

LOW-LEVEL LIQUID RADIOACTIVE WASTE TREATMENT AT MURMANSK, RUSSIA: TECHNICAL DESIGN AND REVIEW OF FACILITY UPGRADE AND EXPANSION

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes:
Printed Copy: A04; Microfiche Copy: A01

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PREFACE

This report documents the technical review and design for upgrading and expanding the existing Low-Level Liquid Radioactive Waste treatment facility (LLRW) located in Murmansk, Russia. This facility, owned by the Ministry of Transportation and operated by the Russian company RTP Atomflot, has been used by the Murmansk Shipping Company to process low-level liquid radioactive waste generated by the operation of its civilian icebreaker fleet.

The purpose of the new design is to enable Russia to permanently cease disposing of LLRW at sea in the Arctic, and to treat liquid waste and high saline solutions from both the Civil and North Navy Fleet operations and decommissioning activities.

Russia, Norway, and the United States have a mutual interest in assuring the safe treatment and storage of wastes, and in avoiding disposal at sea. This report provides the basis for the release of U.S. and Norwegian funds to be used by the Murmansk Shipping Company and RTP Atomflot to complete the construction of the expansion and upgrade. The specific findings of the project review have been, and will be, factored into the final design.

The technical review was conducted over several months by a team constituted by the U.S. Environmental Protection Agency and the Royal Norwegian Ministry of Foreign Affairs. For the United States team representatives were from the U.S. Environmental Protection Agency, Brookhaven National Laboratory, Pacific Northwest Laboratory, and Brookhaven's contractor Raytheon Engineers and Constructors, Inc. For Norway, team members represented the Royal Norwegian Ministry of Foreign Affairs, the Norwegian Radiation Protection Authority, and the Norwegian Defence Research Establishment. For Russia, extensive design information was supplied by ASPECT and others, acting as the contractors for Murmansk Shipping Co. and RTP Atomflot.

The new technical design meets the objectives by providing for an expanded waste treatment capability that will meet national and international discharge limits.

ABSTRACT

The governments of Norway and the United States have committed their mutual cooperation and support to the Murmansk Shipping Company (MSCo) to expand and upgrade the Low-Level Liquid Radioactive Waste (LLRW) treatment system located at the facilities of the Russian company RTP Atomflot, in Murmansk, Russia. RTP Atomflot provides support services to the Russian icebreaker fleet operated by the MSCo. The objective is to enable Russia to permanently cease disposing of this waste in Arctic waters. The proposed modifications will increase the facility's capacity from 1200 m³ per year to 5000 m³ per year, will permit the facility to process high-salt wastes from the Russian Navy's Northern Fleet, and will improve the stabilization and interim storage of the processed wastes.

The three countries set up a cooperative review of the evolving design information, conducted by a joint U.S. and Norwegian technical team from April through December, 1995. To ensure that U.S. and Norwegian funds produce a final facility which will meet the objectives, this report documents the design as described by Atomflot and the Russian business organization, ASPECT, both in design documents and orally. During the detailed review process, many questions were generated, and many design details developed which are outlined here.

Extensive design information and layouts were developed and supplied by ASPECT and MSCo as part of the study. Following detailed review, many technical issues were addressed in the final design phase before construction of the upgraded and expanded facility. The design is based on the adsorption of radionuclides on selected inorganic resins, and desalination and concentration using electromembranes. The U.S./Norwegian technical team reviewed the available information and recommended that the construction commence; they also recommended that a monitoring program for facility performance be instituted. A Protocol to this effect was signed and agreed between Russia, Norway and the United States covering the management, technical, and fiscal aspects for the facility construction.

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1. BACKGROUND AND PURPOSE

In accordance with agreements between the Governments of the Russian Federation, the United States, and Norway, the latter two countries will assist the Murmansk Shipping Company (MSCo) of the Russian Federation to expand and upgrade the existing Low-Level Liquid Radioactive Waste (LLRW) Facility. This facility is owned and operated by Repair Technical Plant (RTP) Atomflot (Atomflot) (for the Ministry of Transportation), and is located in Murmansk, Russia. A conceptual design for the proposed modifications to the facility was prepared for Atomflot and MSCo by the Russian company, the Association for Advanced Technologies (ASPECT).

The ASPECT organization is set up to coordinate the activities of many of the laboratories and research facilities of the Ministry of Atomic Energy of the Russian Federation in their dealings with foreign countries.

In the past, liquid waste from the nuclear icebreaker fleet operated by MSCo, the Russian Navy's Northern Fleet, and from Atomflot's shipyard operations was dumped into Arctic seas. This practice was discontinued in late 1993 (Reference 1), but since there is limited treatment capacity, much of the waste must be stored. According to Atomflot, the capacity to store additional waste has dwindled rapidly to less than 5% of its original capacity and, if the LLRW facility is not expanded and upgraded, some ocean dumping will have to be resumed. In addition, some 1000 to 1500 m³ of waste must be treated every year, and this flow should be minimally interrupted during modification of the facility.

The proposed expansion will increase the capacity of the facility for liquid wastes from 1200 m³ to 5000 m³ per year. This will allow treatment of all liquid waste generated in the foreseeable future, as well as permit some processing of stored waste. Thus, upgrades to the design will allow the facility to process high-salt wastes from the Russian Navy's Northern Fleet. Although Northern Fleet wastes of low salinity already have been processed at the LLRW facility, some of the wastes are highly saline and cannot be treated.

The proposed facility is a prototype demonstration, using technologies that were developed by the Russians, and is the only one of its kind in Russia. These technologies include adsorption of radionuclides on selected inorganic resins, and the desalination and concentration of saline wastes using electromembranes. The design for upgrading and expanding the existing facility, and the existing facility itself, were reviewed and discussed with MSCo, Atomflot, and ASPECT during the visits of a Norwegian and U.S. technical team to Atomflot's facilities in Murmansk, Russia. Participants in these meetings are identified in Appendix A; the purpose of this report is to document the results of that review.

The Joint Project consists of three Phases (1) Final Design, (2) Facility Construction and Operation, and (3) Post-Construction Technical Assessment.

2. REVIEW AND DESIGN OBJECTIVES

The Objective is to ensure that low-level liquid radioactive wastes, generated by the civilian atomic icebreaker Fleet, the Atomflot Shipyard, and the Russian Navy's Northern Fleet submarine decommissioning and operations, are treated and stored safely, and monitored to ensure that processed waste discharge and waste storage practices meet Russian Federation Standards.

Norway and the United States agreed to participate with the Russians to support this initiative because of the project's importance to the Arctic environment. The review was conducted to determine whether the design under consideration by MSCo, Atomflot, and ASPECT will meet the technical and regulatory objectives of Russia, Norway, and the United States, and thus, justify continuing the trilateral effort.

Several factors need to be taken into account in determining whether the Project will be successful.

First, the design is at the conceptual stage, and some aspects may not have been determined fully; uncertainties will remain, even during the final design work.

Second, it is intended that the design and construction is done in Russia by Russian experts. This will limit the application of non-Russian technology, except where the new technology is accepted by Russian, Norwegian, and U.S. engineers as more cost-effective. Funding was allocated to the Project on this basis.

Third, the review is essentially a prudence review to ensure that U.S. and Norwegian funds are to be applied to a design that will meet the objective. Thus, the sole responsibility for designing and operating of the LLRW facility resides with the Russian organizations.

Based on these considerations and the Project's overall objective, the following specific review objectives were established:

1. Determine whether the proposed design incorporates at least the minimum essential features required to meet the overall objective,
2. Determine whether the technology to be incorporated in the design is based on sound engineering principles, and whether that technology has been demonstrated at a scale sufficient to ensure that "scale-up" risks are acceptable,
3. Identify areas of substantial technical or financial risk which need to be addressed during final design,
4. Identify areas where U. S. technology could enhance the design,

5. Identify Russian treatment technologies that could potentially be applied in the United States.

Technical risk is some probability that the proposed system will not work as required without some redesign; financial risk is the probability that it will cost more than the funds budgeted to establish a working system. The two are interrelated since redesign could cause cost overruns. There is not sufficient information available to go beyond qualitative engineering judgements about risk, nor to differentiate between financial and technical risk. Despite that fact, the technical team considered it important to provide its judgement about the state of the design and plans for the proposed system, in terms of these risks. On this basis, a broad risk categorization (high, medium, low) of each of the units of the proposed system and the system as a whole are given in sections 4.1 and 4.2, respectively.

3. FACILITY DESIGN DESCRIPTION

Atomflot's existing Low-Level Liquid Radioactive Waste (LLRW) treatment facility (described in Appendix B) is processing two waste streams, which, for convenience, we define as follows:

Solution #1: radioactive wastewater from the Russian icebreaker fleet operated by the Murmansk Shipping Company (MSCo),

Solution #2: decontamination wastewater generated by operations in Atomflot's repair facilities, and a limited amount of radioactive wastewater from the Russian Navy's Northern Fleet.

The total volume processed is about 1200 m³ per year of low salinity wastewater (less than 6 g/l salt content). The properties of the waste streams being processed are identified in Section 3.1 below, except that wastewater in the High-salt Waters category is not being accepted by the facility presently.

The existing facility will be expanded to a capacity of 5000 m³ per year, and upgraded not only to handle more of all of these waste streams, but additionally, the high salt wastes from Navy operations discussed below. The conceptual design of the improved facility is described in Sections 3.2 and 3.3. This description is based on written material provided by the operator Atomflot, and the designer/engineer ASPECT, and oral and written information provided by these organizations.

The written information consists of the Design Reports given as Reference 2, the design specifications, and the figures in Appendix D.

3.1 Design Specification for Low-level Liquid Radioactive Waste Streams

The properties of the influent LLRW which is to be treated are given below. Some waste streams are being processed presently by Atomflot in their existing facility. The information is based on data provided, and the technical discussions held in Murmansk among Atomflot, MSCo, ASPECT, and the U.S./Norwegian Technical Team.

The liquid radioactive waste streams have been classified by ASPECT and Atomflot into several categories, which are discussed below, and data related to each waste stream is shown in Tables 3.1-1 and 3.1-2. Some of the terminology used has been changed to more common U.S. terminology for the reader's convenience.

Solution #1: "Low-salt Waters" divided into two subcategories:

- (a) Primary Coolant (called "Drainage Circuit Waters") is coolant drained from the primary loops of the icebreaker reactors during refueling.
- (b) Spent Fuel Storage is water that has been used as coolant and shielding in spent- fuel storage pools of atomic icebreakers.

Solution #2: "Salted Waters" (called "Salt-extracted Waters")

- (a) Decontamination waters are those that have been used in decontaminating equipment and tools in Atomflot's shops at the shipyard.
- (b) Laundry wastewaters are produced from operating Atomflot's facility, for cleaning and decontaminating anti-contamination clothing at the shipyard's laundry.

Solution #3 High-salt Waters

Saline waters that come from ships of the Russian Navy's Northern Fleet as the result of mixing seawater with primary coolant, some produced by diluting wastes to enable their transportation in tankers.

Tables 3.1-1 and 3.1-2 consolidate the information on waste streams obtained during the review.

Table 3.1-1
DESIGN BASIS COMPOSITION OF THE INFLUENT LIQUID:
NON-RADIOACTIVE CONSTITUENTS

Properties	Low Salt Waters		Salted Waters		Other
	Primary Coolant #1	Spent Fuel Storage #1	Decon Water #2	High Salt Waters #3	Laundry Waters #2
1. pH	7-12	6-7	6-12	6-9	
2. Total Solids (g/l)	<.1	<.1	<4 (a)	<20 (b)	
3. Suspended Solids (mg/l)	<50	<50	<150	<150	
4. Ammonia (mg/l)	<50	<10 (1)	<50	<20	
5. Iron (in solution) (mg/l)	Trace	Trace	<10	<10	
6. Chlorides (g/l)	Trace	Trace	<1	<14 (c) (2)	0.1
7. Phosphates (g/l)	Trace	Trace	<0.2	<0.1	
8. Nitrates (g/l)			<0.2	<0.1	
9. Detergents (g/l)			<0.2	<0.1	0.1
10. Oil Products (mg/l)			~3 (d)	<3	
11. Sodium (g/l)			<2	<8 (e) (3)	
12. Potassium (g/l) (f)			<0.1	<0.2	
13. Hardness (mg-eq./l)			<20 (g)	<40 (h)	
14. Oxalates (g/l)			<0.5	<0.2	
15. EDTA (g/l) (i)			<0.2	<0.1	.05
16. Sulphates (g/l)			<0.4	<0.8	
17. Carbonates (g/l)			<0.2	<0.7 (4)	0.1
18. Green Algae				TBD	

Table 3.1-1

NOTES

TECHNICAL NOTES

- (a) 2 g/l average
 - (b) 10 g/l average
 - (c) 7 g/l average
 - (d) 0.2 g/l maximum (occurs in about 10% of the total volume)
 - (e) 4 g/l average
 - (f) Presence of manganese and chromium cations is possible
 - (g) 10 mg-eq/l average
 - (h) 20 mg-eq/l average
 - (i) Trilon B is the Russian trade name for EDTA.
- TBD To be determined

Table 3.1-2

**DESIGN BASIS COMPOSITION OF INFLUENT LIQUID:
RADIOACTIVE CONSTITUENTS**

Properties (a)	Low-Salt Waters		Salted Waters		Other
	Primary Coolant	Spent Fuel Storage	Decon Water	High-Salt Waters	Laundry Waters
1. Total Spec. Activity (vol %)(1)					
1.a @ 10^{-4} Ci/l	(b)				
1.b @ 10^{-5} Ci/l	10		80	80	
1.c @ 10^{-5} - 10^{-6} Ci/l	90				
1.d @ 10^{-6} Ci/l			10	10	
1.e @ 10^{-7} Ci/l			10	10	
1.f @ 10^{-8} - 3×10^{-9} Ci/l					100
2. Cesium-137(134)(%)	5-10	5-10	< 70	< 70	< 30
3. Strontium-90 (%)	5-10	5-10 (2)	< 30	< 30	< 10
4. Cerium-144(141)(%)	< 70	< 70 (3)	1-3 (4)	1-3 (4)	< 30
5. Antimony-125(124)(%)	1-3	1-3	1-3	1-3	
6. Cobalt-60(58)(%)	1-3	1-3	1-3	1-3	
7. Ruthenium-106(103)(%) (5)	1-3	1-3	1-3	1-3	< 10
8. Europium-154(152)(%) (5)	5-10	5-10	1-3	1-3	< 30
9. Manganese-54 (%) (5)	~1	~1	< 1	< 1	
10. Zirconium-95 (%) (5)	5-10	5-10	< 1	< 1	
11. Niobium-95 (%) (5)	5-10	5-10	< 1	< 1	
12. Total LLRW Volume (m ³)	650	100	2500	1500	250

Table 3.1-2

NOTES

TECHNICAL NOTES

- (a) Radionuclide designations indicate the primary and secondary (parenthetical designation) isotopes present.
- (b) Every 2-3 years, the facility will receive about 100 m³ at this level.

3.2 Summary System Description

The LLRW Facility is essentially a concentrator for the wastes, except for tritium which remains in solution. The waste streams are filtered to remove particulates, undergo ion-exchange to remove radionuclides, to precipitate the solids for softening, and electro-separation and concentration before final fine-filtering. The reduction in activity is many orders of magnitude. Thus, the purified waters can be safely discharged, and the solids and residues from the treatment bled off for solidification with cements for storage in silos.

Because each waste stream differs (in salinity, particulates and activity) its exact treatment path is unique. Thus, the plant is designed in a modular fashion, within designated Functional Units, which allows for standardization in the layout and for replicating the manufacture of filters, pumps, and fittings, wherever possible.

The system described in Sections 3.2 and 3.3 is the system *designed* by ASPECT and Atomflot for the expanded and upgraded facility. The *existing* system is described in Appendix B. The designs of the old and new systems are considerably different; however, some equipment from the existing system is expected to be reused in constructing the expanded and upgraded facility; this consists primarily of pumps, valves, tanks, piping, and sorbent columns.

3.2.1 Facility Layout and Flowpaths

The Facility is to be erected in several buildings at the shipyard at Murmansk, using existing buildings wherever possible. The overall design of the layout and equipment are given in a series of Design Reports on a Unit-by-Unit basis (Ref. 2). Each includes a description of the Unit flow and operation, and diagrams which indicate in detail equipment interconnections and dimensions. These serve as working design P&IDs (Piping & Instrumental Diagrams) for the facility.

The overall layout is shown in Figure D-1, and the flow streams and options through the plant are described in detail in Section 3.3 on a Unit basis. The system has three trains or flowpaths for processing the three solutions.

The Flow streams for Solutions #1, 2, and, 3 are shown in Figures 3.2.1, 3.2.2, and 3.2.3, respectively. On these diagrams, ASPECT's Unit designations are shown, which will be used throughout this report.

The active Units for each waste stream for a particular Solution are shown as the darker blocks. The Figures show the significantly different flow paths through different Units, which depend on the treatment options, based on a given solution's activity and salinity. Thus, for example, Solution #1 has a relatively simple filtration path, Solution #2 has pre-treatment, whereas Solution #3 has treatment loops to allow softening.

At the inlet of each train, there is a large Accumulation Tank for initially receiving and storing the

wastes. All but the Decontamination Waters are pumped from tankers or ships at dockside to these tanks, while the Decontamination Waters come from the Atomflot repair facility on site.

Solution #1: Low-salt Waters

Low-salt Waters require only simple filtration and removal of radioactive species; Figure 3.2-1 shows the flow of these waters. Unit 9 is comprised of a backwashable micro-filter, a bank of six sorbent columns to remove radioactive species, and a final ultra-filter to remove very fine particulates.

Since these waste waters will have a high tritium concentration ($\sim 10^{-3}$ Ci/l), some of them are intended for reuse as reactor primary coolant. Also, some will be used in cementation operations. The remainder will be stored in shipboard tanks, since existing technologies cannot remove tritium, or will be diluted before discharge.

Solution #2: Decontamination and Laundry Waters

Figure 3.2-2 illustrates the flow of Decontamination Waters.

Organic chemicals are used in decontaminating tools and equipment. In processing the Decontamination Waters, these organics can interfere with the ability of absorbent to remove radioactivity from solution. Hence, the pretreatment provided by Unit 2 is intended to destroy the organic chemicals. An "Electrocatalytic Destructor" is used which is technology developed in Russia according to ASPECT, and has not been used yet outside the Former Soviet Union (FSU). The Electrocatalytic Destructor breaks down the organics into simpler compounds, such as carbon dioxide and water.

