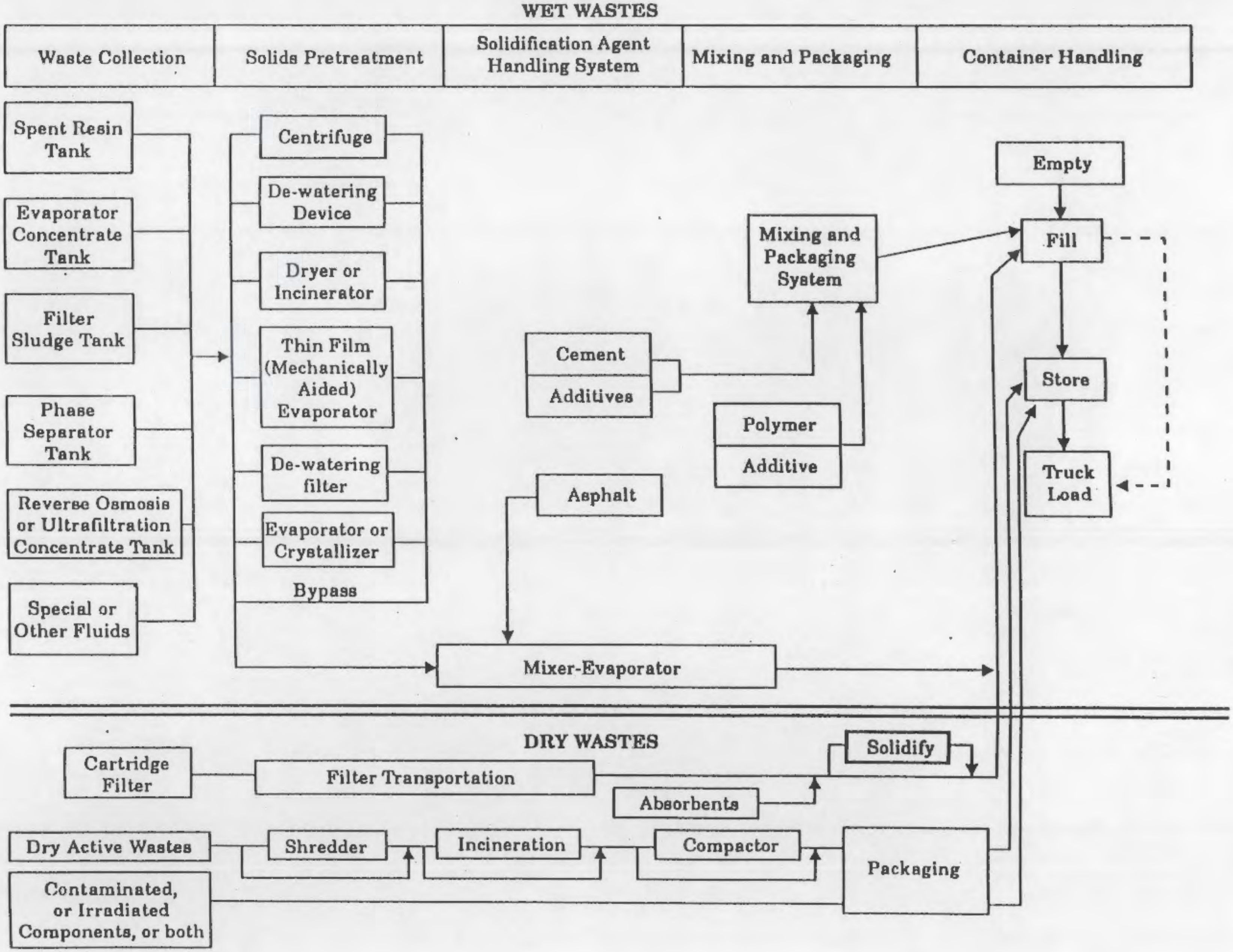
Appendix B: Figures Showing Typical Treatment Methods and Processes



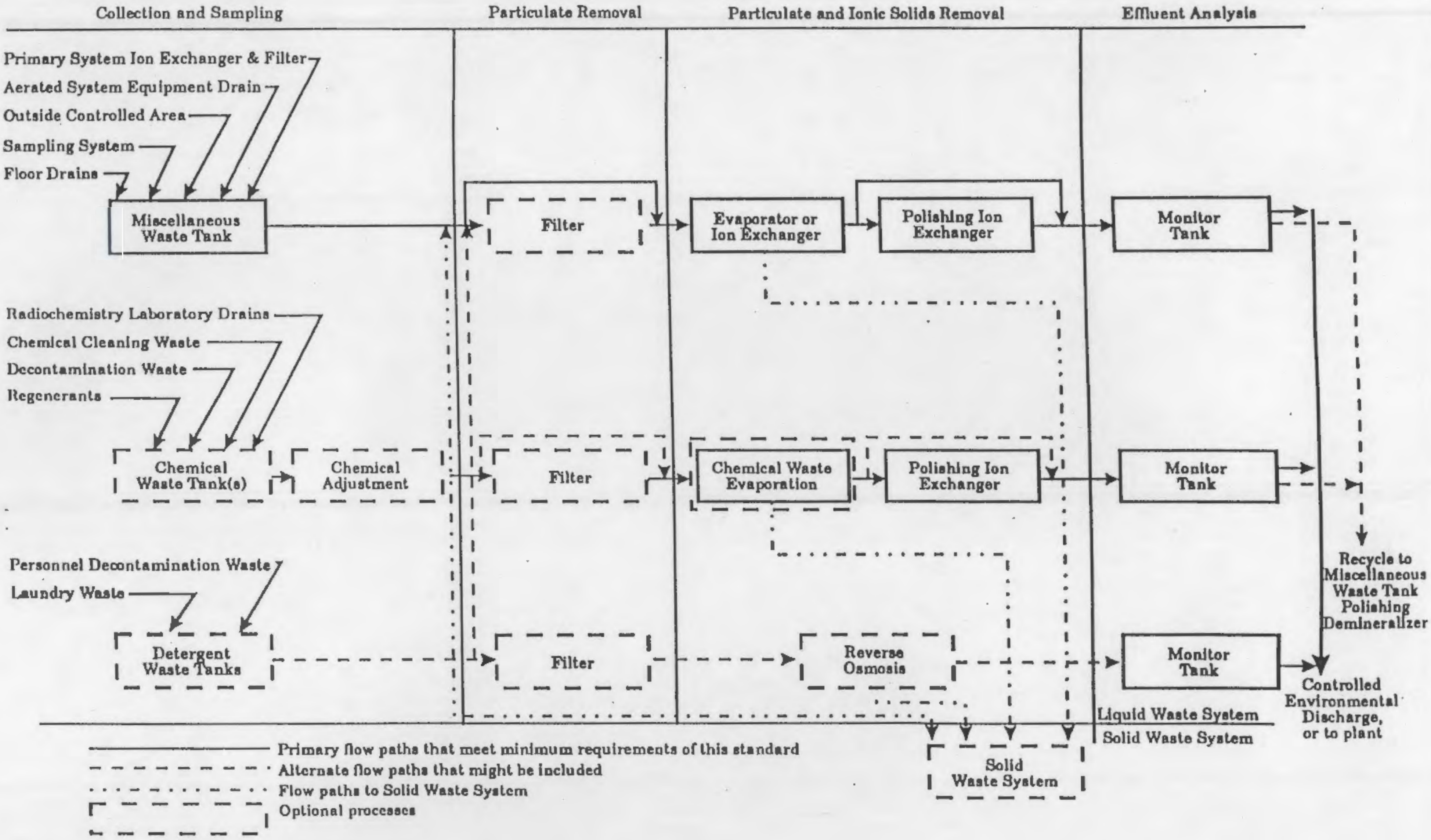
Pacific Northwest National Laboratory

Operated by Battelle for the
U.S. Department of Energy

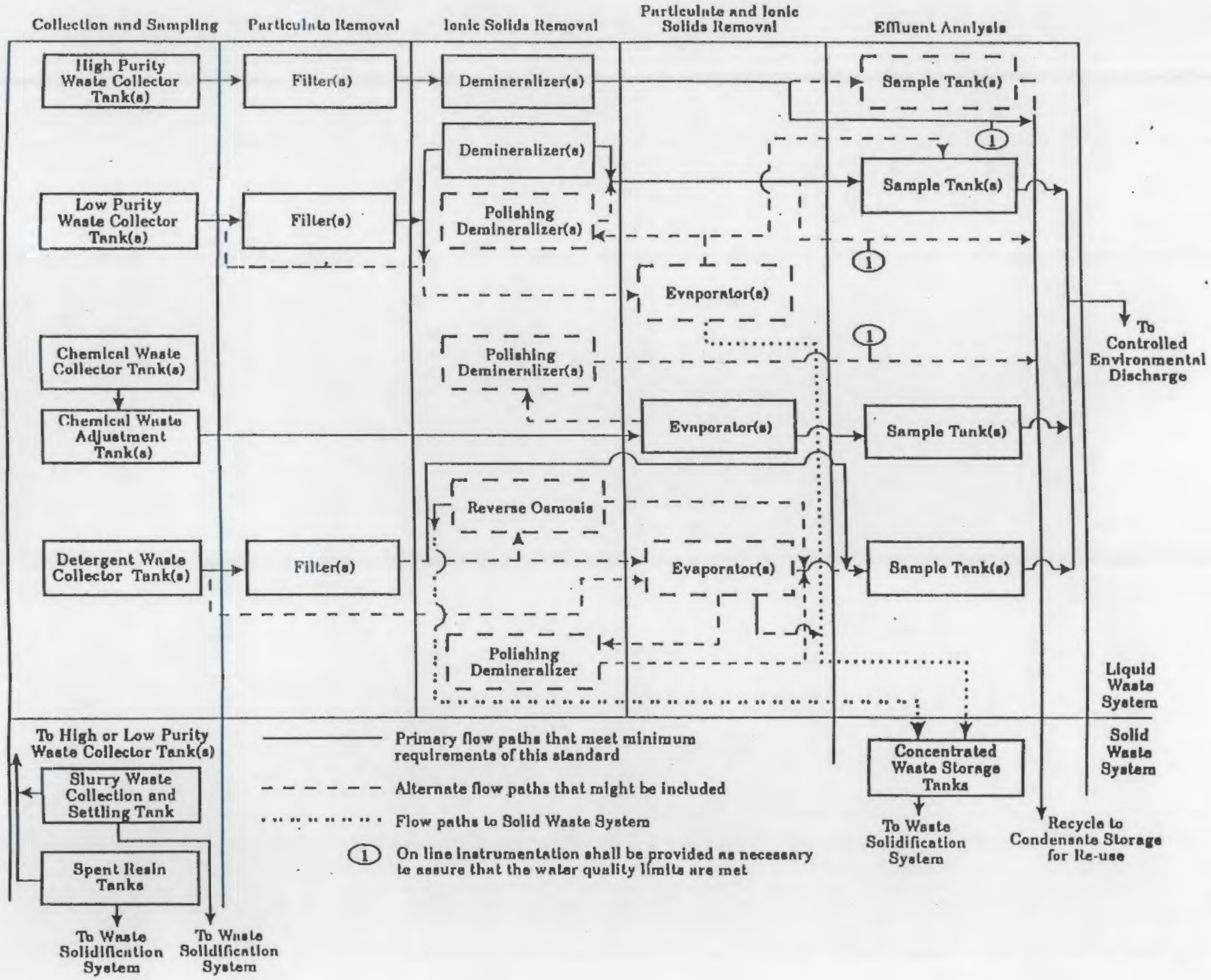
Process Flow



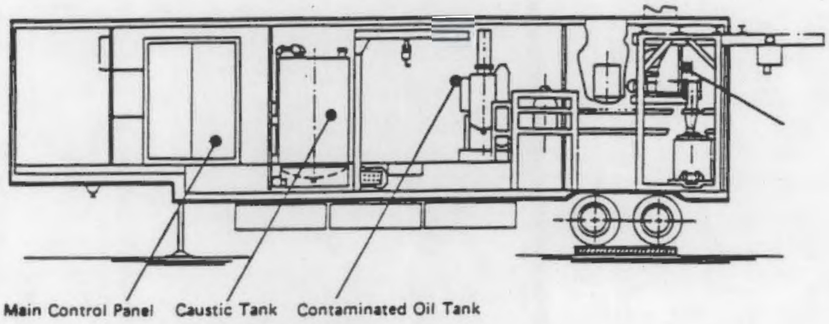
Basic PWR Liquid Radioactive Waste Processing Diagram