Then, the Decontamination Waters are treated using the same processes and equipment as those used for the High-salt Waters, except that Unit 5 sorbent columns take the place of the Unit 4 columns. Like the Unit 4 columns, the Unit 5 columns remove cesium and strontium selectively, but do not remove organic compounds. Processed Decontamination Waters are discharged to Kola Bay by way of the industrial-waters treatment plant.

Generally, Laundry Waters are very low in radioactivity ($\sim 10^{-10}$ Ci/l gross activity) and can be discharged to the industrial waters treatment plant without processing. However, when these wastes do not meet discharge specifications, they will be processed using Unit 7 sorbent columns alone.

Solution #3: High-salt Waters

Figure 3.2-3 shows the flow of High-salt Waters.

Unit 1 provides rough mechanical filtration and processing to reduce the hardness of the incoming water so that the sorbent columns in Unit 4 and the membranes in Unit 6 are not quickly loaded. As a side benefit, the reduction in hardness also removes some of the radioactive strontium from the

waste stream.

Unit 3 is a bank of quartz-sand filters for further mechanical filtration. Although Unit 3 is shown as processing both High-salt Waters and Decontamination Waters, the sand filters for each stream are dedicated to those streams and thus, from a functional standpoint, Unit 3 could be considered as two independent sub-units.

Unit 4 employs sorption columns to selectively remove strontium, cesium, and organics.

Unit 6 reduces the salt content further using electromembrane technology. According to ASPECT, this is also Russian-developed technology, not used outside the FSU. Furthermore, it removes additional radioactivity along with the concentrated brine.

Unit 7 takes the processed wastewater leaving Unit 6 for a final polishing in the sorption columns to remove additional radioactive species so the effluent has a gross activity of less than 10^{-10} Ci/l. Then, the wastewater is discharged to the "Biological control station".

The "Biological control station" removes bacteria, phosphates, ammonia, and nitrates from the non-radioactive wastewaters generated within the Murmansk shipyard. This treatment facility (referred to throughout this document as the "industrial waters treatment plant") was not investigated in any detail since its function, in the context of cleanup of radioactive waters, is to provide further dilution only; it is the only point available in the shipyard from which to discharge to Kola Bay.

Final Waste Form Cementation

All waste generated in each of the other process units will be piped or transported by container to the cementation facility. Initial designs by ASPECT (Reference 2) indicate that they intend to use standard cement encapsulation processes and equipment. Cementation is accepted and standard practice in Russia for waste immobilization storage.

Atomflot states that restrictions on the building space and budgets would make it difficult at this time to implement the design documented in Reference 2. Nevertheless, ASPECT stated that they intend to obtain regulator (Gosatomnadzor) approval of the Reference 2 design. Atomflot may obtain local (Oblast) approval for its partial implementation (at this time), or may buy used equipment for interim use.

3.2.2 Mass and concentration balances

The design data developed included the mass flow through the plant as a function of the yearly volumetric flow. The flow at the input, output, and important side-stream locations were calculated, and the Solution flows through the plant determined. This information is summarized in Figures 3.2-1, 3.2-2, and 3.2-3 for Solutions #1, 2, and 3, respectively, where the Figures are ordered as follows:

- (a) Concentrations of key constituents (kg/m³)
- (b) Radioactive concentrations (Ci/l)

The "Stream Numbers" correspond to sequential numbering of the intermediate locations in the Facility for each Unit flow path. The most important intermediate locations are shown for reference in Figures 3.1.1-3.

Numerous minor corrections were made to these estimates as the design evolved to achieve reasonable consistency between one Unit output and the next Unit input. These Figures may now be taken as the design basis for the plant, and demonstrate *at the Design Stage* that the discharge Objectives and Goals of the facility can be met.

Thus, the design data show the discharge activity will be reduced below 10^{-10} Ci/l, meeting the imposed Regulatory limit and showing that many isotopes have a significant potential (built-in) design margin. These estimates of discharge, activity and concentration will need confirmation during the commissioning, start-up operation, and normal functioning of the plant.

From these data, the integral DFs for particular Units for particular waste components and activity can be deduced. The data for Solution #3 are given for the adopted option of softening with NaHPO₄, rather than NaOH from electrochemical treatment. We note that the activities for Solutions #2 and 3 are nominally identical at the design stage, as the major difference in the waste streams is in their salinity and not activity.

Figure 3.2-1 Overall System Flow Block Diagram - Low-salt Waters Processing Mode Solution #1

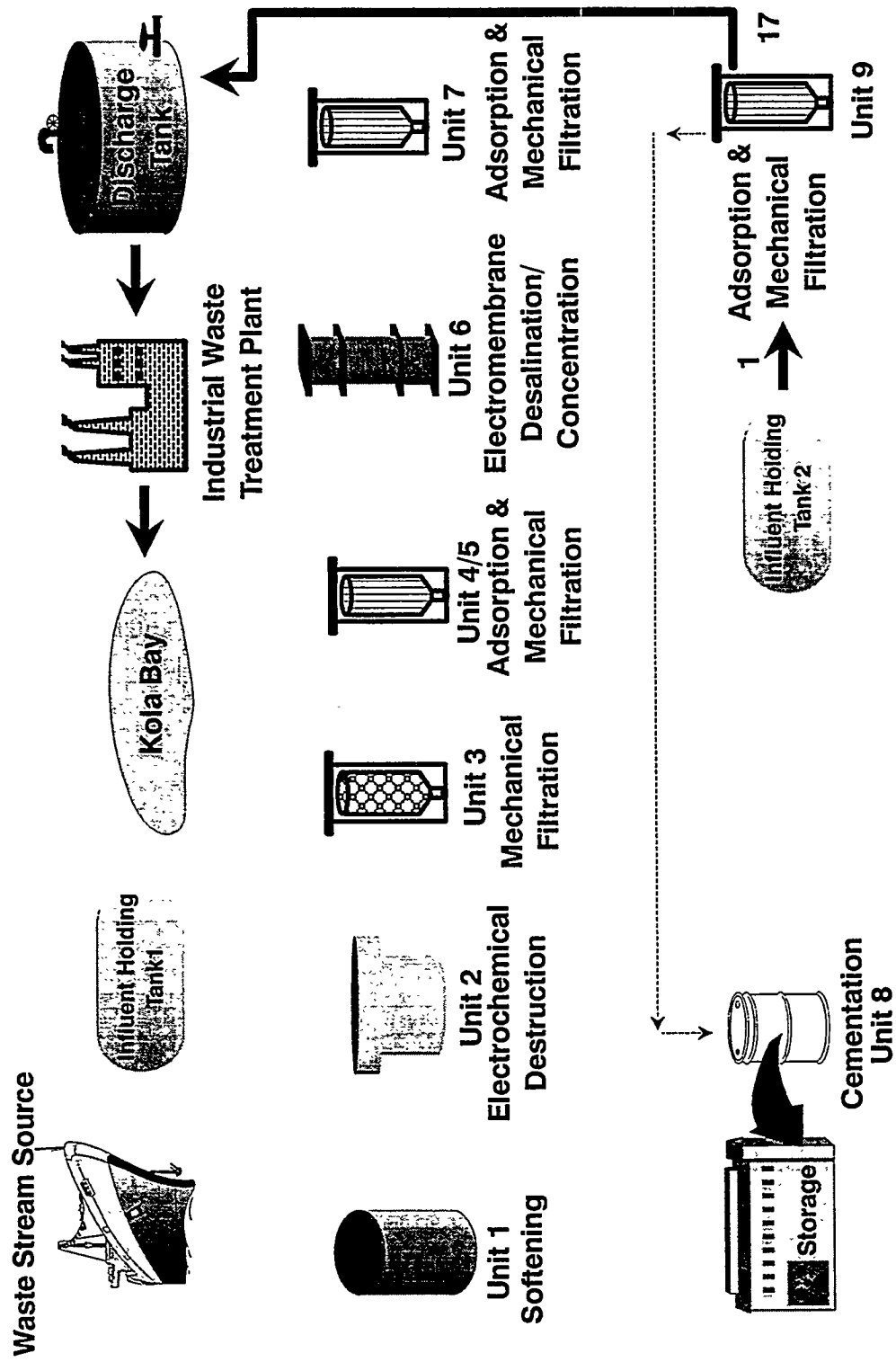


Figure 3.2-2 Overall System Flow Block Diagram - Decontamination Waters Processing Mode Solution #2

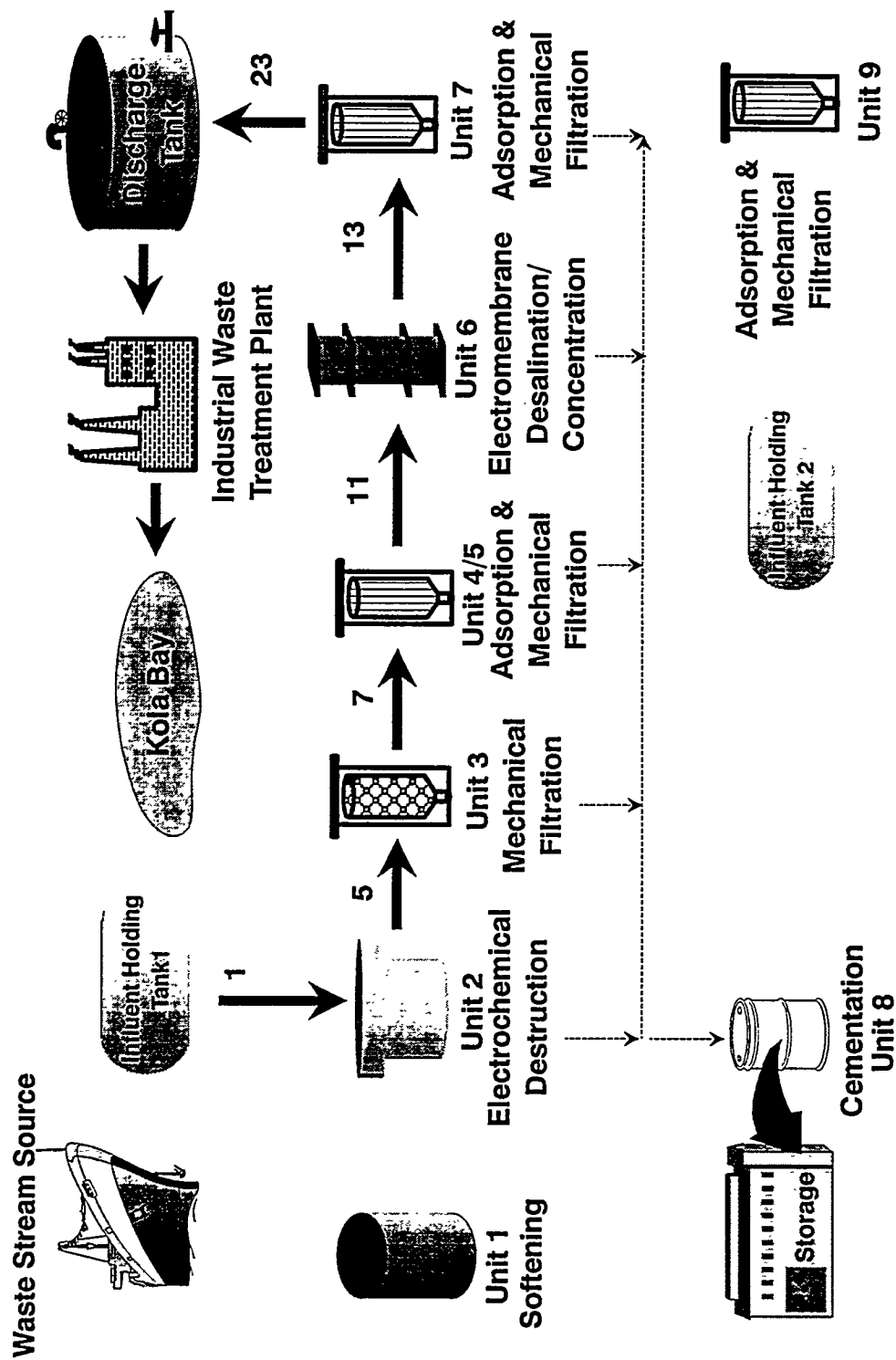


Figure 3.2-3 Overall System Flow Block Diagram - High-salt Waters Processing Mode Solution #3