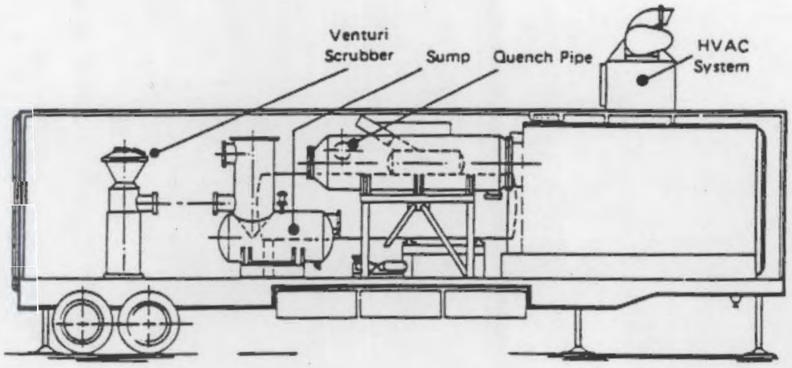
Basic BWR Liquid Radioactive Waste Processing Diagram

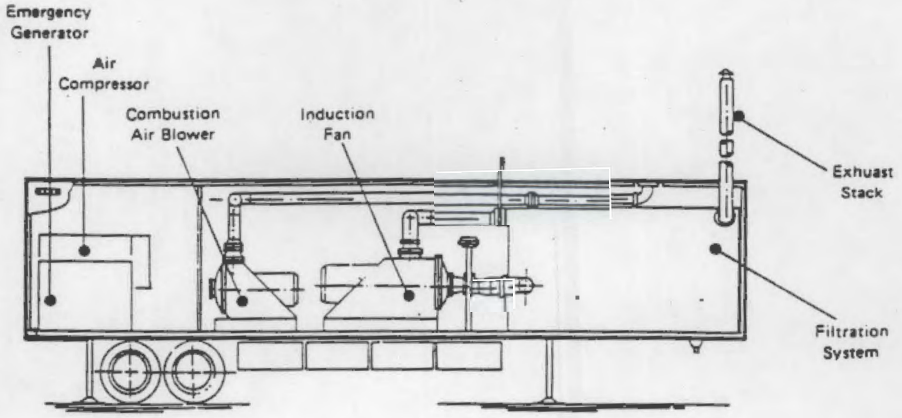


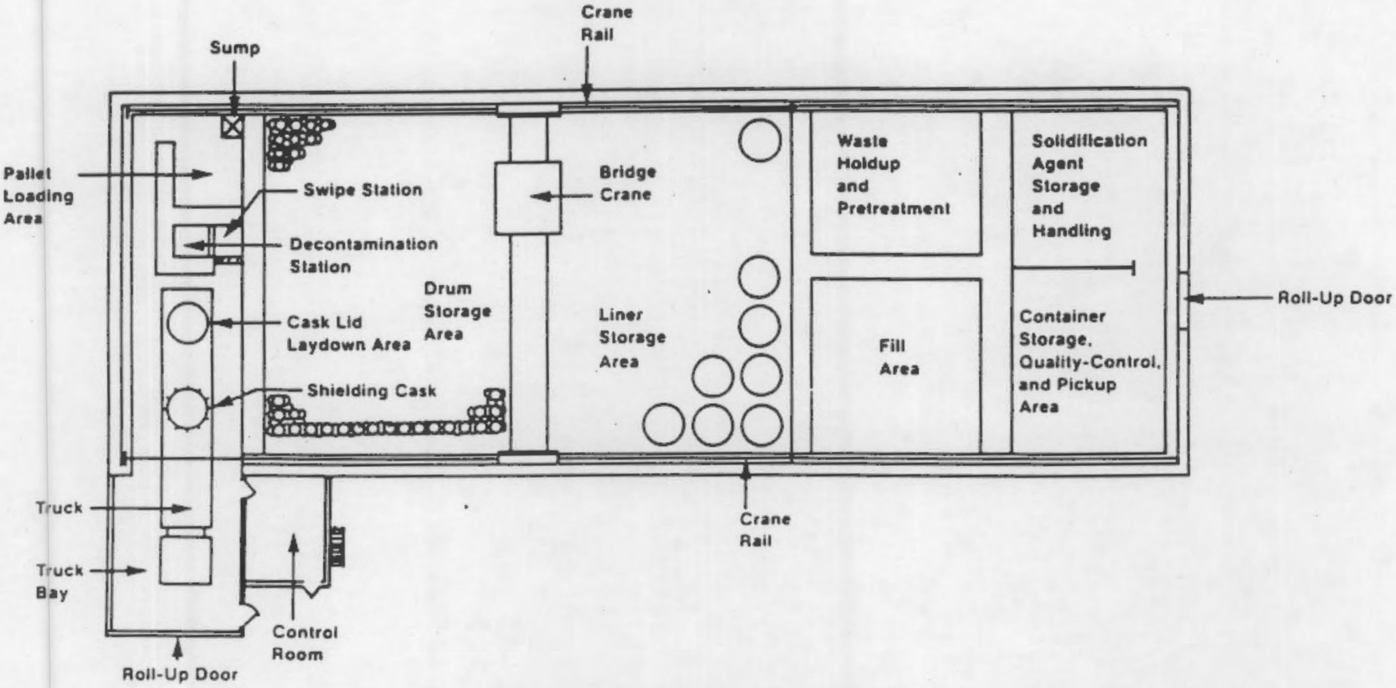
RADIOACTIVE WASTE TECHNOLOGY



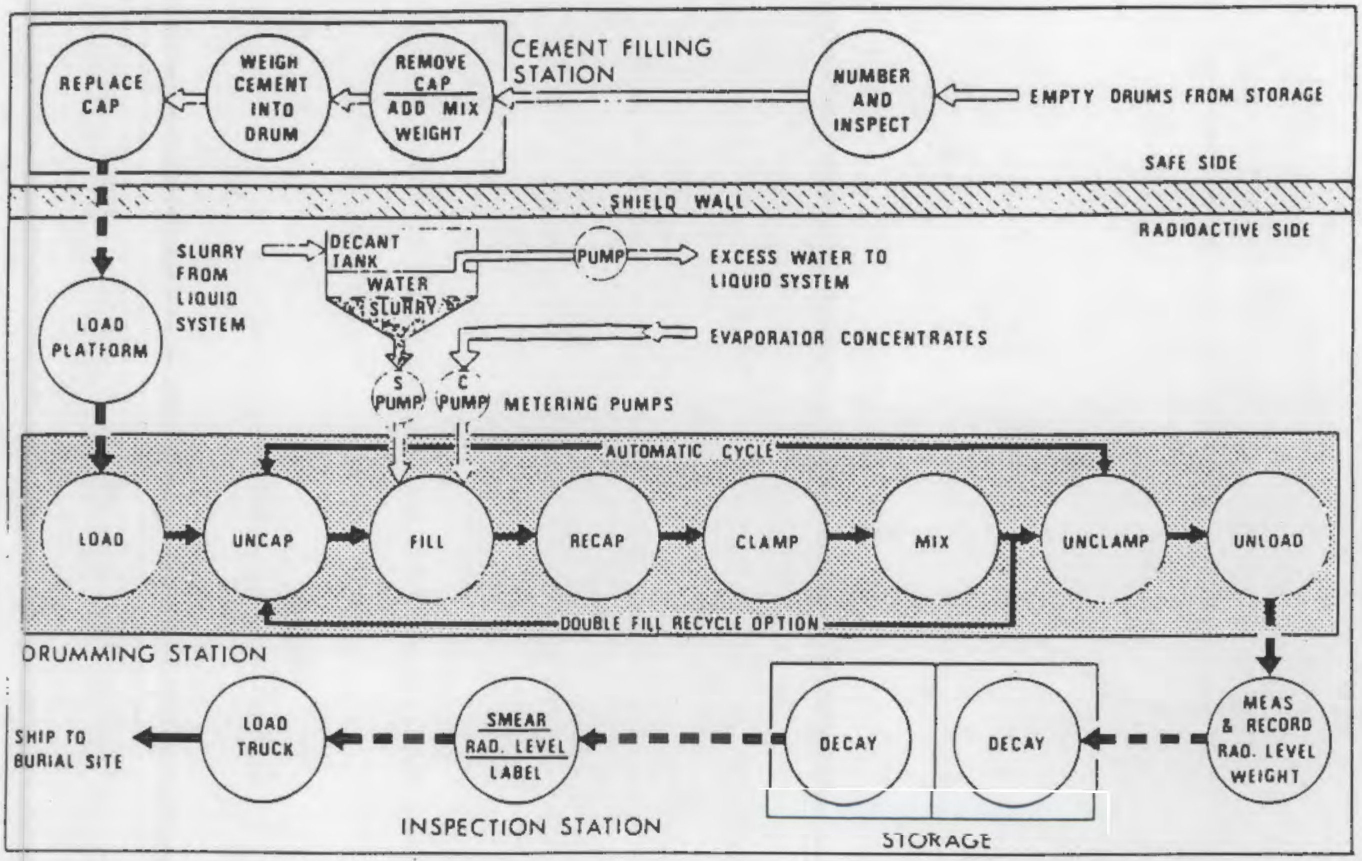
Operations Trailer



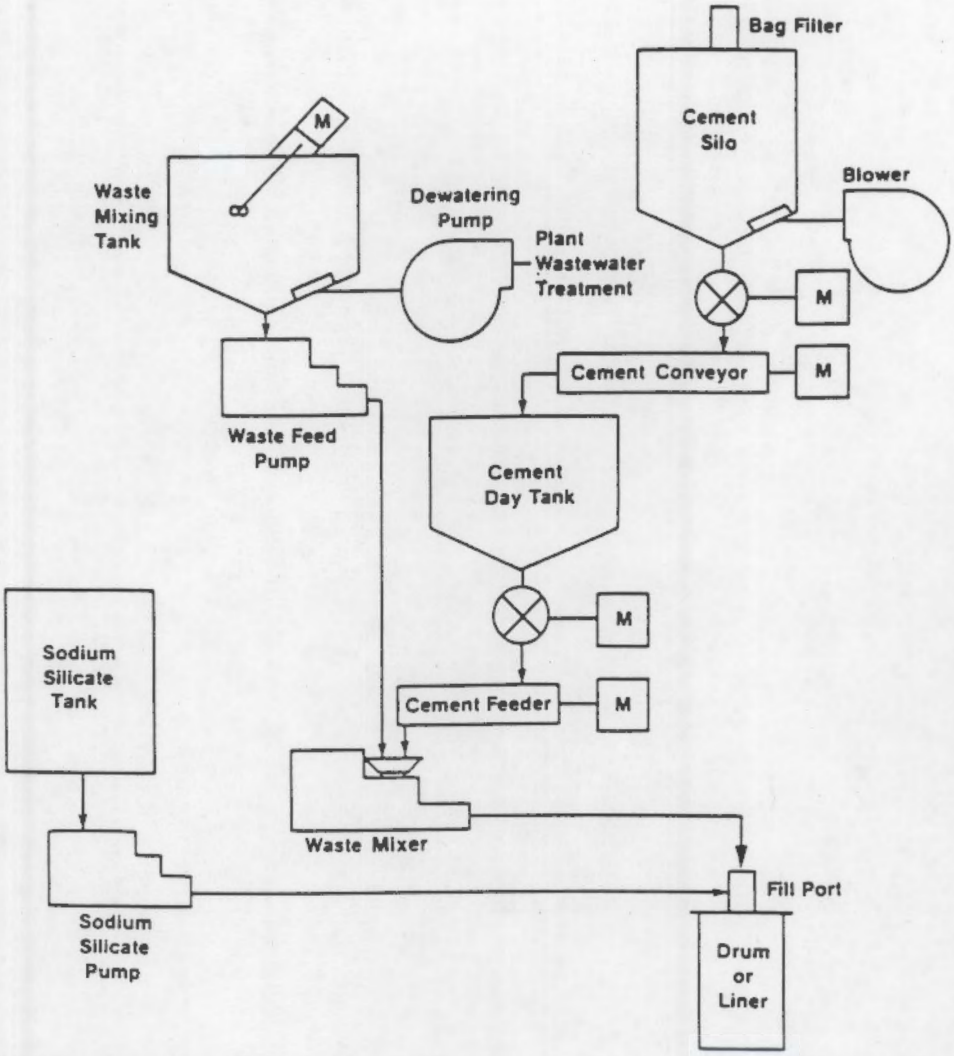




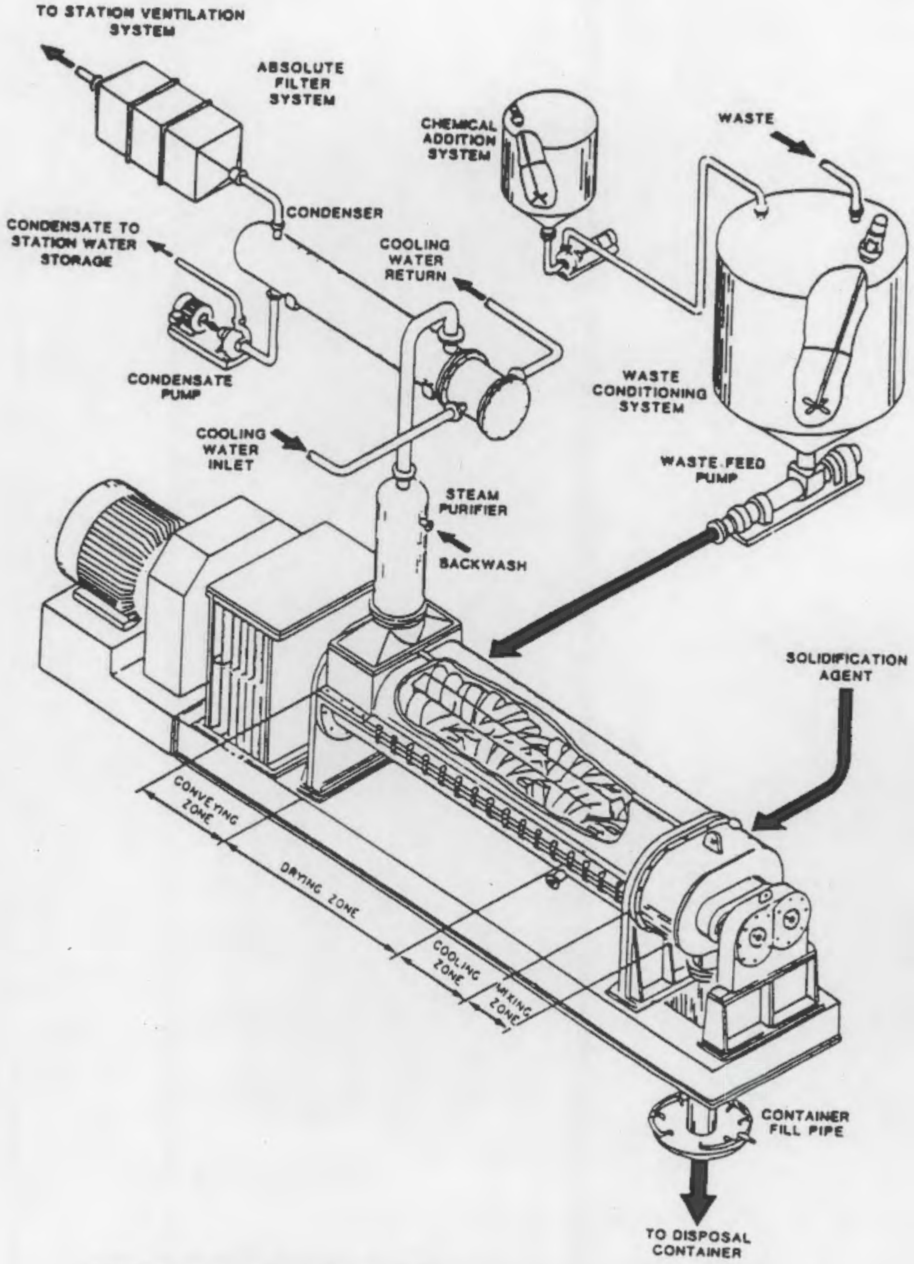
ARRANGEMENT OF A TYPICAL RADIOACTIVE WASTE
SOLIDIFICATION AND CONTAINER HANDLING AND STORAGE FACILITY
(Courtesy of Electric Power Research Institute.)