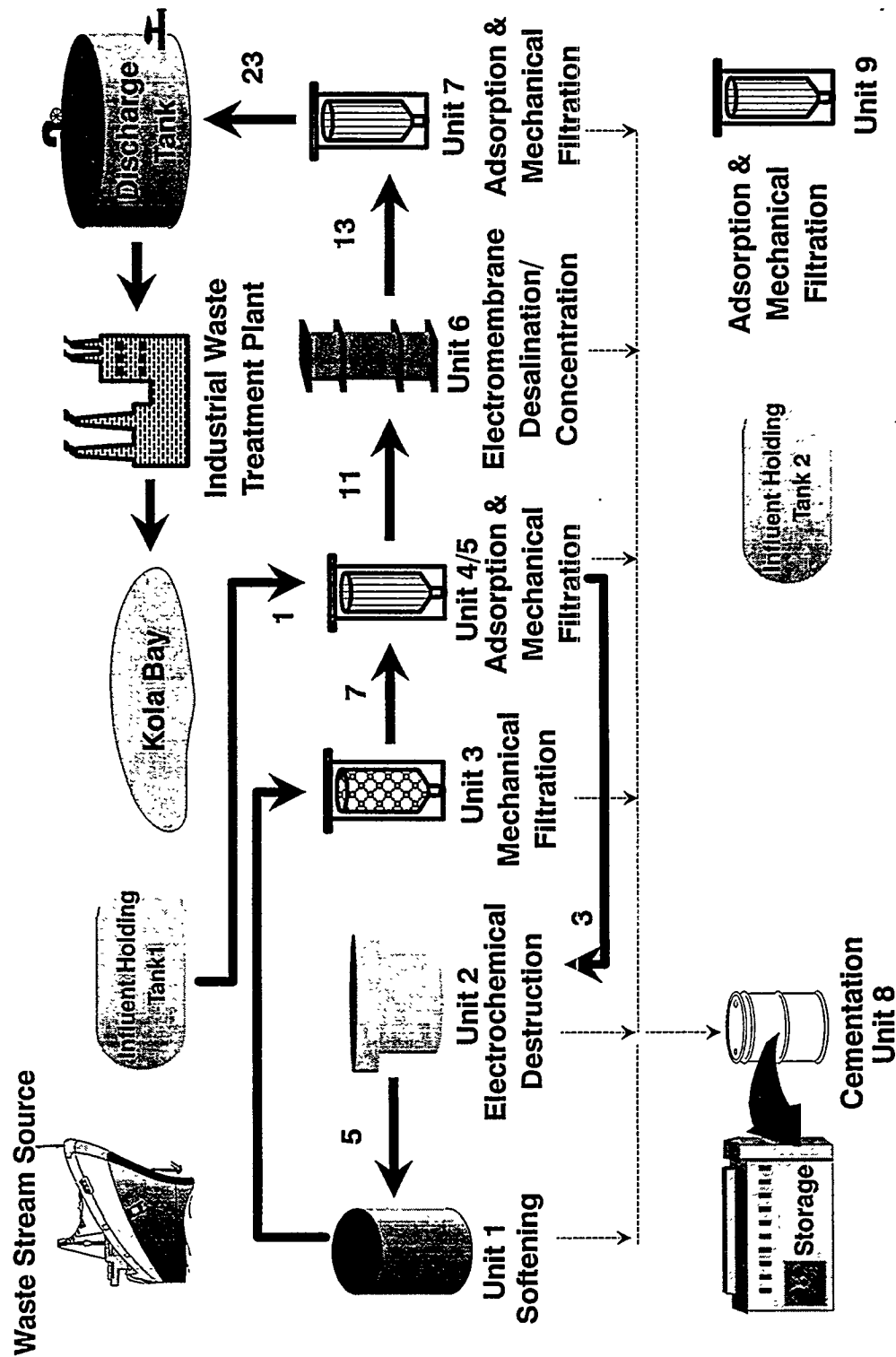


Figure 3.2-1(a) Overall Flow Concentrations - Solution #1

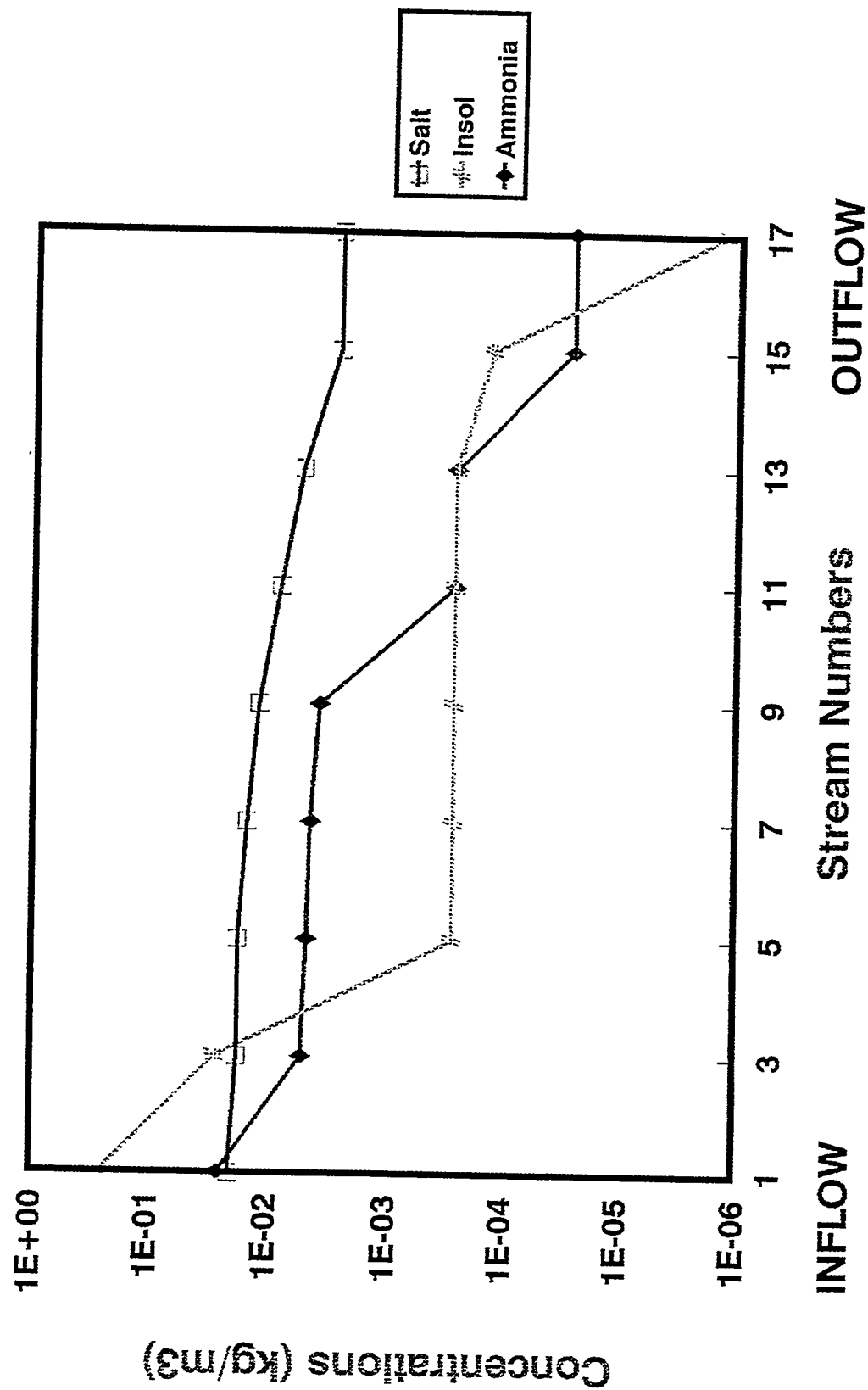


Figure 3.2-1(b) Overall Flow Activity - Solution #1

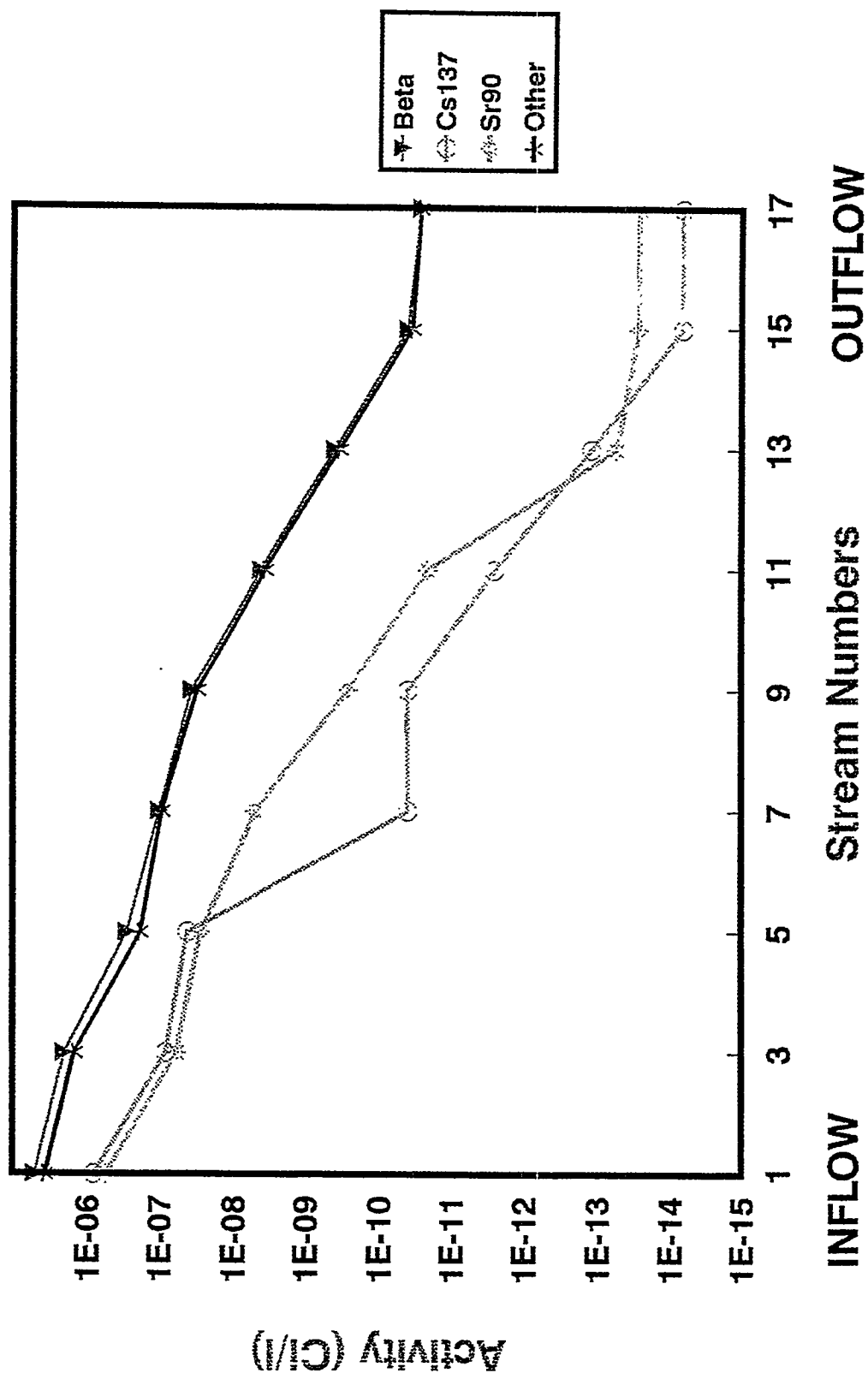


Figure 3.2-2(a) Overall Flow Concentrations - Solution #2

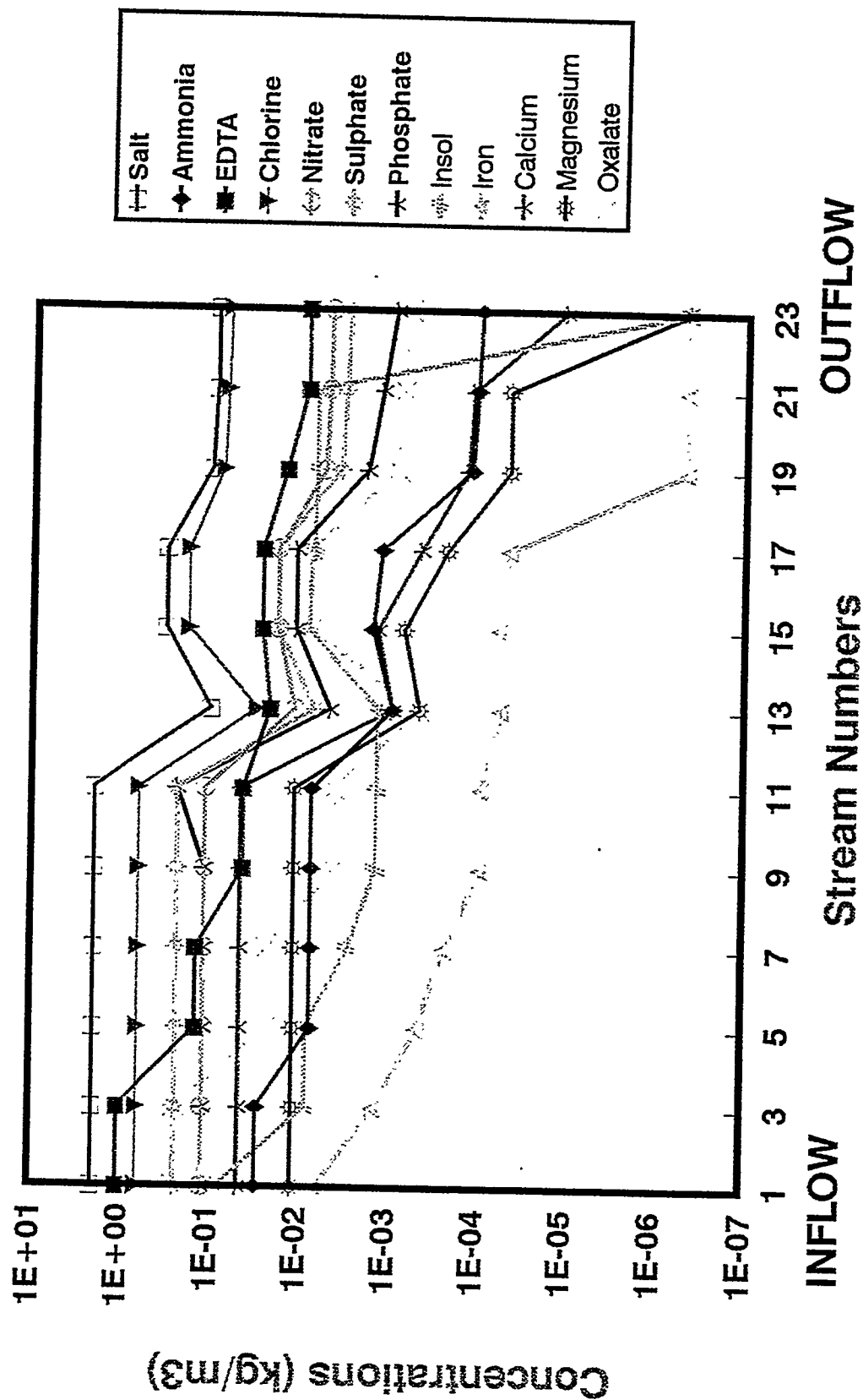


Figure 3.2-2(b) Overall Flow Activity - Solution #2

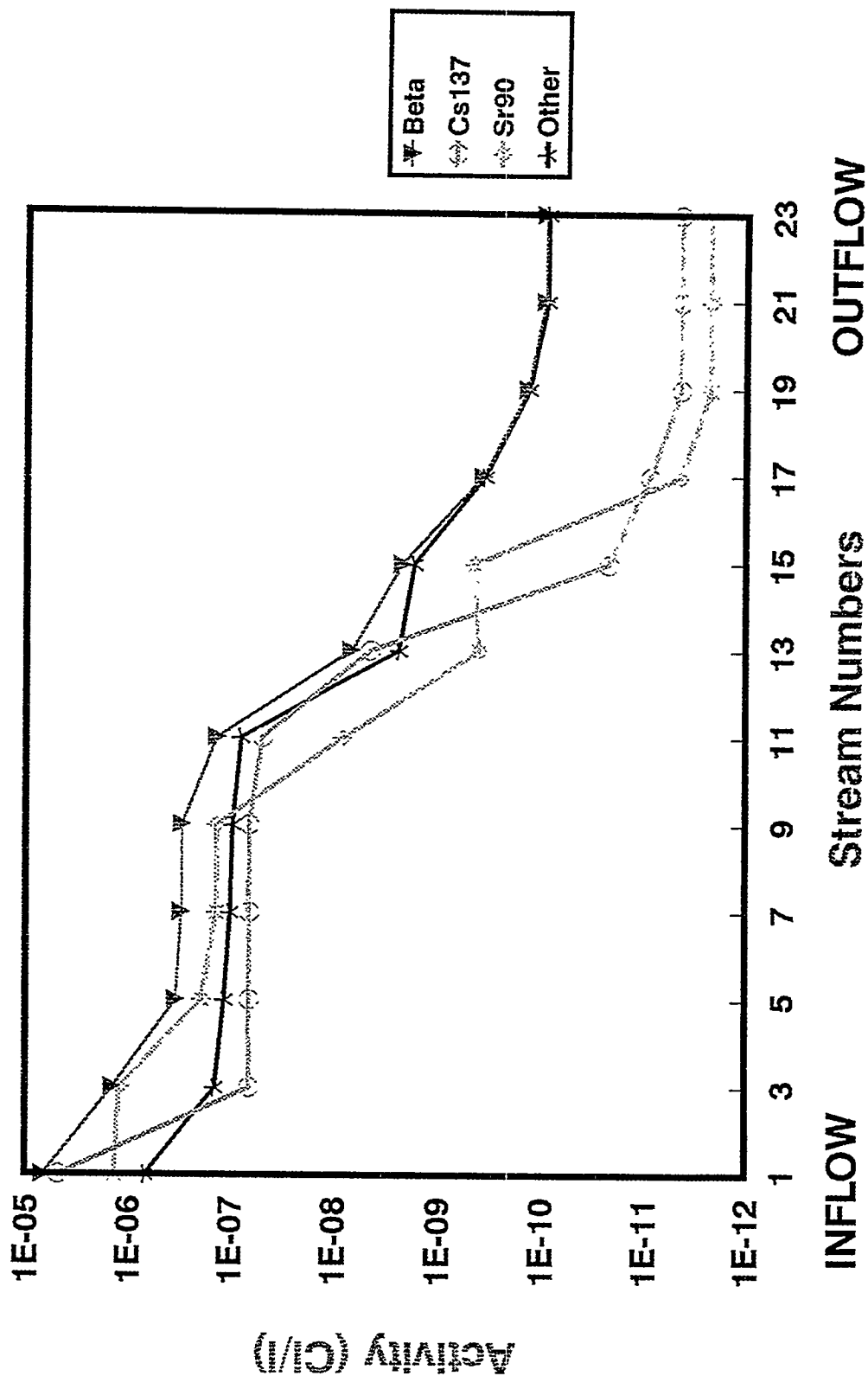


Figure 3.2-3(a) Overall Flow Concentrations - Solution #3

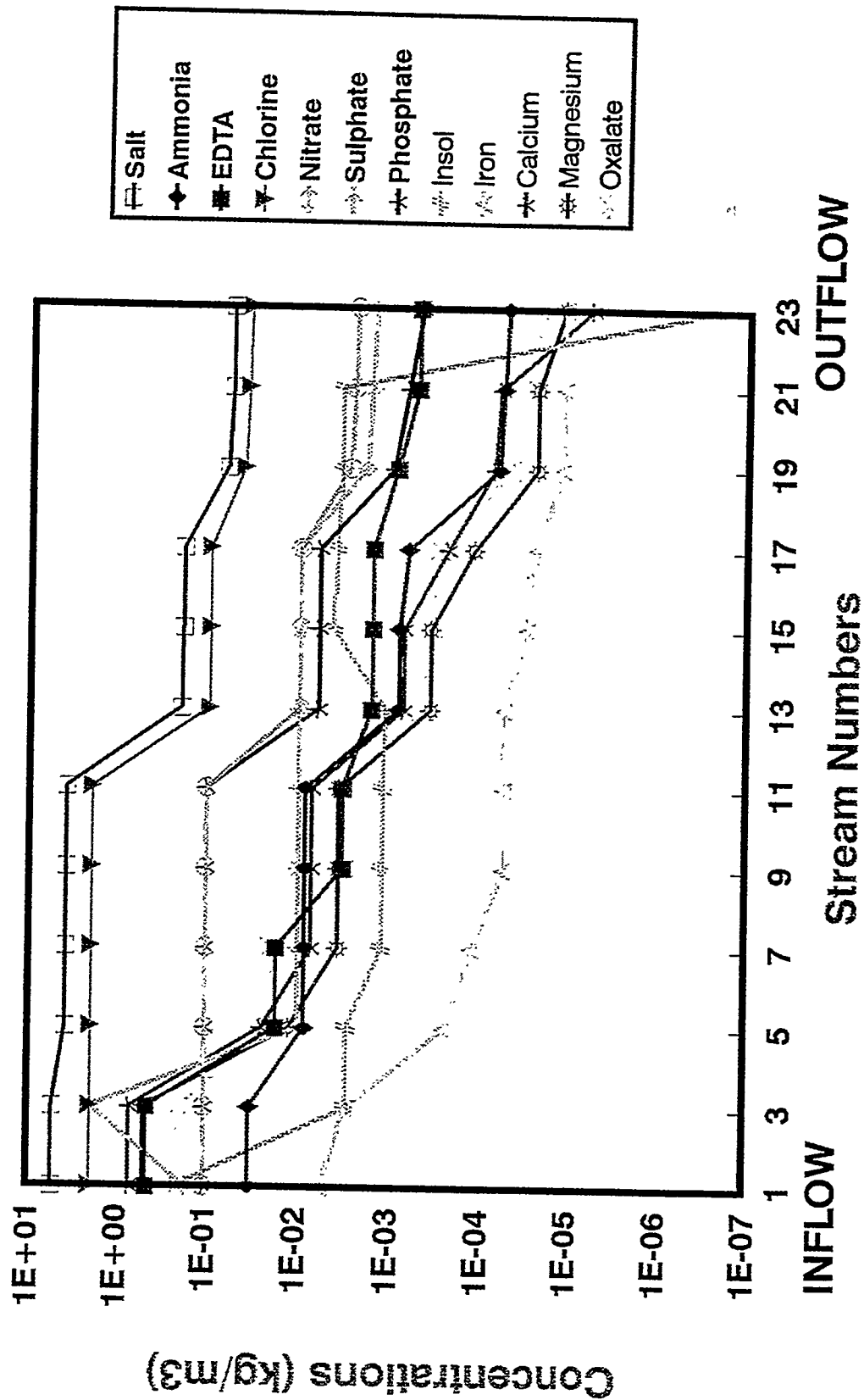
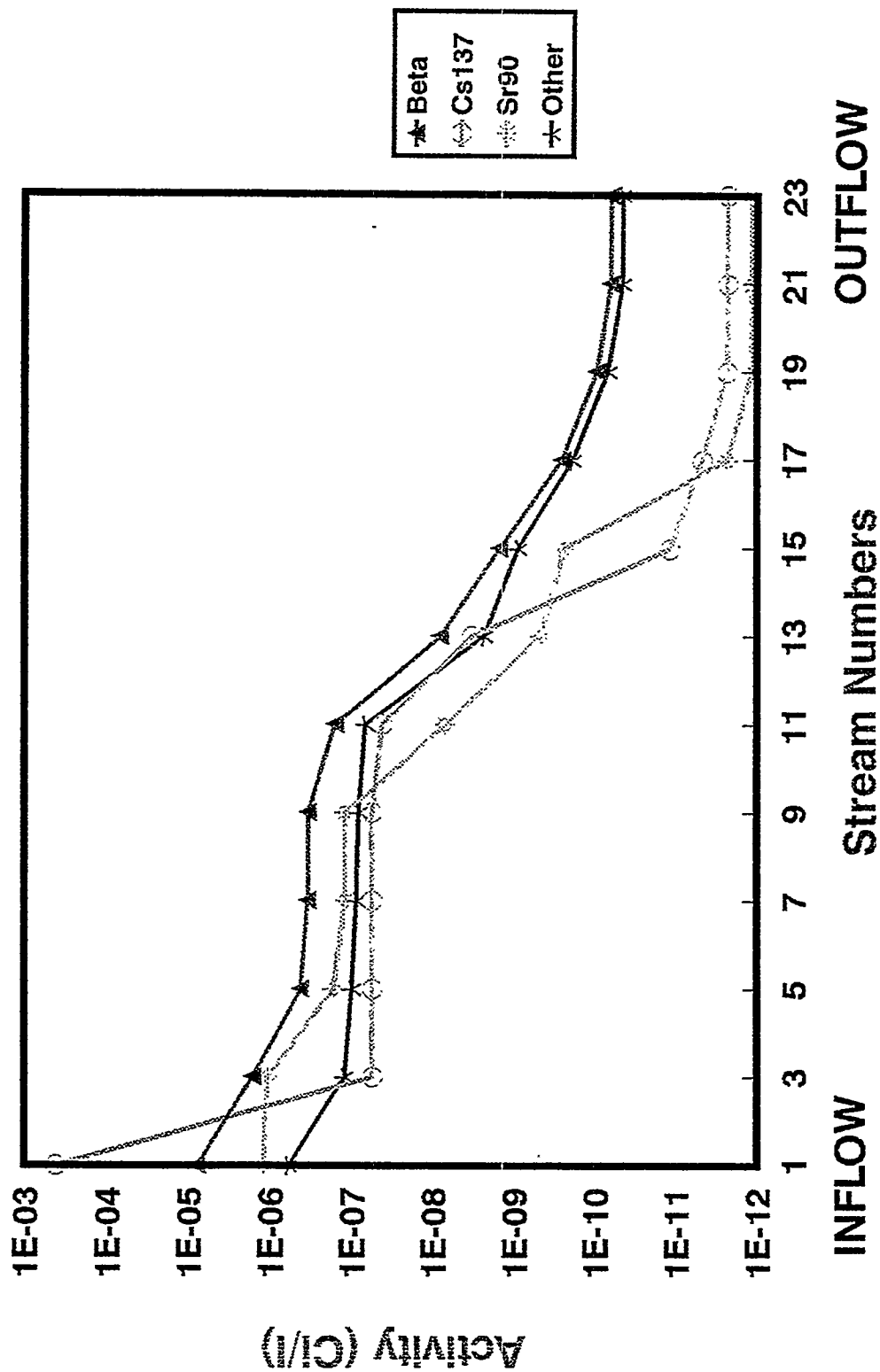