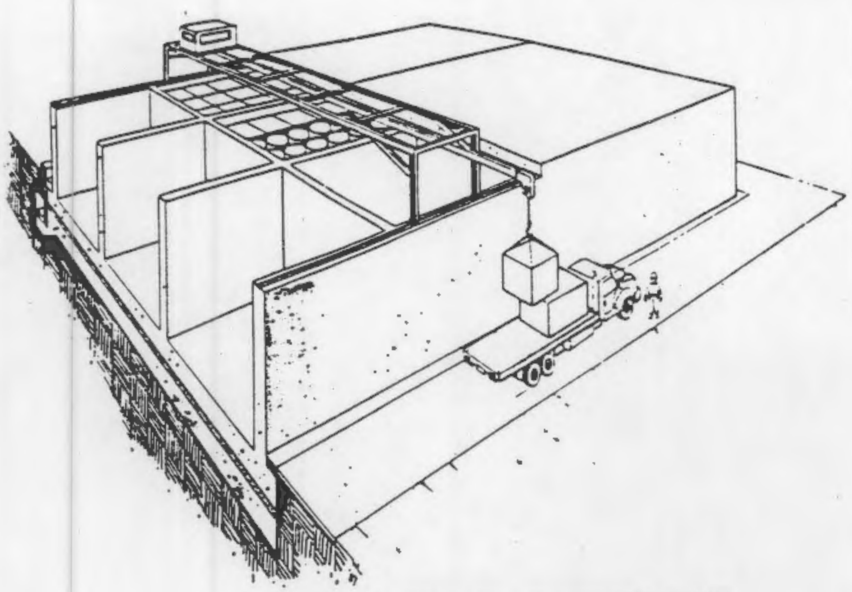
SIMPLIFIED PROCESS FLOW DIAGRAM FOR AN IN-DRUM TUMBLING CEMENT RADIOACTIVE WASTE SOLIDIFICATION SYSTEM (Adapted from Stock Equipment Co. Literature.) (Courtesy of Stock Equipment Co.)