Figure 3.2-3(b) Overall Flow Activity - Solution #3



3.3 Detailed Unit Description

This Section provides a Unit-by-Unit description of the Facility to clarify the purpose, function, and design of each. There are some eight Units in the full process flow of the LLRW Facility, and each Unit has a specified and different function. The waste streams Solutions #1-3 are treated by the particular interconnections and flow through selected Units, as shown in Section 3.2.

3.3.1 Unit 1 - Preliminary Decontamination Unit for High-salt Waters

SUMMARY DESCRIPTION

The characteristics of High-salt Waters are discussed in Section 3.1, and system flow diagrams for this waste stream are illustrated in Figures 3.2-1, D-1 and D-2.

The objective of processing the High-salt Waters is to reduce the level of radioactive contamination below a self-imposed limit ($<10^{-10}$ Ci/l gross contamination other than tritium¹) and to reduce the amount of non-radioactive constituents below regulatory levels, such that most of the treated wastewaters may be discharged to the environment. Unit 1 is the first stage in this treatment and management.

The high salinity of this waste stream results from seawater. High-salt Waters accumulate from deliberately diluting wastes with seawater to reduce their activity level so they may be shipped in tankers for processing. In addition to common salt (sodium chloride), seawater contains strontium, magnesium, and calcium, and many minor constituents including oils and other organic compounds.

Hardness Reduction

Pretreatment provided in Unit 1 is intended to reduce the water hardness by removing primarily calcium (Ca), magnesium (Mg), and non-radioactive strontium (Sr). The removal of radioactive strontium is a beneficial secondary result of the process. The decontamination factor (DF) for removing of radioactive strontium is estimated by ASPECT to be about 100.

There are two primary reasons why hardness must be reduced. First, some of the sorbents in Unit 4 are intended to remove radioactive strontium selectively. However, if non-radioactive strontium was not removed first because of its relative abundance compared to the radioactive strontium, it would be trapped on the selective adsorbents too, significantly reducing their useful lifetime. Reducing the hardness of the High-salt Waters also ensures the proper operation of the electrodialysis

¹In the Murmansk discussions, the Russians stated that their regulatory discharge limits were $<10^{-10}$ Ci/l for each isotope other than tritium, and $<10^{-6}$ Ci/l tritium. Atomflot elected to be more restrictive by adopting the limit of $<10^{-10}$ Ci/l for the gross activity excluding tritium; they will comply with the stated tritium limit.

and electroosmosis components of the Electromembrane Desalinator (Unit 6) which is also used to treat this stream. If these ions were allowed to enter the desalination unit, they would quickly foul the unit's membranes, causing premature failure and increasing maintenance. ASPECT indicated that calcium oxalate fouling would also be a problem for Unit 6.

Unit 1 is designed to pretreat High-salt Waters, to precipitate several of these constituents which would interfere with processing in subsequent units.

Unit 3 is a subsequent treatment step, filtering the waste stream through a series of packed columns.

Unit 4 selectively absorbs the isotopes of cesium and strontium.

Unit 6 is the next stage of treatment in reducing the waste's volume, which is accomplished by electrodialysis and electroosmosis .

Unit 7 provides final absorption polishing of the large volume of desalinated water from the process, before its discharge to the industrial waters treatment plant.

Unit 8 receives wastes from these processes for cementation or to be packaged and stored, as appropriate.

This section describes Unit 1: the other equipment modules will be described subsequently.

DETAILED DESCRIPTION OF UNIT 1

Major Equipment

Accumulation Tank

Tank A1-1 is shown on the system flow diagram for the proposed LLRW system (Figure D-1). It is a 100 m³ tank made from a duplex material comprised of 2 to 3 mm of stainless steel (interior tank surface), bonded to 10 mm of carbon steel. The tank will be used to accumulate the High-salt Waters pumped from waste tankers which unload at dockside discharge facilities.

It is understood that this tank will be one of the Accumulation Tanks from the existing system and will have the service connections currently installed on the existing water treatment system. These service connections include influent and effluent piping, provisions to adjust the solution's pH with acid or base, air-sparging piping, and return lines from subsequent process modules, e.g., provision to return the sand-filter backflush. These connections are not shown on the system flow diagram.

Appendix B of the report notes that one of the existing 100 m³ accumulation tanks failed after seven years of service. It is being replaced with a new tank fabricated of 12 mm stainless steel.

Coarse Filter

Coarse filtration removes suspended particulates down to 50 - 100 microns in size, and will be provided by filter A1-3. Current plans are to use a wire mesh design, which will have backflush capability. The review team recommended considering an alternate design, specifically pleated membrane filters which can be backflushed using compressed air, substantially reducing the volume of secondary waste. Literature on pleated membrane filters will be reviewed by ASPECT and this alternative may be specified in the final design.

Hardness Reduction

(a) Electrochemical Unit for Producing and Adding NaOH

In the original design concept, the Electrochemical Unit is the central component of Unit 1 to reduce hardness. Detailed information on the design of the Electrochemical Unit, such as the identity of some reagents and the capacities of several components, was not given, only a general description. ASPECT holds a patent on the technology and regards some information about the component as proprietary.

The components of the Electrochemical Unit assembly are those within the rectangle labeled A1-4 (Figure D-1). In reviewing the operation of Unit 1, ASPECT provided a revised flow diagram (Figure D-2).

The electrolysis unit (EM), the device shown at the center of Figure D-2, has multiple chambers separated by "normal" anion and cation exchange membranes where, here, the term "normal" means commonly available. The electrolysis of water from a solution of reagent sodium chloride (NaCl) produces two intermediate streams: one basic (sodium hydroxide - NaOH), and the other acidic (hydrochloric acid - HCl), which are maintained separate from one another using the membranes. As described below, the sodium hydroxide is used to reduce hardness. The acid is removed from Unit 1, and does not re-enter the treatment system, but could, however, be used to adjust the pH of the wastewater at some time.

Electrically generated "fresh" NaOH was originally proposed for the process, rather than simply adding NaOH solution. ASPECT experimentally determined that, for unspecified reasons, the precipitate from the electrochemical process settles out more rapidly from solution than one formed from a simple addition of reagent NaOH. It was stated that the simple addition results in a very fine precipitate which takes days to settle.

The EM unit itself is multi-chambered, with the chambers separated by anion and cation membranes. It was described as having a central chamber in which the sodium chloride in solution is dissociated into sodium and chlorine ions. These ions pass through membranes to adjacent chambers where they are supplied with hydrogen and hydroxyl ions passed through membranes from adjacent outer chambers. The sodium and hydroxyl ions form a stream of NaOH. The chloride and hydrogen ions

form a stream of HCL. The processes that generate hydrogen and hydroxyl ions in the outer chambers depend upon the proprietary reagents identified on Figure D-2 as "analyte" and "catalyte".

During the review, it became clear this design concept for adding "fresh" NaOH was expensive, sophisticated, and required significant building space. Thus, alternate processes were also examined and a revised concept based on simple addition of phosphate was developed.

(b) Final Design Using Phosphate addition

Although not apparent in Figure D-1, the design made provisions to inject additional chemicals (a compound containing ferric ion was a possible candidate) into Unit 1, to achieve the required capability for softening. The enhanced precipitation caused by the added chemical was expected also to enhance the removal of polyvalent isotopes by coprecipitation/sorption, and provide additional flexibility to meet system goals.

In recent tests, both simulant and real waste solutions were tested for efficiency of softening and effectiveness of precipitation, including radionuclide removal using sodium carbonate, hydroxide and dihydrophosphate. The following phosphate addition was effective in precipitating Ca and Mg, and still left a solution compatible with subsequent zeolite absorption:

- a) Addition of Equimolar phosphate per mole of calcium and magnesium in solution
- b) pH 10 conditions by adding two moles of sodium hydroxide per mole of alkaline earth metals (e.g., Ca, Mg)
- c) Radionuclide strontium DF of 10 to 25 down to an activity of 5.10^{-2} Ci/l by reducing hardness to 1-2 mg-eq/l from 30 mg-eq/l
- d) Residual phosphate concentration of the order of 70-100 mg/l

The results clearly show that settling occurs after 24 hours, and that the reduction in radioactivity scales exactly with the reduction in hardness as the strontium precipitates. The concentrated precipitate is removed from the settlers, described below.

Settlers

The settling tanks and the intermediate tank shown in A1-4 are traditional, straight-forward technology, so design information on them was not pursued actively nor obtained.

Initially, precipitation and settling after adding NaOH is a two-stage process involving both settlers. Settler 1 provides the initial stage, in which the incoming (raw) LLRW stream is first mixed with a basic solution and some precipitation and settlement occurs; however, not all of the hardness constituents are removed. The basic solution entering Settler 1 comes from the "bottoms" of Settler

2 and contains both precipitates and some NaOH which did not react in Settler 2. Mixing the "bottoms" of Settler 2 with the incoming LLRW in Settler 1 is expected to neutralize the precipitate slurry which passes from the bottom of Settler 1 to the cementation unit. The sludge formed at the bottom of Settler 1 is primarily carbonates of calcium, magnesium, and strontium.

The "clarified" LLRW stream leaving Settler 1 is partially softened wastewater as feed for Settler 2, where it mixes with the alkaline solution (NaOH) produced in the EM unit. This highly alkaline solution precipitates calcium, magnesium, and strontium. Settler 2 is deliberately fed with an excess of NaOH from the EM unit to maximize precipitation of the hardness constituents remaining in the Settler 1 "clarified" effluent. The clarified solution leaving Settler 2 is the soft LLRW which is passed to Unit 3 for further processing.

In the final design using the addition of phosphate, a 10-cubic-meter mixing tank followed by a separator is considered the alternate configuration to the two Settler layout. The sludge or precipitate would pass to the cementation Unit, with the softened wastewater passing on to Unit 3.

Final Collection Tank

A small Final Collection Tank (A1-5) 4 m³ in volume, is sited after the Electrochemical Destructor A1-4 to serve as a surge tank to balance input and output flows.

Process Flow

High-salt Water will arrive at the treatment facility by ship. Presently, there are two dockside pumping sites. Wastes will be pumped from the transporting vessel to the Accumulation Tank A1-1.

Pump A1-2 draws on the Accumulation Tank to pump the untreated wastewater through the Coarse Filter (A1-3) and then to the settling tank. The clarified flow from the Settler passes into Final Collection Tank (A1-5) before being pumped by pump A1-6 to the sand filters (Unit 3). Processed liquid leaving Unit 1 is referred to as "soft LLRW" in Figure D-2.

The sludge that collects at the bottom of Settler 1 will be sent to the cementation module (Unit 8). In the near term, any secondary waste generated in Unit 1 (such as failed filters or failed membranes from Unit 4) will be packaged and placed in temporary radioactive-waste storage. The management of wastes from this unit and other units of the treatment system is discussed in sections 3.3.8, 4.1 and 4.2.

3.3.2 Unit 2 - Preliminary Decontamination Unit for Decontamination Waters

SUMMARY DESCRIPTION

Decontamination Waters are generated from decontaminating tools and equipment at the Atomflot site. Organic chemicals are employed often in the decontamination processes to aid in removing

radionuclides. In waste processing, these same chemicals can interfere with the ability of absorbents to remove radioactivity from solution. One of these chemicals, oxalate, can deposit out in the Electromembrane Desalination unit also. Hence, the pretreatment in Unit 2 is intended to destroy organic chemicals that would reduce the effectiveness of absorption Units 5 and 7, or could deposit on, and foul membranes used in, Unit 6.

Section 3.1 described the Decontamination Waters waste stream and tabulated its radioactive and non-radioactive constituents and properties. System flow diagrams for processing Decontamination Waters are shown in Figures 3.2-2 and D-1. The primary objective of this processing is to reduce the level of radioactive contamination below a self-imposed limit ($<10^{-10}$ Ci/l for all isotopes other than tritium²) such that the purified effluent from the process may be discharged to the environment and be within the Regulatory requirements (Ref . 8). Unit 2 is the first stage of the treatment of Decontamination Waters.

After coarse filtration, the Decontamination Waters are treated electrochemically to destroy organic chemicals, namely complexants and chelates. The subsequent steps include passing the Decontamination Waters through a series of packed columns which scavenge oxidants (generated in the electrochemical treatment), filter the water (Unit 3), and selectively absorb cesium and strontium isotopes (Unit 5).

The next stage is to reduce the volume of the waste by electrodialysis and electroosmosis (Unit 6). A large volume of purified water from this process will receive a final polishing (Unit 7) before discharge to the industrial waters treatment plant. The process concentrate from Unit 6, which contains the majority of solids and some polyvalent radionuclide contamination, will be sent to a cement solidification module (Unit 8).

This section of the report describes Unit 2. Other processing units mentioned above are described later.

DETAILED DESCRIPTION

Major Equipment

Accumulation Tank

Tank A2-1 shown on the system flow diagram (Figure D-1) is a 100 m³ tank identical to Tank A1-1; it receives Decontamination Waters before processing those wastes in this unit. Section 3.3.1 has a description of the tank.

²See footnote on page 29.

Coarse Filter

Filter A2-3 is identical to filter A1-3 and is described in Section 3.3-1. It is now considered that the pleated membrane filters, which can be reused, will be employed to reduce secondary waste.

Electrocatalytic Destructor

The Electrocatalytic Destructor A2-4 is a vessel fitted with titanium cathodes, and either platinum-coated titanium or ruthenium-dioxide-coated titanium anodes. Passage of current (electrical power required ranges from 1 to 3 kw) through the unit generates active forms of chlorine, e.g., hypochlorite. The source of chlorine for the electrochemical decomposition is salt (NaCl) present in the decontamination solution. Active chlorine destroys organics due to its high oxidizing potential, the ultimate end products being carbon dioxide and water.

Although the unit was not designed expressly to remove radionuclide, some precipitation is expected. As the organics are destroyed, the solution will lose of some its ability to retain dissolved solids, and thus some of the them will precipitate.

A small amount (several percent of the input to the Electrocatalytic Destructor) of radionuclides will be electro-deposited on the unit's cathodes. However, continuous dissolution of this material is expected to occur. Hence, significant permanent deposition of radioactivity on the cathodes should not be a problem.

Small amounts of chlorine- and hydrogen-gas are produced as byproducts of electrolysis. These potentially hazardous gases will be vented from the system.

The liquid leaving the Electrocatalytic Destructor is highly corrosive due to the active chlorine. The Destructor and downstream equipment which come in contact with the liquid must be made of titanium. The final design will have a titanium column containing either sulphocarbon³ and/or manganese dioxide inserted at the back end of Unit 2. The column will scavenge residual active chlorine. Reducing the corrosivity of the liquid will allow subsequent processing units to be made from stainless steel.

Deaerator/Settler Tank

The primary function of the Deaerator/Settler tank A2-5 is to vent byproduct gas generated in the Electrocatalytic Destructor. A secondary function is to remove solids, and about 5% of the polyvalent nuclides are expected to precipitate. Also, by destroying the complexants and chelates

³Sulphocarbon is activated carbon that has been treated with sulfuric acid, creating sulfate and carboxylate groups on its surface. These chemical groups are the functional exchange groups present on strong-acid and weak-base organic ion-exchange resins, respectively. This creates relatively inexpensive ion-exchange media.

which were used to aid in the dissolution of contamination, the capacity of the treated Decontamination Waters to retain dissolved solids will be reduced.

Traditional, straight-forward settling technology is to be employed in settler A2-5; therefore, additional details on design were not requested nor supplied.

Final Collection Tank

A Final Collection Tank (A2-6) is provided in Unit 2 to serve as a surge tank to balance input and output flows.

Process Flow

The Decontamination Waters are pumped by pump A2-2 from the Accumulation Tank (A2- 1) through the Coarse Filter (A2-3) and into the Electrocatalytic Destructor (A2-4). Electrically produced forms of active chlorine attack and destroy organic complexants and chelating agents in the Electrocatalytic Destructor. The treated flow proceeds through the Deaerator/Settler Tank (A2-5) to the Final Collection Tank (A2-6) which collects the processed Decontamination Waters. Pump A2-7 transfers the liquid from this tank to Unit 3 for the next stage of treatment. The settler "bottoms" are transferred to Unit 8 for solidification.

The unit will be operated in a once-through mode with no recirculation. In the final design, there will be provision to return an off-specification product. This ability to recycle off-specification material was stated to be a requirement of the Russian design standard.

Sludge that collects in the settler will be transferred to the cementation module (Unit 8). Failed filters will be packaged and placed in temporary storage. Sections 3.3.8, 4.1 and 4.2 discuss waste stabilization and storage.

3.3.3 Unit 3 - Mechanical Filtration Unit

SUMMARY DESCRIPTION

Unit 3 is a bank of columns filled with quartz sand which are designed as mechanical filters. In actuality, although Unit 3 is considered as a single module, it has two distinct, separable functions. The first three sand columns are dedicated to processing Decontamination Waters from Unit 2; the other three columns process High-salt Waters from Unit 1.

DETAILED DESCRIPTION

Major Equipment

Unit 3 consists of six stainless-steel columns filled with quartz sand. It is expected that some of the

column vessels may be removed from the existing system and reused in this unit to reduce costs. Each column vessel is an estimated 10 feet high with a 1 foot diameter. The capacity is about 0.5 m³; however, as with the existing system, it is expected that they will be filled to only 70 percent of that volume. Sand is replaced by slurring the old sand to a waste container, and slurring the new sand into the empty column.

Any newly fabricated vessels required will be of a new design (Figure D-4). These vessels will have sand packed in a more easily removable cartridge. The spent sand cartridge will be removed into a shielded container for transport to storage or to the solidification facility, when its design is modified to process such wastes.

The quartz sand is layered so that the waste passes through sand of decreasing particle size, as it moves downstream. Hence, the columns can remove particulates down to about 100 μ in size.

Several small tanks also act as surge and head tanks for the pumps, providing minimal storage capacity between processing stages.

Process Flow

As noted above, Unit 3 accepts both processed Decontamination Waters from Unit 2 and High-salt Waters from Unit 1.

Decontamination Water Operation

The effluent piping from Unit 2 is connected to the first three quartz sand columns (A3-1.1 through A3-1.3) shown in Figure D-1 by way of piping "OC". These three columns are piped and valved for parallel operation. Effluent is pumped from Unit 2 using the Unit 2 pump (A2-7), through the three parallel columns and into the surge tank (A3-4). It is then transferred from this tank using Unit 3 pump (A3-5) to Unit 5 for sorbent removal of cesium and strontium.

Salt Waste Operation

The effluent piping from Unit 1 is connected to the last three quartz sand columns (A3-1.4 through A3-1.6) shown in Figure D-1 by way of piping "YM". These three columns are piped and valved for parallel operation. Effluent is pumped from Unit 1 using the Unit 1 pump (A1-6), through the three parallel columns, and into the surge tank (A3-2). Then it is pumped from this tank using the Unit 3 pump (A3-3) to Unit 4 for sorbent removal of cesium, strontium, and organic impurities.

Backflush Operation

Valving and flushing lines are provided so that any one or all of the columns can be backflushed periodically. Using the normal wastewater flow path, tank A3-1.7 can be filled with water to be used in backflushing. By properly aligning the valves, water can be pumped from this tank using Unit 3

pump (A3-1.8) to the outlet of the sand beds. After passing up through them, backflush flow enters the piping connecting Unit 3 and the Unit 1 Accumulator Tank (A1-1). Particulates backflushed from the sand columns can then be removed by way of the Coarse Filter or the Unit 1 settler and piping to the waste solidification facility, Unit 8. It is assumed that there will be a bypass of the mechanical filter.

If the operation of the sand column cannot be restored by backflushing, the sand from the columns will be removed to be solidified in Unit 8 and stored. Then, the columns will be refilled with clean sand.

3.3.4 Unit 4 - Sorption Column Unit for High-salt Waters

SUMMARY DESCRIPTION

Unit 4 is a bank of sorbent-filled columns, designed to remove radioactive species from the High-salt Waters processed previously by Units 1 and 3.

DETAILED DESCRIPTION

Major Equipment

Unit 4 consists of six sorbent filled stainless-steel columns. These columns will be identical to those used to hold the quartz sand in Unit 3 (Section 3.3.3 gives a physical description of them).

The first two columns are filled with a sulphocarbon⁴ sorbent to remove organic impurities.

The following two columns are nickel ferrocyanide⁵, primarily to remove the residual cesium-137(134). Although nickel ferrocyanide is generally known to be a good sorbent material, it has not been used extensively in the United States. Without a carrier material, nickel ferrocyanide packs too tightly in a column to be of any practical use. U.S. manufacturers have not developed a process to manufacture nickel ferrocyanide in a useable form; however, the Russians have developed carrier particles (0.2-0.8 mm dia.) coated with nickel ferrocyanide (40 mg per gram of carrier) which have been proven in actual use.

⁴See footnote on page 29.

⁵The term nickel ferrocyanide will be used throughout this text. The compound actually is a proprietary, ternary ferrocyanide compound containing nickel, iron, and another unidentified element. Apparently, this compound has an affinity for the support carrier used to create particles coated with that compound; the result is a practical solid adsorber.

The final two columns are filled with zeolite, which removes strontium-90 (and residual cesium) selectively.

Process Flow

As noted above, Unit 4 is dedicated to the cleanup of radioactive species, primarily cesium and strontium which remain in the High-salt Waters after pre-processing by Units 1 and 3.

High-salt Waters Operation

The Unit 3 pump (A3-3) moves pre-processed wastewater (reduced hardness and lowered levels of radioactive and non-radioactive strontium) from tank A3-2 to the Unit 4, first- stage sulphocarbon columns (A4-1.1 and A4-1.2) using interconnecting piping "YM". There are two such columns connected in parallel (Figure D-1). Then, the wastewater flows through the nickel ferrocyanide (A4-1.3 and A4-1.4) and zeolite (A4-1.5 and A4-1.6) columns connected in series. The nickel ferrocyanide and zeolite columns are double columns also with the two columns of the same sorbent connected in parallel.

Having completed the circuit through the six columns of Unit 4, the processed High-salt Waters normally flow to Unit 6, although, it may be bypassed, sending the flow directly to the final polishing stage, Unit 7.

3.3.5 Unit 5 - Sorption Column Unit for Decontamination Waters

SUMMARY DESCRIPTION

Unit 5 is a bank of four sorbent-filled stainless steel columns designed to remove radioactive species from the Decontamination Waters that have been processed by Units 2 and 3.

DETAILED DESCRIPTION

Major Equipment

Unit 5 consists of four sorbent-filled columns. These columns may be reused from the existing facility, or may be vessels of a new design, as described previously for Units 3 and 4.

The first two columns are nickel ferrocyanide primarily to remove the cesium-137(134).

The last two columns are filled with zeolite which selectively removes strontium-90 (and residual cesium).

Process Flow

Unit 5 is dedicated to the cleanup of radioactive species, primarily cesium and strontium, which remain in the Decontamination Waters after preprocessing in Units 2 and 3. Very little cesium and strontium are removed in pre-processing.

Decontamination Waters Operation

The Unit 3 pump (A3-5) sends pre-processed wastewater from tank A3-4 to the Unit 5 first -stage nickel ferrocyanide columns (A5-1.1 and A5-1.2) using interconnecting piping "OC". There are two such columns connected in parallel (Figure D-1). Then, the wastewater flows through the double zeolite columns (A5-1.3 and A5-1.4) connected in parallel, also.

Having completed the circuit through the four columns of Unit 5, the processed Decontamination Water flows to Unit 6 normally, although, it may be bypassed, sending the flow directly to the final polishing stage, Unit 7.

3.3.6 Unit 6 - Electromembrane Desalination Unit

SUMMARY DESCRIPTION

The Electromembrane Desalinators unit will process both High-salt and Decontamination Waters. The primary purpose of desalination is to reduce waste volume. Influent to the process is converted into two effluent streams: a diluate flow (low total solids), and a brine flow (high total solids). The volume of brine (small in comparison to the influent volume) can be disposed of by solidification in cement and temporary storage (until a permanent disposal site is established). The diluate after polishing can be discharged to Kola Bay by way of the industrial waters treatment system.

Unit 6 has two types of active devices: electrodialytic desalinators (ED), and electroosmosis concentrators (EO). EDs and EOs are designed to function in different concentration regimes, but both employ the same cation-anion membrane technology. Electrodialysis and electroosmosis must work together to achieve the desired waste concentration (working diagrams are given in Figure D-2)

The technology employed in Unit 6 was selected for the following reasons. Conventional distillation (i.e., a waste evaporator) is energy-intensive and should be operated continuously for best efficiency; there will not be enough wastes at this site to do this. In addition, special, expensive titanium equipment would be needed for evaporating the High-salt Waters, with its associated high chloride levels. Finally, radioactive sediments would form in the interior of the evaporator, interfering with heat transfer, necessitating cleaning and, thereby, producing additional liquid radioactive waste.

Another option, reverse osmosis (RO) has the advantage of being inexpensive. However, it cannot produce liquids with a solids content approaching 200 g/L. The membranes employed in RO (pore size $< 0.2 \mu$) are easily fouled by organics and biological contamination (viruses and bacteria).

Thus, electrodialysis and electroosmosis were selected over evaporation or RO primarily because less energy is needed than for evaporation. Also, a higher reduction in volume can be obtained than with RO, and the membranes used are not as susceptible to fouling as those used in RO.

ASPECT considers some information about the Units, in particular the EOs, to be proprietary.

The Unit's primary function is to substantially reduce the volume of waste. This is to be accomplished in two stages. First, the EDs produce two flow streams, one of relatively pure water (diluate), and the other a concentrate of the contaminants of the wastewater (brine). This brine becomes the feed for the EO units. The EO units also generate diluate and brine effluent streams. The combined ED and EO process is designed to yield brine containing ~200 g/l solids for disposal. The overall decontamination factor for Unit 6 was stated to be 10 to 100 and the majority of the radioactivity remains in the brine. The brine will be sent to the cementation module. EO diluate will be recycled as feed to the EDs for further treatment. The diluate from the EDs is the purified stream and will be designed to contain less than about 200 mg/l solids. This will be an adequate level of desalination and will allow the diluate after polishing to be discharged to the site's industrial waste treatment system, and ultimately, to the environment.

DETAILED DESCRIPTION

Major Equipment

Electrodialysis Units

The ED units are divided into chambers by multi-spaced, ordinary, common membranes (anion and cation exchangers in the form of polyethylene films). The passage of electrical current through the system transports material across the membranes, i.e., it drives the charged ions across the membranes, while they retard the movement of water. Hence, in operation, the liquid in a chamber on one side of the membrane will become more concentrated with impurities, while the liquid on the opposite side becomes more dilute. The desired concentration of solids at the output (diluate) of the EDs is 400-500 mg/L; the concentrate will contain ~40 g/l solids.

Unit 6 contains four EDs (B6-1.1 through B6-1.4). These appear in the upper portion of Unit 6 in Figure D-1. EDs will be operated as parallel pairs, with the two pairs connected in series.

Russian experience with the particular ion-exchange membranes used in the EDs indicate that they will not be susceptible to much scaling and fouling (after the intended pretreatments of the raw Decontamination Waters and High-salt Waters). The EDs are expected to operate for five years before the membranes need replacing.

Electroosmosis Units

It was stated that the EOs are new technology which has not been used outside the FSU. Limited

information was given on the design of the EOs since some of it is considered to be proprietary. However, the general description given below was obtained.

Unit 6 has two EO units, shown in Figure D-1 in the lower portion of Unit 6. The EOs will be designed to produce a brine containing 200-240 g/L solids (initial concentration of the feed from the EDs is 40 g/l). The EO units are multi-chambered devices also, separated by the same types of membranes used in the ED units. The EOs operate similarly to the ED units. [This is intriguing, since, in osmosis, the solvent (in this case water) is transported generally across the membrane, a process opposite to that in dialysis.] While the EO and ED units utilize similar membranes, they are constructed differently and, thus, produce different results.

Based on previous Russian experience, the membranes are not expected to foul easily, and an estimated membrane lifetime of ~1.5 years is projected for the EO units.

These EO units are to be operated in parallel. The diluate from the process exits at the top of the unit, while the brine exits at the bottom. The diluate will be returned to the EDs for further treatment, whereas the brine is sent to the cementation unit (Unit 8).

Tanks

Within Unit 6, there are five tanks (Figure D-1), each with a volume of 4 m³. The Filtrate Tank (B6-2.1), the Diluate Tank (B6-2.2) and the Intermediate Brine Tank (B6-4) receives filtrate from Units 4 or 5, receives diluate from the EDs, and holds intermediate concentration brine, respectively. The Intermediate Brine Tank is common to both ED and EO units, receiving concentrate from the EDs and feeding it to the second stage of treatment, i.e., the EOs.

The Concentrated Brine Tank (B6-9) collects the concentrated brine, which will be transferred to Unit 8 for solidification. The liquid which collects in the Purified Water Tank (B6-6) has less than ~200 mg/L dissolved solids. This liquid is sent to Unit 7 for a final polishing before release to the site's industrial waters treatment plant.

Process Flow

At startup, the Filtrate, Diluate, and Intermediate Brine Tanks (B6-2.1, -2.2 and -4) are filled with effluent from the sorption Units 4 or 5, depending on which type of waste is being processed. The solution from the Filtrate tank goes into one side of the ED membrane system; the solution from the Intermediate Brine Tank goes into the other side. The compositions of the solutions in these two tanks will change as the ED units operate. The salt concentration of the solution in the Diluate tank becomes lower, while that in the Intermediate Brine Tank becomes higher.

In the normal mode, operation is as follows: Salted Waters from either sorption Unit 4 or 5 are transferred to the Filtrate Tank (B6-2.1). Pump B6-3.1 directs filtrate to the bottom of EDs B6-1.1 and -1.2, which are operating in parallel. From the tops (as drawn) of these EDs, a diluate stream

is directed to the Diluate Tank (B6-2.2), while a concentrate is directed to the Intermediate Brine Tank (B6-4).

Liquid from the Diluate Tank is pumped, using pump B6-3.2, to the lower sections of the second pair of EDs, B6-1.3 and -1.4, which also operate in parallel. Effluent from the tops of these EDs is directed to the Purified Water Tank (B6-6), while the concentrate is directed to the Intermediate Brine Tank (B6-4). Purified water in tank B6-6 is moved by pump B6-7 to Unit 7 for a final polishing before release to the site's industrial waters treatment plant.

Pump B6-5 transfers intermediate concentration brine (~40 g/l solids) to the lower sections of EOs B6-8.1 and -8.2, which operate in parallel. The bottoms from the EOs (~200 g/l solids) are directed to the Concentrated Brine Tank (B6-9). From B6-9, brine will be sent to Unit 8 for cementation. The diluate, produced by the EOs, also is sent back to the Filtrate Tank, to be recycled through the EDs.

The flow rates are 50 l/hr for the concentrate going into Concentrated Brine Tank, and 1 m³/hr for the total unit. Since the brine pump has a capacity of 20 m³/h, and the filtrate and diluate pumps both have a 2 m³/h capacity, the flows through the system can be varied. In fact, the salt content can be controlled by changing the flows (depending on the filtrate's concentration).

The brine that is to be produced by the EOs is designed to be 200-240 g/l (with a corresponding activity of ~10⁻⁴ Ci/l). However, various levels of diluate purity can be achieved (200-400 mg/l is typical). The salt concentrations will be monitored at three points: tanks B6-2.1, B6-4, and B6-6.

Unit 6 will be controlled by monitoring salinity and controlling flow rates. It will require an automatic control system.

3.3.7 Unit 7 - Sorption Polishing Unit

SUMMARY DESCRIPTION

Unit 7 is a bank of six sorbent-filled columns, designed as a polishing unit to lower radioactive species concentrations below discharge limits. It processes all waters passing through the facility, except primary coolant.

DETAILED DESCRIPTION

Major Equipment

Unit 7 consists of six sorbent-filled stainless-steel columns (Figure D-1). These columns may be reused from the existing facility, or may be vessels of a new design, as described previously for Units 3, 4 and 5. Section 3.3.3 gives a physical description of them.

The first two columns contain nickel ferrocyanide, primarily to remove the cesium-137(134).

The next two columns are filled with zeolite, which removes strontium-90 selectively. The fifth column contains activated carbon to remove trace organics. The last column is a mixed-bed ion exchanger to remove the balance of the radioactive species.

A small surge tank of 1 m³ capacity (C7-2), and a micro-filter (C7-4) which will remove particles larger than 10 µ are also included.

Process Flow

As noted above, all waters passing through the facility except primary coolant must pass through Unit 7 before discharge.

The Unit 6 pump (B6-7) sends processed wastewater from tank B6-6 to the Unit 7 first- stage nickel ferrocyanide columns (C7-1.1 and C7-1.2) using interconnecting piping "O". These two columns are piped for parallel operation. Then, the wastewater flows through two zeolite columns (C7-1.3 and C7-1.4) configured in parallel also. Finally, if needed, the flow passes through an activated-carbon column and a mixed-bed column (C7-1.5 and C7-1.6) connected in series.

Having passed through these six columns, the processed wastewater enters the surge tank (C7-2) from which it is pumped (C7-3) through the micro-filter (C7-4) to the 250 m³ Discharge Tank (not shown on the diagram) described in Appendix B. It is understood that this tank will be reused from the existing system.

3.3.8 Unit 8 - Cementation Unit

Although ASPECT developed a design for the Cementation Unit (Reference 2), it was not reviewed since Atomflot has not selected a specific design. Until additional building space is constructed (estimated to be three years), candidate designs for cementation units will be required to fit into the existing Atomflot facility. This space limitation resulted in a decision to attempt to locate used equipment which will solidify brine from Unit 6 and sludges from several other units. Therefore, other wastes, in particular sorbent materials, generated in the water cleanup will be packaged and placed in interim storage.