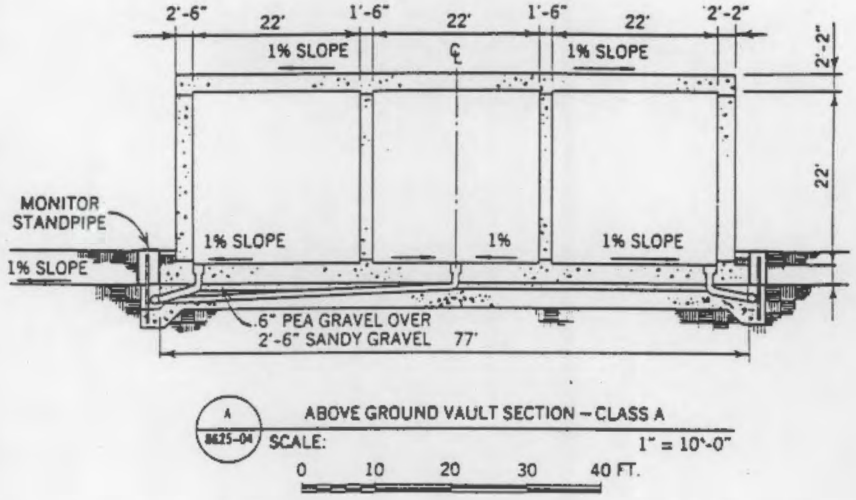
SIMPLIFIED PROCESS FLOW DIAGRAM FOR AN IN-LINE CEMENT/
SODIUM SILICATE RADIOACTIVE WASTE SOLIDIFICATION SYSTEM
(Courtesy of Electric Power Research Institute.)



MIXER / DRYER RADIOACTIVE WASTE SOLIDIFICATION SYSTEM
(Adapted from ATCOR Engineered Systems Literature.)
(Courtesy of ATCOR Engineered Systems.)

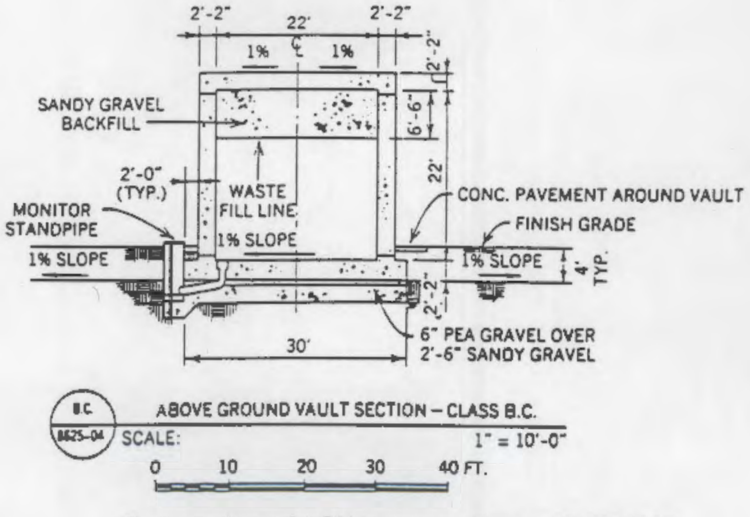


Schematic of AGV facility. Source: (DOE 1987).



ABOVE GROUND VAULT SECTION – CLASS A

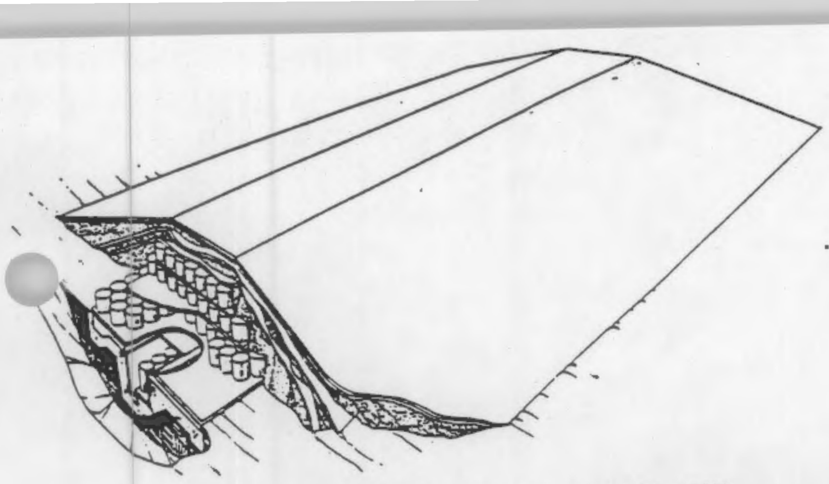
SCALE: 1" = 10'-0"



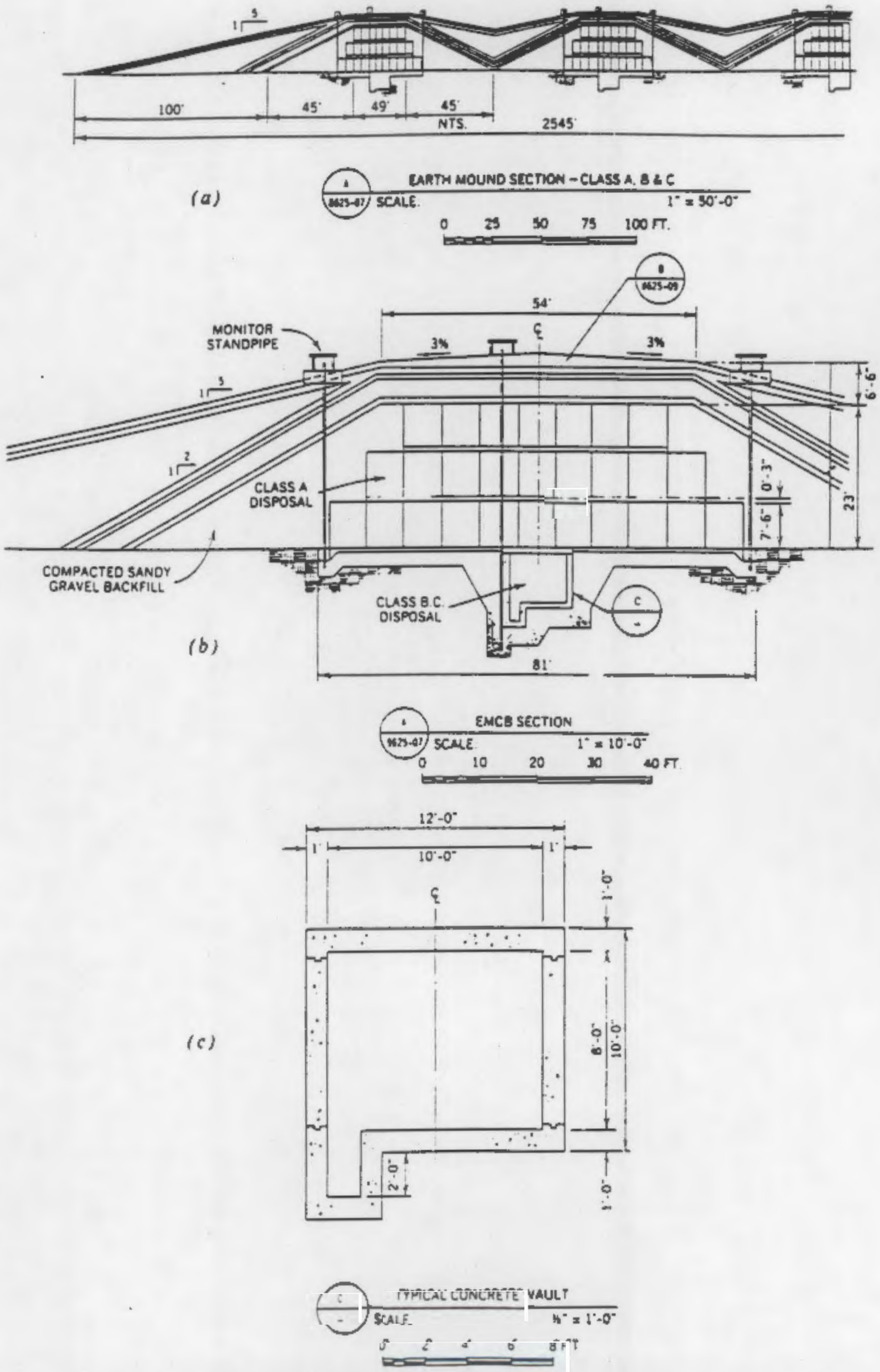
ABOVE GROUND VAULT SECTION – CLASS B.C.