ASPECT will continue with the proposed design of the full facility and obtain regulator, Gosatomnadzor (GAN), approval for that design. Then, as an alternative to buying used equipment, Atomflot could get local regulator approval for implementing a partial installation of the GAN-approved design. Atomflot intends to select and to procure a cementation unit when additional space is available, which is expected to stabilize all wastes from the proposed treatment facility.

The implications of this situation are evaluated in Section 4.2 of this report.

3.3.9 Unit 9 - Decontamination Unit for Low-salt Waters

SUMMARY DESCRIPTION

Unit 9 consists primarily of a bank of sorbent-filled columns designed to remove radioactive species from the Low-salt Waters. In addition, the sorbent columns are preceded in the flow stream by a backwashable micro filter and a large accumulation tank which is designed to accept wastewater from dockside discharge points. A micro-filter following the columns, removes fine particulates before discharge.

DETAILED DESCRIPTION

Major Equipment

Accumulation Tank

The Accumulation Tank is a 100 m³ storage tank which will receive wastewater from dockside discharge points. This tank is expected to be identical to the Accumulation Tanks used in Units 1 and 2 (described in Sections 3.3.1 and 3.3.2).

Micro Filter

The backwashable micro filter located just downstream of the Accumulation Tank has porous metal (titanium) as the filtration medium and will remove particulates greater than 10 μ . Pleated membrane filters will be considered as an alternative because the metal filters require backflushing with water, thus creating additional waste, whereas, the pleated membrane filters can be backflushed with air.

Sorbent Columns

Unit 9 includes six sorbent-filled stainless-steel columns connected in series. The physical characteristics of the vessels used to house these columns are expected to be identical to those of the vessels used in the columns of Units 3, 4, 5, and 7 which were previously described in Sections 3.3.3, 3.3.4, 3.3.5, and 3.3.7, respectively.

The first column is filled with clinoptilolite which primarily removes cesium-137(134) and the second with zeolite, which selectively removes strontium-90.

The third column contains nickel ferrocyanide primarily to remove the residual cesium.

The fourth column contains additional zeolite to further reduce strontium levels.

The fifth column has mixed-bed organic ion-exchange resins to remove polyvalent radionuclides and non-radioactive anions. The final column contains activated-carbon to remove trace organic

chemicals.

The expected lifetime of the sorbents in the first four columns is about 5 years, whereas the media in the last two columns will have to be replaced annually.

Intermediate Tanks

There are three intermediate tanks of unspecified capacity. However, consistent with the design of other modules, these are expected to have a capacity between 4 - 10 m³. Tank E9-6 is a supply tank for use in backflushing the Coarse Filter. Tanks E9-4 and E9-9 both provide surge capacity in the system.

Final Filter

Filter E9-13 will remove particulates greater than 1.5 μ . The specific design of this ultra-filter was not discussed.

Process Flow

Low-salt Waters Operations

Low-salt Waters will arrive at the treatment facility by ship to two dockside pumping sites. Wastes are pumped from the transporting vessel to Accumulation Tank (E9- 1). Pump E9-2 draws on the Accumulation Tank sending the untreated wastewater through the Coarse Filter (E9-2) to the surge tank (E9-4).

Then, pump E9-5 moves the filtered wastewater through the series-connected sorption beds in the following order: clinoptilolite, zeolite, nickel ferrocyanide, zeolite, mixed-bed, and activated carbon. Leaving the final sorbent column, the wastewater enters another surge tank (E9-9) from which it is pumped, using pump E9-10, through the Final Filter (E9-13).

Since this water will still exceed the discharge limit for tritium, it will be stored in tanks until it can either be reused as reactor primary coolant, or used in the cementation process.

Backflush Operations

The micro filter can be backflushed to an Accumulation Tank (A2-1 in Unit 2) using pump E9-7. After closing the isolation valves at the inlets to tanks E9-4 and E9-6 and the micro-filter inlet valve, backflush flow is established through the filter using the pump to draw on the contents of tank E9-6, which was previously filled.

4. DESIGN EVALUATION HIGHLIGHTS

The previous section of this report gave a factual description without evaluation of each of the units of the proposed LLRW treatment system. This section evaluates each unit in terms of the review objectives discussed in Section 2. Additionally, opportunities for technology transfer are identified.

4.1 Equipment Design

General

Section 3.1 describes the properties of the input wastewater which will be the basis for designing the proposed facility. A set of technical design documents were prepared under a contract with the Murmansk Shipping Company, and supplied to the participants. The U.S. technical team reviewed the data and noted technical matters requiring clarification. These were listed as a set of **Questions** which were sent to the design organization, ASPECT, who supplied **Answers** in written and verbal form at a Final Review meeting in Oslo, in December, 1995.

The full set of **Questions and Answers** is given as Appendix C. There was full discussion of many ideas and issues on concepts, design data, waste streams, and operation, as well as about items of clarification of translation and mutual understanding.

We give here only the highlights of the design review.

Unit 1 - Pretreatment of High-salt Waters

Conceptually, the basic processes used in Unit 1 operation are relatively simple and straight-forward. The steps of filtration, precipitation, and settling are well known and are sufficient functionally to meet the unit's design objective, which is to reduce significantly the hardness constituents of the wastewater stream. This water softening is necessary to reduce fouling of the electrodialysis and electroosmosis membranes in Unit 6.

Water softening also has the added benefit of removing both radioactive and non-radioactive strontium. The primary purpose of the Unit 4 zeolite column is to remove strontium-90 to near discharge levels. Without removal, the Unit 4 zeolite columns would be exhausted quickly by the much higher levels of non-radioactive strontium present in the High-salt Waters.

The key component in Unit 1 is the Electrochemical Unit which produces sodium hydroxide, which causes the precipitation of the hardness constituents of the waste stream. The technical team has several concerns with this component; one is that the team does not have knowledge of the details of the Electrochemical Unit's design. It is a unique device which has had no application outside the former Soviet Union (FSU), so the technical team has no independent knowledge of the design and operation of similar units on similar waste streams. Furthermore, the High-salt Waters have no

common analog in the United States.

The information provided has been very limited since ASPECT considers the design to be proprietary and ASPECT stated that a similar unit has operated satisfactorily in Ukraine where it was used to process mine water contaminated with uranium and radium. It had a considerably larger capacity than the proposed unit, although it was not made clear to the technical team whether the separation and decontamination factors were comparable. Also, ASPECT constructed a prototype of Unit 1 and experiments performed to date are the basis for anticipated performance.

Subsequent to the initial meetings, ASPECT gave a report on the pilot test to the technical team stating that the pilot Electrochemical Unit performed satisfactorily. Water softening with this Unit was 3-7 times more effective than with using ordinary alkali. Hardness was reduced by 20-30 times, rendering the effluent from the Unit suitable for electromembrane desalination. While this information gives the technical team some confidence that Unit 1 can be made to operate successfully, they need more design details.

In summary, the precipitation and settling processes, and equipment (other than the Electrochemical Unit) associated with Unit 1 are of no concern since they are based on common technology. However, the design of this unique Electrochemical Unit is considered to present a medium financial and technical risk. There is also a medium level of uncertainty in this conclusion since the technical team has not yet been given detailed information on its design and operation because of proprietary reasons.

After reviewing cost and space requirements, it is now proposed to add phosphate as the softening process. This is low risk, provided the redesign of the plant does not affect the schedule.

Unit 2 - Pretreatment of Decontamination Waters

As with the Electrochemical Unit, the technical team is not aware of the use of Electrocatalytic Destructor technology outside the FSU. Therefore, it has no direct knowledge of similar units processing similar waste streams. All of the information the team has was gathered during the discussions in Murmansk.

Despite the proprietary nature of the Electrochemical Destructor, the technical team was given enough information to classify it, and Unit 2 as a whole, as presenting a low financial and technical risk.

The basic principles of unit operation: filtration, production of active chlorine using an electric current in a saline solution, electrochemical oxidation of organics in the presence of active chlorine, and precipitation are well known and well understood. Functionally, these processes will achieve the unit's objective of removing organics from the waste stream to keep them from interfering with the subsequent sorption processes in Units 5 and 7.

At one time, a similar Electrocatalytic Destructor was installed and tested as part of the second-stage treatment process in the existing Atomflot facility. The team was told that it operated satisfactorily. The required capacity of the Electrocatalytic Destructor in the new facility is roughly the same as that of the device tested. This successful test was one of the bases for its selection in this application.

In summary, the filtration and settling processes and equipment associated with Unit 1 are of no concern since they are based on common technology. While not common technology, the Electrocatalytic Destructor is judged to be simple and feasible. Also, it is said to have been proven in testing at the existing facility. Thus, the design of this unit is considered to present a low financial and technical risk. There is a moderate level of uncertainty in this conclusion, since the technical team was not given detailed information on the design and operation of the Electrocatalytic Destructor because they are proprietary.

Unit 3 - Sand Filters

Filtration using sand beds has had widespread successful application in the past. In fact, as noted in Appendix B, the existing Atomflot facility used sand filters successfully. Although technological advances outside Russia have replaced sand filters with alternate designs to reduce the generation of secondary waste, there is no doubt that they will perform acceptably. This technology was apparently chosen for this application because it is inexpensive and the sand beds are not expected to need replacement often, so that generation of secondary waste is not a significant problem.

The U.S./Norwegian technical team raised the issue of oil fouling of the sand columns used to filter High-salt Wastes. Oil contaminants can build up on the sand if not removed upstream; this can be deleterious to filtration and also can result in difficulty in solidifying the sand with cement. While the Russian experts agreed that this may occur, they believe that a fouled filter bank could be remedied easily by backflushing or replacing the sand. However, the Russians stated that the need for up-front oil removal was to be evaluated during the final design process.

The Unit 3 design is considered to have very low financial and technical risk.

Units 4, 5, 7, and 9 - Sorbent Columns

The technology associated with units 4, 5, 7, and 9 is very similar and, thus, a common evaluation is given below.

The design of the packed sorbent columns for the proposed LLRW facility is fairly standard technology, although, sulphocarbon and nickel ferrocyanide sorbents are not known to be used in the United States. However, ASPECT stated that these two sorbents have been used successfully in Russia and supplied a specimen to the United States for examination.

The sorbent column design is considered to have low financial and technical risk.

Unit 6 - Desalinator Unit

Unit 6 employs Electrodialysis (ED) and Electroosmosis (EO) which ASPECT stated were Russian technologies which have not been used outside the FSU. Therefore, the technical team has no direct knowledge of similar units processing similar waste streams. All of the information the team has on this unit was provided during the discussions in Murmansk. However, a later visit was made to the RADON waste treatment facility outside Moscow, where the design had been used for treating high-saline wastes (see below).

The processes in Unit 6 are viewed as being much more complex compared with the other units in the system. There are four ED units operating as two parallel pairs and two EO units, also operating in parallel. There are three intermediate tanks and pumps managing the distribution of three separate flow streams (filtrate, diluate, and brine) among the ED and EO units. Process control is maintained by multi-point process monitoring and multiple flow control. Also, as noted above, the ED and EO units are innovative technology themselves.

Two applications of similar, but not identical, technology in Russia were described by ASPECT.

- (1) The private company RADON owns and operates a mobile facility for concentrating salts and radioactive wastes. Reference 4 describes tests on this unit using waters of lower solids content (0.5 g/l) and lower salinity (<10 g/l) but at about the same capacity (24 m³/day) and a different spectrum of radioactive species (primarily actinides). Concentrations about 65x were achieved. The RADON facility was visited by the technical team, where the successful bench top operation for high salinity was described, but data for full-scale operation awaited progress on the Murmansk project.
- (2) The other facility is a pilot scale plant called the Moscow Station of Radioactive Waste Treatment. An abstract of the test report (Reference 5) on this facility was provided by Atomflot; it indicated a decontamination factor of about 100 for wastewaters which contained a mixture of isotopes similar to those expected in the waste to be treated in the proposed Atomflot facility. Waters to be treated had a lower solids content (< 5 g/l). Capacity information was not provided. The measured degree of concentration of solids is consistent with that projected for Unit 6.

In summary, several factors were considered in determining the financial and technical risk of Unit 6 to be medium.

On the negative side, the unit employs innovative technology not used outside the FSU; therefore, having no independent knowledge of similar systems processing similar wastes, the technical team relied only on the information provided by the Russian side. Detailed information was withheld by ASPECT because of the proprietary nature of the technology. On the other hand, there is operating experience with the technology at the RADON mobile unit and the Moscow Station of Radioactive Waste Treatment. Therefore, the technical team concludes that the basic technologies employed in

the system can be made to work. However, the system is complex, and a well designed control system will need to be incorporated into the final design. Additional tests on high salinity streams are needed, and refinement of the design to allow for easier remote membrane replacement is underway.

Unit 8 - Cementation of Brine and Sludge

At present, there is considerable uncertainty about the final design of the cementation facility. Some drawings of the facility proposed by ASPECT were available to the team; however, they were not reviewed by the technical team since Atomflot has not committed to the proposed design.

An outline design specification was supplied based on a grouting plant developed by the Moscow company "Radon" designated Module Plant for Cementation. The system described had a capacity of 4 m³/hr with a loading of 40-80 % LRW for radioactivity in the range of 1-10 Ci/l. This facility also was discussed at the visit to the RADON facility, where a more detailed description of development work was given on improved mixer designs. The cementation process itself was at an advanced stage of routine utilization and implementation in Russia, and was considered low risk. In fact, methods to reduce the immobilized waste volume were considered desirable in the longer term.

Based on present plans, Atomflot will not have building space to house the equipment proposed by ASPECT for nearly three years. As an alternative, near term solution, Atomflot is considering buying used equipment, doing the design themselves, and installing the equipment in space available in the existing facility.

This interim solution will solidify only the concentrated brine from Unit 6 and the sludges generated in Units 1 and 2. The estimated activity in these waste streams is about 20 percent of the total activity removed from wastewaters. Spent sorbents, which contain the remaining 80 percent of the activity, will continue to be stored in the cylinders described in Appendix B.

The technical team is concerned about Atomflot's long-term plans to solidify high saline wastes and used sorbents. The stability of cement waste forms containing organic resins is notoriously unpredictable to the point where, in the United States, cement is now used infrequently. The team was told by Atomflot that special cements are under development to meet Atomflot's specifications. Atomflot agreed to provide the team with a copy of a report on these cements. Given the lack of success in the United States in developing an acceptable cement formulation, it does not seem prudent to rely on cementation as the method to stabilize waste. In addition, the cemented waste will be stored in concrete containers and stacked in a waste storage building.

The U.S./Norwegian team recommended using High Integrity Containers (HIC) as an additional barrier to the concrete containers. HICs are licensed in the United States for similar applications, but the volume (1000 liters) and environmental requirements (-40°C) require special consideration. Atomflot should establish a plan for packaging waste and incorporate that plan in the final design.

Unit 9 - Low-salt Waters Decontamination

The team has no particular concern about the design of this unit; however, there is some confusion as to why this unit exists at all. This was never cleared up by either Atomflot or ASPECT.

The information provided indicates that the Low-salt Waters to be processed in Unit 9 consist of primary coolant from the nuclear icebreaker fleet and spent fuel pool coolant. However, during the discussions in Murmansk, the team was told that this unit would process primary coolant from Russian Navy reactors and return some of the processed coolant to those reactors. It was explained further that the Navy could not utilize all of the processed coolant; therefore, the unused coolant would have to be either stored or used in the cementation process because of its tritium concentration.

Several times during the discussions, ASPECT stated also that this waste stream originated from decommissioned submarines. In that case, there would be little or no opportunity to reuse the coolant.

4.2 System Design

Design Discharge Limits

The Russian regulatory discharge limits are 10^{-10} Ci/l for each radionuclide, except 10^{-6} Ci/l for tritium (Ref 8). In Table 4.2-1, these limits are compared to the NRC limits (10 CFR 20, Appendix B - Table 2) for the radionuclides present in the inlet waste streams (See Section 3.1). The Russian discharge limits are more restrictive than the NRC limits, except for tritium. In addition, Atomflot elected to be even more restrictive by self-imposing an administrative limit of 10^{-10} Ci/l for gross activity excluding tritium. Thus, the technical team judges the system's design requirements for radioactive nuclide discharge to be more than adequate.

It is clear that Atomflot must get approval from local (Oblast) authorities before discharging. These authorities can levy civil fines for violating discharge limits. In addition, a routine environmental monitoring program is in place and the results of this program must be reported to the local authorities. Therefore, it is expected that the design will meet all Russian regulatory limits for non-radioactive constituents of the waters discharged.

It is considered prudent to apply a post-construction environmental monitoring program for the Facility in order to ensure that (a) the plant meets and complies with the limits, (b) the impact of the facility is known and monitored, and (c) the parties have assurance and confirmation of reduced or insignificant environmental consequences.

Liquid Waste Processing

The proposed LLRW system is comprised of three independent trains, two of which partly rely, on

technology which is unique to Russia. The design decontamination factors projected by ASPECT for the individual units and for each train are sufficient to treat the design waste streams to meet radioactive waste discharge standards. Concerns about the ability of the technology to achieve these decontamination factors are discussed in Section 4.1.

Substantial reduction in waste volume ($> 10x$) is projected, which will reduce substantially future interim and long-term waste storage requirements.

Waste Solidification and Storage

From a system standpoint, a major shortcoming of the overall system is that the back end of the waste cycle has not been closed. The system can achieve significant volume reduction, thereby relieving the liquid problem of waste storage. However, new problems will be created unless specific plans are developed and implemented about waste containers, waste stabilization, and a temporary waste storage facility.

As the technical team understands the situation, the near-term performance objective for the cementation unit is to solidify only brine and sludges, so stabilizing only about 20 percent of the radioactivity removed from the processed waters. Approximately 80 percent of the activity will be absorbed by the treatment columns. Spent sorbent will be transferred from the treatment columns, along with the absorbed activity, to carbon-steel storage containers, as Atomflot has done in the past. During a tour of the existing LLRW processing facility, plant staff expressed concern about the condition of these storage containers to the technical team, some of which have been stored for as long as seven years. The technical team was told that there were no leaking containers in the temporary waste-storage building; however, this could not be verified since arrangements could not be made to tour the building during the visit.

There is concern about whether the sorbent waste containers presently in storage can continue to maintain their integrity. Since the present practice is definitely not an acceptable long-term solution to the problem of storing sorbent wastes, the team is concerned about plans to continue this practice, even for the near term.