SCALE: 1" = 10'-0"

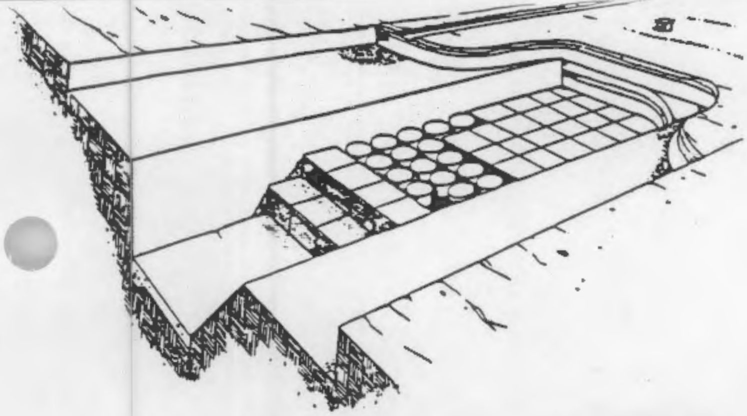
Cross sections of AGV structures. Source: (DOE 1987).



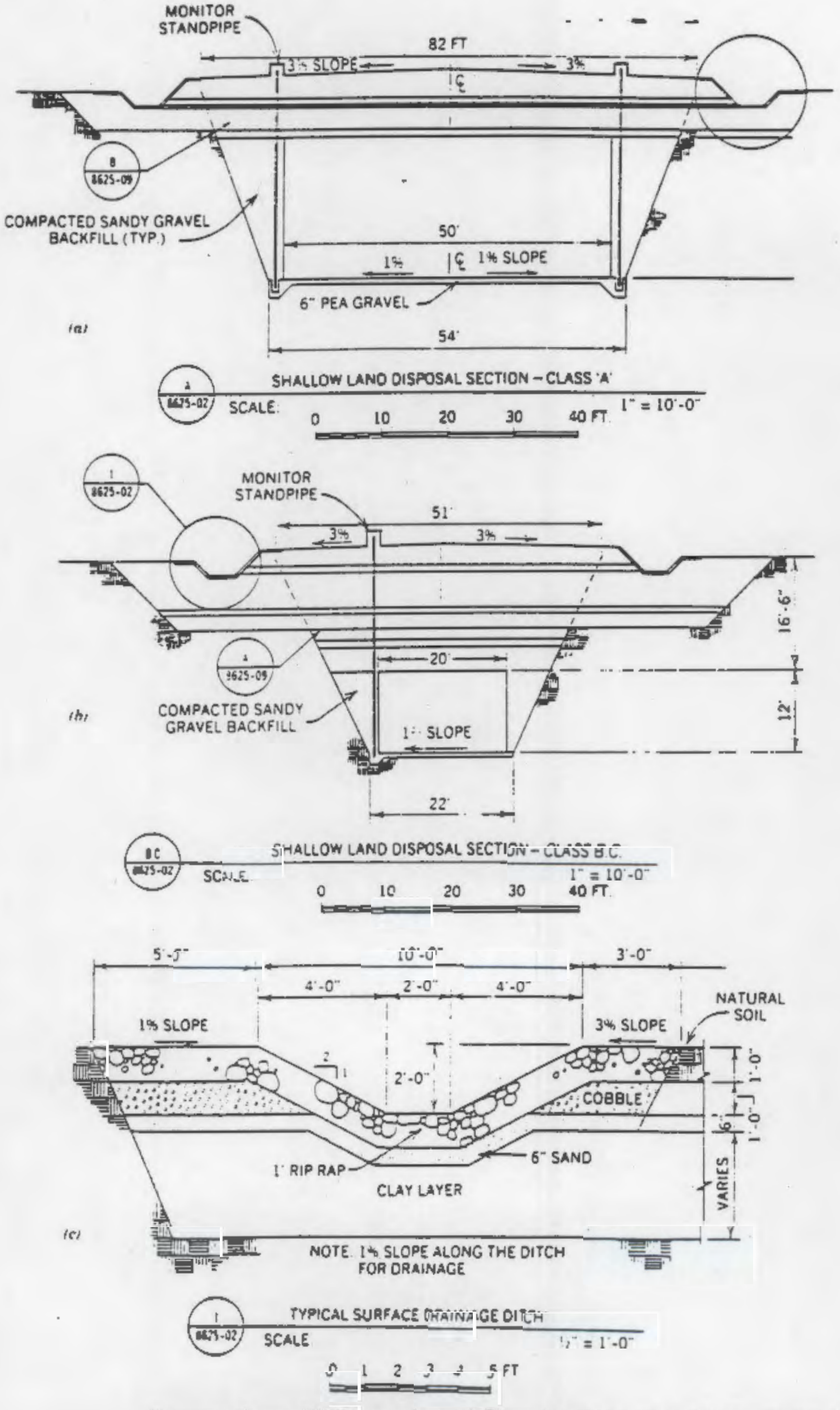
Schematic of EMCB facility. Source: (DOE 1987).



Cross section of colocated EMCB tumulus and monolith. (a) Overall layout; (b) tumulus detail; (c) concrete detail. Source: (DOE 1987).



Schematic of SLD facility. Source: (DOE 1987).



Cross sections of SLD trenches. (a) Class A waste trench; (b) segregated class B–C waste trench; (c) surface drainage ditch details. Source: (DOE 1987).

Appendix C: Classification of Radioactive Waste in the Former USSR

Categories of radioactive waste for the former USSR are as follows:

Type	Activity Level
Liquids:	
Low-Level	$< 1 \times 10^{-5}$ Ci/l
Intermediate-Level	$\geq 1 \times 10^{-5}$ Ci/l
High-Level	≥ 1 Ci/l
Solid Wastes Based on Dose Rate, 10 cm from Surface[a&d]:	
Low-Level	0.1 - 30 mr/hr
Medium-Level	30 - 300 mr/hr
Intermediate-Level	0.3 - 1 r/hr
High-Level	≥ 1 r/hr

Solid Waste Classification Based Upon Activity[b]:

	Group 1	Group 2	Group 3
Beta Activity, Ci/kg	2×10^{-6} - 1×10^{-4}	1×10^{-4} - 1×10^{-1}	$> 1 \times 10^{-1}$
Alpha Activity, Ci/kg	2×10^{-7} - 1×10^{-5}	1×10^{-5} - 1×10^{-2}	$> 1 \times 10^{-2}$

Gaseous Waste Classifications[c]:

Low-Level	$\leq 3.7 \times 10^{-3}$ Bq/l	(1×10^{-13} Ci/l)
Intermediate-Level	$> 3.7 \times 10^{-3} \leq 370$ Bq/l	($> 1 \times 10^{-13} \leq 1 \times 10^{-8}$ Ci/l)
High-Level	> 370 Bq/l	($> 1 \times 10^{-8}$ Ci/l)

(a) National Academy of Sciences (1990), Bukharin 1991.

(b) Bukharin 1991.

(c) Mosinets (1991) (based on Sanitary Rules for Radioactive Waste Management, SPORO-85).

(d) Egorov NN, et al, 1994. IAEA-CN-59/50

NOTE: Solid wastes below µr/hr are not considered radioactive and do not require any special treatment or handling. 1 Ci = 37 GBq 1 R = 258 µCi/kg

Appendix D: Questions Submitted to GOSKOMATOM Regarding the Proposed Facility

Questions on the Details of the Ukrainian Proposal to Build a Central Radwaste Processing Facility

1. What documentation has been prepared to date describing the proposed central radioactive waste processing facility?

2. What are the Ukrainian licensing requirements for such a facility?

3. Is the transport of liquid radwaste from a VVER plant to the proposed central facility required? What method is proposed for shipment of the liquid radwastes? Do the VVERs have operational evaporators and supporting filters and demineralizes?

4. For each plant type VVER-1000, VVER-440, and RBMK-1000 the following information is needed:

   a. How is the liquid radwaste categorized, e.g. high-level, low-level, clean, dirty, primary, secondary, evaporator concentrates, demineralizer resin discharges?

   b. For each category, what is the annual volume of liquid radwaste produced in gal (l)?

   c. For each category, what is the generation rate of liquid radwaste produced in gal/min (l/sec) (for demineralizer resin discharges in ft^3/yr (m^3/yr))?

   d. What are available storage tank capacities in gal (l).

   e. How many evaporators in each plant and what are their capacities in gal/min (l/sec)? Are they operational?

   f. For low-level liquid wastes processed without evaporators through filters and mixed bed demineralizes what is the capacity in gal/min (l/sec)?

   g. How is the solid radwaste categorized, e.g. high-level, low-level, filter cartridges, resins?

   h. For each category, what is the annual volume of solid radwaste produced in ft^3 (m^3)?

i. For each category, what is the generation rate of solid radwaste produced in ft^3/yr (m^3/yr)?

j. What is the available storage space for solid radwastes in yd^3 (m^3) or building size?

k. How is the solid radwaste packaged e.g. 55gal drums, shipping boxes etc? Is compaction used?

5. For the proposed central processing facility, what are the design processing capacities for both liquids and solids and the proposed storage space?

a. How many radwaste processing trains will the facility have? If more than one, what are the individual process train capacities in gal/min (l/sec) or ft^3/hr (m^3/hr)?

b. How many evaporators will be used and what are the individual capacities gal/min (l/sec)? What are the evaporator decontamination factors?

c. How many mix-bed and or cation demineralizes are proposed? What are their resin volumes ft^3 (m^3) and total volumes ft^3 (m^3)? What are the demineralizer decontamination factors?

d. How many filters are proposed and what are their capacities gal/min (l/sec) and filter sizes in microns?

e. Have charcoal absorbers been incorporated to address any organic (oil contaminates) material in the liquid waste stream?

d. For the liquid processing trains, has an off gas and cover gas system been incorporated in the design?

e. Has a solidification process been established (e.g. cement, grout etc.)? If so, what is the proposed solidification train capacity drums/hr or m^3/hr?

f. What is the proposed monitor tank (evaporator condenser distillates) storage capacity gal (l)?

g What is the proposed solid waste storage area capacity yd^3 (m^3) or building sizes?

6. What are the Ukrainian limitations for effluent releases and the isotopic inventory in terms of Ci/yr or concentration Ci/gm for the individual plants and for the proposed processing facility?

7. Has a source term evaluation been completed to identify the activity of the radwaste to be processed?

8. Have specialized material concerns been considered? This would include such items as precluding corrosive attack through the use of Inconel 625 on evaporator components in contact with the evaporator concentrates, etc.

9. What type of in-line monitoring and analysis systems are proposed for the central processing facility?

10. The GOSKOMATOM letter requesting support from DOE indicated an estimated cost of US $40 million with half of the cost being capital equipment. Please provide details on the cost assumptions that went into this estimate. For example, per unit costs in terms of dollars per m^3 of waste processed, capital equipment cost estimates, design, engineering and construction labor cost estimates, and operations and maintenance cost estimates.

11. What are the types and volumes of radwaste estimated to be generated from the decommissioning of the Chernobyl NPP that will be processed in the central facility.