As noted above, the technical team did not tour the waste storage facility and, thus, was unable to get a sense of the capacity remaining in that facility. Also, various individuals with whom the team discussed the remaining capacity could not give definitive answers; however, the general opinion was that it was about 1 to 6 months before it would be filled. Hence, construction of additional waste-storage capacity is of concern to the technical team.

Table 4.2-1**RUSSIAN AND U.S. EFFLUENT LIMITS**

ISOTOPE	10 CFR 20 Limit	Russian Limit
	pCi/ml	pCi/ml
T-3	1000	100
Cr-51	500	.01
Mn-54	30	.33
Fe-55	100	0.1
Fe-59	10	1
Co-60	3	3.3
Sr-90	0.5	20
Zr-95	20	0.5
Nb-95	30	.33
Ru-106	3	3.3
Sb-127	10	1
Cs-134	0.9	11.1
Cs-137	1	10
Ce-144	3	3.3
Eu-155	50	0.2

4.2 Construction Phase and Acceptance Testing

An outline Work Schedule was developed, which indicates construction will take some 18 months from initiation. The major Milestones are given in the list below, but the present schedule includes considerations for minimizing the impact to existing and continuing waste-treatment operations.

Preliminary Milestone List

- M1: Commence site preparation (Time zero)
- M2: Complete Plans and Specifications (4 months)
- M3: Complete site preparation (6 months)
- M4: Commence construction (6months)
- M5: Commence assembly (9 months)
- M6: Equipment delivery complete (12 months)
- M7: Assembly complete (17 months)
- M8: Complete acceptance tests (18 months)

Lists and specifications of equipment for the Units were developed, and used as a basis in the design. The lists include both standard and non-standard equipment, and cross reference the design drawings in Reference 7. Following Construction and Acceptance Testing of individual components and the whole system, an Assessment Phase is needed to ensure the plant meets its goals and objectives in relation to actual achieved discharge limits and quantities processed.

To support this effort, an expanded Environmental Monitoring Program is proposed. This effort will provide assurance and credibility to the stated goals, and independently verify the performance of the facility during extended operation.

4.3 Opportunities for Technology Transfer

During the conceptual design review in Murmansk, the technical team identified five opportunities for technology transfer. Three U.S. technologies could improve the proposed design of the LLRW treatment facility. Russian absorbents, in particular a solid-phase nickel ferrocyanide, should be explored for use in the United States. Also, the Electromembrane Desalinator unit has the potential for reducing liquid waste volume with a relatively low expenditure of energy.

U.S. TECHNOLOGY

The technologies identified for possible transfer from the United States. to Russia are High Integrity Containers (HICs), Pleated Membrane Filters (PMFs), and Programmable Logic Controllers (PLCs).

High Integrity Containers

As noted in section 4.2, most of the activity (80%) removed from wastewaters will be absorbed on media which, when exhausted, will be placed in carbon steel containers. This practice will continue, at least for the near-term, until a more suitable container is found. There are also longer-term plans, to solidify these sorbents, using cement. The remaining activity contained in brine and sludges will be solidified, also using cement. As also noted in section 4.2, the U.S. and Norwegian technical team has concerns about these practices.

U.S. industry, using U.S. Nuclear Regulatory Commission design criteria, provides U.S. waste generators with an alternative to solidification; simply to de-water and package waste in HICs for disposal. There are HIC designs which meet NRC design objectives available from several U.S. manufacturers. The technical team expects they would meet with the approval of the Russian regulator GAN, also.

Replacing carbon-steel absorbent containers with HICs would ensure that future sorbent wastes are packaged in structurally sound packages suitable for both interim storage and long-term disposal. U.S. HICs are designed to have a 300-year lifetime. HIC transport containers are available, so that the waste containers could be transported safely to an alternate long-term storage or disposal facility when that facility becomes available.

The waste sorbents already in carbon steel vessels in the shipyard's waste-storage building could be slurried immediately into HICs and de-watered, thereby, quickly eliminating one of Atomflot's and the team's concerns. Also, by discontinuing the practice immediately, it may lower workers' radiation exposure associated with repacking/overpacking or solidifying materials stored in degraded carbon-steel containers.

It is assumed that sludges and brine still will be solidified in cement. HICs could also be used as the containers for this solidified waste and these could be placed in the concrete containers in the waste storage building.

The unique question is the performance of HICs at extremely cold (-40°C) conditions, and the cycling through the seasons; this problem would need to be addressed in the licensing and procurement.

Pleated Membrane Filters (PMF)

PMFs were discussed in Sections 3.3.1 and 3.3.2 of this report. The primary advantage of PMFs is the ability to backflush them using compressed air rather than water. They are relatively inexpensive and can provide the capability for removing desired particulates. This will eliminate backflushing as a source of waste and, thus, reduce the volume of waste that needs to be solidified and stored.

The U.S. experience on these PMFs includes operation at many nuclear power plants. The design could use filters that cover the range from 5-100 micron, in single and combination configurations.

Computer Control

Section 3.3.6 describes Unit 6, and there it was noted that operating this Unit is complex. Multi-point monitoring and multi-point flow control will be required to balance flows and achieve the water purity and brine concentration desired. Thus, Unit 6 is an ideal candidate for application of computer control technology. ASPECT and Atomflot both expressed an interest in this technology and have requested a computer be supplied; they will provide the specifications for acquisition of PLCs that they will program.

RUSSIAN TECHNOLOGY

There are also items of the facility that are potentially useful and applicable in other facilities.

Absorption materials

Appendix B describes a unique absorbent material currently in use at the Atomflot facility and, presumably, elsewhere in Russia. This is the proprietary ternary ferrocyanide referred to in the text simply as "nickel ferrocyanide". The reagent is supported on the surface of an inert carrier of suitable size for packing in sorption columns. Such columns will be used in the proposed facility, also, and attests to Atomflot's confidence in the material. The technical team is not aware of a U.S. analog of this material in current operation. Nickel ferrocyanide sorbent should be considered for technology transfer to the United States.

Electromembrane Desalination

The Electromembrane Desalination Unit, which is technology not used outside Russia, has the potential to significantly reduce liquid waste volumes with a relatively low energy-expenditure compared to technologies, such a evaporation. This should be considered for technology transfer to the United States, also.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A cooperative initiative on avoiding discharge of LLRW was undertaken under the U.S.-Russian Joint Commission on Economic and Technological Cooperation, with the active and key participation of Norway.

The initiative produced a Joint technical review of a design to upgrade and expand the Murmansk LLRW Facility. The new technical design of the Murmansk Facility is a considerable advance in both capacity and technology over the existing liquid-waste-treatment capability. The upgraded facility will be able to treat all liquid LLRW from the operations in the Baltic icebreaker and decommissioning of Navy fleets.

The Plant has been designed to meet the necessary throughput and Regulatory discharge limits. It is clear that there is design margin in the facility, and that refinements have been developed; these include the adoption of phosphate softening, the use of pleated membrane filters, and the cementation unit. There are provisions for treating multiple waste streams of different initial salinity and organic content.

The international technical review effort and technical interchange have been useful and mutually beneficial.

The facility construction will take about 18 months, and operation will be preceded by training, procedure development, and acceptance testing. A full year of assessment of the operation is deemed necessary to ensure adherence to the discharge limits, which will, therefore, include an enhanced environmental monitoring program.

Opportunities for two-way technology exchange and transfer were identified and will be pursued.

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ACKNOWLEDGMENT

This work was performed under the auspices of the U.S. Environmental Protection Agency under Contract No. DE-AC02-76CH00016.

APPENDIX A
TECHNICAL EVALUATION TEAM AND REPRESENTATIVES
LLRW DESIGN REVIEW MEETINGS

Norway

Mr. Per Kristian Pedersen, Special Advisor, Royal Ministry of Foreign Affairs

Mr. Kare Bryn, Director General, Royal Ministry of Foreign Affairs

Mr. Erik Aakre, Executive Officer, Resource Department, Section for the Environment and Sustainable Development, Royal Norwegian Ministry of Foreign Affairs

Dr. Steinar Høibråten, Senior Scientist, Norwegian Defence Research Establishment

Mr. Finn Ugletveit, Senior Health Physicist, Norwegian Radiation Protection Authority

Mr. Knut Gussgard, Director, Norwegian Radiation Protection Authority

Ms. Anita A. Sorlie, Senior Executive Officer, Norwegian Radiation Protection Authority

Mr. Oddvin Horneland, Advisor, Royal Norwegian Ministry of Defence

Mr. Olav Berstad, Counsellor, Embassy of Norway, Moscow

United States

Mr. Thomas A. Loftus, Ambassador, Embassy of the U.S.A., Oslo

Mr. Robert S. Dyer, Deputy Director, Program Development, U. S. Environmental Protection Agency

Dr. Charles Newstead, U.S. Department of State

Dr. Romney B. Duffey, Senior Advisor, Department of Advanced Technology
Brookhaven National Laboratory

Mr. John B. Mulligan, Consultant , Brookhaven National Laboratory

Dr. Dennis W. Wester, Senior Research Scientist, Chemical Technology Dept., Pacific Northwest Laboratory

Dr. Richard E. Davis, Senior Scientist, Department of Advanced Technology, Brookhaven National Laboratory

Mr. Donald A. Gardner, Project Manager, Raytheon Engineers and Constructors, Inc.

Russia

Mr. Vadim Rozanov, Minister Counsellor, Embassy of the Russian Federation, Oslo

Mr. Anatoly Berkov, Russian Transport Ministry

Mr. Andrey Tumparov, Director, RTP Atomflot

Mr. Stanislav Pichugin, Chief Engineer, RTP Atomflot

Mr. Evgeny Belyakov, Chief of Central Laboratory, RTP Atomflot

Dr. Roman A. Penzin, Executive Director, Association for Advanced Technology

Mr. Vjacheslav V. Rouksha, Vice President and Director of the Atomic Fleet, Murmansk Shipping Company

Mr. Michael Fillipov, Head of Radiation Security, Murmansk Shipping Company

Mr. Vladimir Blinov, General Director Assistant, Murmansk Shipping Company

Capt. Nikolai Khvoscinski, Vice President of Arctic Operations, Murmansk Shipping Company

Mr. Alexandr A. Shvedov, Head of Division, Russian Federation Atomic Power Ministry, VNIPIET

APPENDIX B

LOW-LEVEL LIQUID RADIOACTIVE WASTE TREATMENT FACILITY DESCRIPTION OF EXISTING DESIGN

SUMMARY DESCRIPTION

The existing Low-Level Liquid Radioactive Waste (LLRW) treatment facility is owned and operated by Atomflot, a government owned subsidiary of the Murmansk Shipping Company (MSCo). It is housed in parts of two separate buildings at the MSCo shipyard in Murmansk, Russian Federation.

The facility treats waste from five sources: primary coolant which is drained from the primary loops of nuclear icebreakers during refueling, coolant used in spent fuel storage pools, contaminated laundry wastes, water contaminated during decontamination of tools and equipment, and some waste for the Russian Navy's Northern Fleet. The facility has not treated any waste with salinity in excess of 6 g/l. MSCo has agreed to accept higher salinity wastes from the Northern Fleet, but cannot do so until the existing facility is expanded and upgraded.

Three stages of treatment are provided. One stage consists of coagulation and settling, another of mechanical filtration and sorption removal of radionuclides (primarily cesium and strontium), and the final stage is sorption polishing. The influent liquids are accumulated in two large tanks and then processed in batches employing one or more of the three stages, depending on the specific contaminants in the waste stream.

The waste can be sampled after each stage, and recycled through any stage or stages should a batch fail to meet discharge limits.

Figures B-1 and B-2 are the process flow diagrams.

DETAILED DESCRIPTION

Major Equipment

Accumulation Tanks and Enclosure

There are two 100 m³ tanks (Figure B-1, tanks 1 and 2) which accumulate waste from various sources both within the yard and from shipboard tanks. Both are made of a duplex material comprised of 2 to 3 mm of stainless steel (interior surface), bonded to 10 mm of stainless steel. They are mounted side-by-side in a concrete shielding enclosure.

In addition to the influent and effluent waste-stream piping connections to each tank, there are connections to permit adding either an acid or base to adjust the pH, to add cold water for dilution, to supply compressed air for tank sparging, and to vent the tanks. Each tank contains internal sparging piping.

One tank has significant corrosion to the point where it is presently undergoing replacement. A new tank made of stainless steel is being constructed in Atomflot's repair facility. The tanks can be removed and replaced from the top of the enclosure which is fitted with removable concrete covers.

First-stage Sorbent Columns

There are a series of sorbent and mechanical filter columns used in the first-stage of sorption processing. Each column is estimated to be about 10 feet high and 1 foot in diameter. The columns are vertically mounted and arranged in proximity to each other and to the Accumulation Tanks. They are in a shielded enclosure, which is separate from the Accumulation Tanks. Although Figure B-1 shows three columns, there appear to be six to eight columns actually installed. Total volume of each column is 0.5 m³, and each is packed to about 70% of capacity with either sorbent or filter material.

Two different types of sorbents are used, a zeolite and nickel ferrocyanide⁶. The zeolite primarily removes strontium-90, the ferrocyanide removes cesium-137(134). Although nickel ferrocyanide is generally known to be a good sorbent material, it has not been used to any great extent in the United States because without a carrier material, it packs too tightly in a column to be of any practical use. U.S. manufacturers have not developed a process to manufacture useable nickel ferrocyanide; however, the Russians have developed carrier particles (0.2 - 0.8 mm dia.) coated with nickel ferrocyanide (40 mg per 1g of carrier) which have been proven in actual use.

Mechanical filtration is accomplished using columns of quartz sand. The system is designed so that the quartz sand columns can be backflushed to the Settler (see below) which removes the particulate matter in the flush water.

Electrocoagulator/Settler

The Electrocoagulator removes polyvalent metals that would not be absorbed by the nickel ferrocyanide or zeolite columns. It is a relatively small device which, including the power supply, occupies a volume estimated to be about 2' x 3' x 3'. It is located on top of the concrete shield enclosure which houses the Accumulation Tanks.

⁶ The term Nickel Ferrocyanide will be used throughout this text. The compound is actually a proprietary, ternary ferrocyanide compound containing nickel, iron, and another unidentified element. Apparently, this compound has an affinity for the support carrier used to create particles coated with that compound. The result is a practical adsorber utilizing ferrocyanide.

The Electrocoagulator consists of a vessel with a 300 liter-capacity containing a set of identical iron electrodes. There are ten pairs of electrodes: five anodes and five cathodes. The current density at the electrodes is 1.2 amp/dm² and the total electrode surface area is 0.5 - 0.8 m². Polarity of the voltage to the electrodes is switched roughly every half hour, thus reversing a given electrode from a cathode to an anode, and vice versa. This procedure minimizes the deposition of radionuclides on the electrodes.

Under equilibrium conditions, as the waste stream passes through the Electrocoagulator, iron hydroxide (Fe(OH)₃) will be produced at the anode. The polyvalent radionuclides (primarily cerium-144(141), antimony-125(124), cobalt-60(58), ruthenium-106(103), europium- 154(152), manganese-54, and niobium-95) will coprecipitate with the iron hydroxide in the Settler. When the Fe(OH)₃ concentration approaches 30-50 mg/l, about 85% of the polyvalents will precipitate and be removed in the Settler.

Since settling technology is fairly straight-forward, no detailed information on the settlers was obtained.

Intermediate Tanks

These are two carbon-steel tanks (Figure B-2, tanks B2 and B3) each with a capacity of 10 m³. They are used as third-stage batch processing tanks for waste streams which have completed processing through the first two stages (First-stage Sorbent Columns, and/or Electrocoagulator/Settler). These tanks are located in a second building (separate from the building housing the Accumulation Tanks) which houses the Final-stage Polishing Columns and the Discharge Tank.

Final-stage Polishing Columns

The Final-stage Polishing Columns are those shown in Figure B-2. These columns are physically similar to the First-stage Sorbent Columns. Ten columns shown on this diagram; however, during a tour of the facility, it was found that only nine are actually installed. Also, many of them are not used. This was once an experimental facility where various combinations of many different sorbents were tried. Now, only nickel ferrocyanide and zeolite are required for laundry waste processing and for final-stage polishing of the other waters.

Discharge Tank

This is a 250 m³ stainless steel tank which is used as a holding tank for fully processed waste before to sampling and discharge. Wastewater is discharged from this tank to the Kola bay by way of the industrial waters treatment plant. The latter is not considered to be part of the LLRW treatment facility and will not be discussed further.

Process Flow

Waste Streams

The waste streams presently being treated at the existing facility are those identified in Section 3.1 as "Low-salt Waters", "Decontamination Water", and "Laundry Waters".

Low-salt Waters constitute primary coolant and spent fuel pool coolant from icebreakers. They are both relatively free of contaminants, other than radionuclides.

Decontamination Water is contaminated water from decontamination of tools and equipment at Atomflot's repair facility. In addition to radionuclides, it contains the residues of various cleaning compounds, such as EDTA and detergents and other compounds normally found on tools and machines, such as petroleum products.

Laundry waste is wastewater from the cleaning and decontamination of clothing at the on-site laundry. This wastewater is contaminated primarily with radionuclides and detergents.

Presently, the facility is receiving and processing about 100 m³ per month. Section 3.1, Tables 3.1-1 and 3.1-2 provide detailed information on the waste constituents of these waters. The volumes noted in Table 3.1-2 are projections for the new facility and do not necessarily apply to present operations.

Waste Acceptance

Wastewater to be treated in the LLRW treatment facility is first introduced into the system by way of Accumulation Tanks 1 and 2. These tanks are hard-piped to two tanker-discharge points located on the waste tanker docking pier and to Atomflot's equipment and tool decontamination facility. Wastewater can be put into either tank; however, the water is sampled before being pumped to a tank and, if possible, it is put into the tank containing that wastewater which is most similar in its concentrations of hazardous and radiological waste.

It is generally desirable to have the pH of the water to be processed in the range of 9-10, at which the removal processes are most efficient. Before processing the wastewater, a sample is taken from the Accumulation Tanks. Typically the incoming waters are neutral to slightly basic so it is rare that an acid must be added; rather, typically, a base (ammonium hydroxide) is added to boost the pH. If necessary, after adding of the acid or base, the tank may be sparged to thoroughly mix the added chemicals with the wastewater.

Since laundry waste usually requires processing only through the final-stage of polishing and often requires no treatment at all, it is introduced into the system by way of tank B2.

Decontamination Waters Processing

As noted above, Decontamination Waters contain primarily cesium and strontium but little of the polyvalent radionuclides found in the Low-salt Waters. Therefore, it does not require processing through the Electrocoagulator; rather, it is processed only through the First-stage Sorbent Columns and the Final-stage Polishing Columns.

Decontamination Water, having been pumped into either Accumulation Tank, is first processed through the First-stage Sorbent Columns. The system is aligned so that flow first passes through the zeolite bed to remove strontium, then through the nickel ferrocyanide column to remove cesium, and, finally, through the quartz-sand bed to remove any particulate materials greater than 50m. The water is then returned to the selected tank. Recirculation continues and the wastewater is sampled periodically until the gross activity ranges from 10^{-6} to 10^{-8} Ci/l. Recirculation is then stopped and the wastewater is moved to either tank B2 or B3 in 10 m³ batches for processing through the Final Polishing-stage Columns. Typically, a 100 m³ batch will require about 24 hours before it can be sent on to the final polishing stage.

In the final polishing stage, the wastewater is circulated continuously through one zeolite and one nickel ferrocyanide column until the gross activity level falls to 10^{-10} Ci/l and the levels for individual radionuclides are below Russian Federation Standards. It is then pumped to the Discharge Tank. These columns are in either of the two lower banks of three columns shown in Figure B-2. The third column in each bank is held in reserve. This process is repeated in 10 m³ batches until the Decontamination Waters in the Accumulation Tank are completely processed. The clean water in the Discharge Tank is held until it is convenient to discharge. The Chief of the Central Laboratory and the Supervisor of the LLRW Facility and an official of the local (Oblast) government must approve any discharge. Water is not discharged directly to the Kola bay. Rather, to further dilute the wastewater, it is first pumped to the industrial waters treatment plant where it is processed with other wastewater, and then discharged with these waters.

Low-salt Waters Processing

Section 3.1, Table 3.1-2 shows that the wastewaters classified by Atomflot as "Low-salt Waters" have radionuclide contamination dominated by polyvalent radionuclides; ninety percent of the activity in these waters is from these species. Removing polyvalent elements in sorbent columns is not an efficient process; therefore, Low-salt Waters must first be treated in the Electrocoagulator/Settler.

The low-salt wastewater is first pumped into Accumulation Tank 1. If necessary, the pH is adjusted to the range of 9-10. The system is aligned to circulate the waste from tank 1 through the Electrocoagulator/Settler. Tank 2 is bypassed by closing the tank inlet isolation valve (added to Figure B-1 based on discussions with the Atomflot technical staff) and opening valve No. 33. Thus, decant flow from the Settler is returned to tank 1. With the Electrocoagulator energized, the coagulant iron hydroxide is generated at the anode. Within about one hour, the concentration of coagulant reaches 30-50 mg/l which is within the desired operating range.

Once in the operating range, the system is realigned to direct Settler decant flow to tank 2. At this point, 85% of the polyvalent radionuclides precipitate in the Settler, along with the coagulating agent. Settler bottoms are being transferred continuously to a small tank for ultimate disposal.

The radionuclides in the processed wastewater going to tank 2 are primarily cesium and strontium (similar to the unprocessed Decontamination Water). Thus, of this "low-salt" wastewater is completely processed by circulation through the First-stage Sorbent Columns and the Final-stage Polishing Columns in the same manner described above for Decontamination Water.

Laundry Waste Processing

Laundry waste is pumped into tank B2, shown on Figure B-2, and sampled before processing. About ninety percent of the unprocessed laundry waste will meet discharge standards and can be pumped directly to the Discharge Tank. The other ten percent is circulated from tank B2 through the four sorbent columns shown at the top of Figure B-2. This wastewater is sampled periodically during circulation and processing is stopped once the water meets discharge standards. It is then pumped to the Discharge Tank to await discharge through the industrial waters treatment plant.

Waste Storage

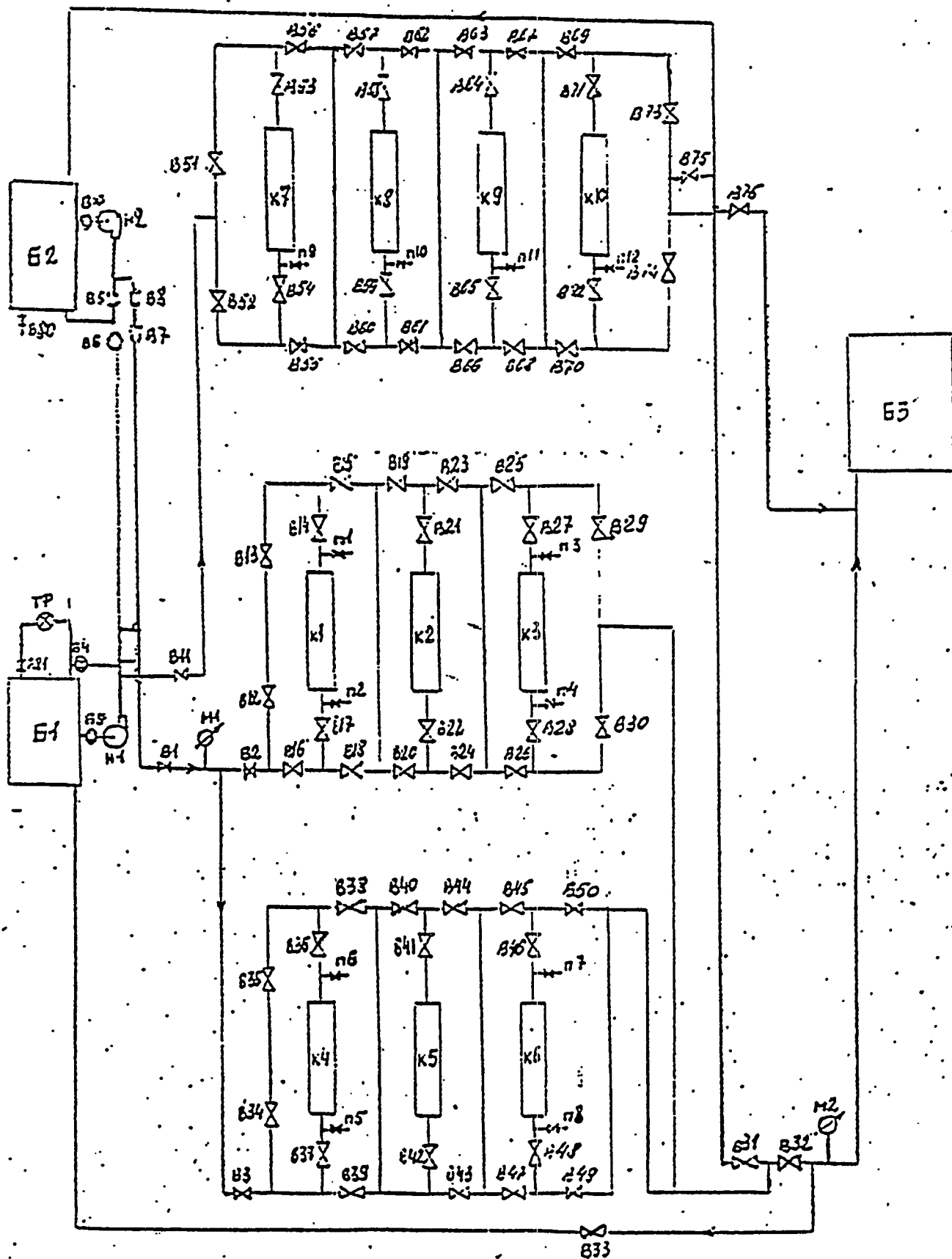
The waste from the processes described above include spent sorbents (radioactive nickel ferrocyanide and zeolite) and quartz sand, and settler bottoms (iron hydroxide, polyvalent radionuclides and particulate from backflushing the sand columns). There are presently no processes to immobilize these wastes, although a cementation facility is planned.

Sorbents and sand are slurried out of the columns into cylindrical containers which have roughly the volume of one column. Then, the inlet and vent piping on the container are sealed and the cylinders are stored in the waste storage building on site.

For other wastes, Atomflot uses both concrete and metal containers with a capacity of about one cubic meter (standard containers). They have some non-standard size containers of similar construction also. The stackable metal containers are double-walled with a pellet-type shielding material between the walls.

All wastes are stored in the on-site temporary waste storage building, which also houses the solid waste incinerator and has some storage for solid waste. The technical team was not afforded the opportunity to tour this facility and little information on floor space, arrangement was made available.

Figure B-2. Existing LLRW System - Second-Stage Flow Diagram



APPENDIX C

TECHNICAL REVIEW "QUESTIONS AND ANSWERS"

Technical Review

Questions and Answers About the Design of the Low-Level Liquid Radioactive Waste Treatment Facility Rev 4-December 1995

Introduction

To illustrate the type and extent of the review, this is the written part of the technical dialog, consisting of Questions submitted by the Technical Team (numbered and ordered by System and Unit) and the written Answers (shown in italics) received from ASPECT. Although somewhat formal, the exchange actually was quite frank and open. A few verbal additions are also recorded in the text; some minor errors in translation remain to show the flavor of the exchange.

A. General System

1. A goal stated in the document "Technical Assignments to the Installation of Modernized Liquid Radioactive Wastes Processing Technology at the Repair Plant "Atomflot" (Stage 1.1 of the Contract No. 11/94 Implementing) is that the plant will meet all of its processing requirements operating 24 hours per day, 5 days per week.

It does not seem likely that the present design can meet the stated goal for the reasons described below.

The report on Unit 6, pages 8, 9 and 10 gives calculations of the processing time for this unit. No other reports calculate processing time. This would lead one to believe that the Electromembrane units are the limiting time-constraint, and that all processing can be done in 4595 hrs./yr. However, this does not seem to be the case. For solution 2, the Electrodestructor unit is time-limiting at about 3190 hr./yr. ($2550\text{m}^3 / .8\text{m}^3 / \text{hr.}$). For solution 3 the Electromembrane unit is time-limiting at about 3220 hr./yr. (see Unit 6 report). Since both solutions use much of the same equipment, parallel processing is not possible; thus, the total processing time for the two solutions is the sum, or 6410 hr./yr. which exceeds the goal of 6240 hr./yr. at 100 % equipment availability

If you account for time for sorbent changes, ion-exchanger regeneration, equipment failures, waiting to get discharge approval when the discharge tank is full, equipment breakdowns and the like, the availability is probably no better than 80%, or about 7000 hours a year. This means that there is very little margin in the time to process all of the liquid, even operating 7 days a week, 24 hours a day.

If you do not agree with the above analysis, please provide a time analysis that shows that the goal can be met. This analysis should include a detailed estimate of the number of hours the system is expected to be down for maintenance and repair, and estimates of processing time for

each piece of equipment.

If you agree with the above please tell us what design changes you will make in order to meet the goal.

A (ASPECT)

A.1. Electrodestruction Unit (Unit 2) is completely equipped with unique technological apparatus not used in other units. It follows from the installation block-diagram that solution 2 is fed to the Unit 6 through the line of Units 2,3,4 and 5, specifically that the processing time at the Unit 2 amounts to 1594 hours under capacity of 2×0.8 cubm/h.

It is this criterion (dynamic ion change capacity, DCC, $K \ll$) that was used to calculate its annual consumption of all sorbents used for decontamination of Solutions 1. DCC of modified $K \ll$ (of sorbent brand of "Selecs-KM") for the ammonium ions amounts to 0.8 mg-equiv./g. Dynamic mode of use assumed for "Selecs- KM" sorbents assists in almost complete extraction of ammonium ions.

At the same time, we shall show below in the answer to page (b), that upon the transition into ammonium- type species $Df K \ll$ for cesium dramatically drops and has a value close to 10.

Specifically this value was assumed under calculation of cesium content in filtrate between the points 13 and 15.

Thus, design loading of the main technological equipment is more than enough to ensure the expected repair and maintenance or emergency works. Given all that, it does not seem expedient to produce detailed time calculation for each item of equipment.

Verbal Addition:

There are two electro-destructor units. Each one processes 0.8 cm/hr. Thus the limiting stream is 4595 hr/yr. in the electro-membrane units. ASPECT indicates there are about 105 days/year set aside for maintenance. The system can be easily restarted. This gives about a 30% maintenance reserve compared to a requirement of 25% per year.

2. A convention used in the United States on flow diagrams is to indicate whether a valve is normally open or normally closed. It makes these diagrams much more understandable. It would be very helpful if we could get copies of all the flow diagrams marked up in this manner.

A(ASPECT)

A.2. All cut-off devices on technological mains are used normally shut.

Verbal Addition:

A manual markup of the flow diagrams will be made this week to provide valve position for each diagram for a typical operational case.

3. There are many inconsistencies between the numbering of equipment on the various flow diagrams provided and the numbering of equipment on the various equipment arrangement drawings provided. For example, the equipment numbering on the Unit 1 flow diagram is totally different than that on the arrangement drawing provided in the report on task N7. Please provide us with a set of consistently numbered drawings.

A(ASPECT)

A.3 We quite agree that the material delivered to you had a number of flaws (repeated denomination of one and the same equipment pieces etc.)

At present we are engaged in systematizing all design plans and specifications (enumeration and standards on equipment, modules and single units). the job is rather cumbersome and takes some time. Hopefully, we shall finish it by early December and send a report to you.

Verbal Addition:

The list provided in Oslo corresponds to the drawings.

4. We understand the reasoning behind the mixed solution mass balance as you discussed it in your letter of October 10, 1995; however, we still have a problem with a single mass balance since there is different equipment involved in the two separate trains. If at all possible we would still like to have mass balances for the Solutions 1 and 2 separately.

A(ASPECT)

A.4 The meaning of your question is not clear enough.

***Please, give us the precise explanation what do you mean by mass balances of solutions I and II. Mass balances for Solution I was provided earlier (see report on the Unit 9). It will be possible to make out the separate mass balances for Units 1-5 and 6. Mass balances for Unit 7 will be identical to one sent earlier, because of the output of the electromembrane desalination unit solutions are expected to have practically similar project characteristics.*

***Please, let us know if it is enough for you to have this kind of answer. if so, we will send you these mass balances.*

Verbal Addition:

The data presented in Oslo by the US as graphs needs to be cross-checked by the Russians, as certain data points are anomalous. Also, why are the curves for streams 2 and 3 so similar?

ASPECT will follow up. ASPECT indicates that the two streams have similar chemical characteristics. Sr-90 is considered the most restrictive isotope and the current system meets the criteria by an order of magnitude. When asked if this could be looked at as design margin, with the possibility of reducing operating units accordingly, ASPECT was not interested in reducing design capability because their Regulatory environment is unstable.

5. It appears to us that the tritium activity has not been included in the mass balance for Unit 9 since 'Other Activity' is below 10^{-10} Ci/l at position 17 on the mass balance. If tritium had been included it would have been at 10^{-3} to 10^{-4} Ci/l. Is this correct?

A(ASPECT)

A.5 You are in the right. We detailed it in F.14

B. Unit 1

1. Unit 1 appears to present a difficult control problem. Please provide an explanation of the control scheme. As a minimum, this explanation should answer the following questions:

a) Over what range can the NaOH concentration and flow rate at the inlet to the settlers vary and still provide an acceptable precipitation rate in the settlers?

A(ASPECT) NaOH solution produced from electromembrane apparatus decomposition has fixed concentration of 100g/l

Flowrate to the settlers is 1.1 cubm/h

Verbal Addition:

The response indicates that the concentration is fixed. It appears that control of this unit will be difficult. There are at least five different parameters that can change the concentration. It is extremely important that ASPECT indicate how the parameters affect concentration and how concentration will be controlled. ASPECT said they will send a response in writing in the near term, but requests that the US provide another set of questions formally.

b) Which operating parameters and which equipment will be used to control the "dosing" operation from gauge box 18?

A(ASPECT) Supply of alkali solution to the settlers would go non-forcibly, by itself, from the metering tank, pos.18.

Alkali rate flow, designed and calculated from the findings of initial LRW chemical analysis, would be fixed by the valve according to rotameter.

c) What is the normal operating range for NaOH production (concentration and flow) from the electromembrane Unit (16)?

A(ASPECT) Alkali solution concentration is 100g/l, electrodialysis apparatus of decomposition throughput, pos.16- 30..60 l/h.

d) There appear to be at least 5 operating parameters which could affect production of NaOH in the electromembrane unit (16). These five are NaCl concentration and flow from tank 8, HCl concentration and flow from tank 6, NaOH concentration and flow from tank 7, electrode voltage, and fluid temperatures. Which parameters are significant with regard to the control scheme? Which of these operating parameters and which equipment will be used to control NaOH production within the desired range?

A(ASPECT) In aim to keep NaOH production at preset levels, the mode of supporting operating current at the fixed level (apparatus, pos. 16) is assumed

e) Please provide a mass balance for the NaOH production unit.

A(ASPECT)

Fig 1(attached new figure) shows the hourly mass balance of decomposition apparatus, pos.16

f) How will fluid levels in tanks 2 through 8 be controlled?

A)ASPECT) Tanks, pos.2-8, are equipped with level indicators for visual monitoring. More, automatization system is designed to measure the level and to distribute signals when the upper or the bottom level has been reached.

g) What is the purpose of the water main connections to tanks 5, 6 and 7? Will water from the main be used to adjust NaCl, NaOH and HCl concentrations during operations? If so, what parameters and equipment will be used to control these concentrations?

A(ASPECT) Supply of running (distilled) water into tanks, pos.5,6,7 is intended to make acid, alkali and salt solutions.

h) Describe how the unit will be started up and adjusted to its normal operating point.

A(ASPECT) To start the Unit, working solutions of acid, alkali and salt are prepared and the tanks, pos.6,7,8 are being filled.

Pumps, pos.13,14,15 are activated. Solutions start circulating through the apparatus, pos.16. Then, voltage is applied on the apparatus and the operating current goes up. Alkali and acid produced with apparatus pos.16, are collected in tanks, pos.3,4. Metering tanks, pos.18,19 are filled. Initial LRW are fed to the settler, alkali solution goes there as well.

i) Is the addition of NaCl to tank 5 automatic or manual? If it is automatic, which parameters and equipment will be used to control the addition? If it is manual, how will the operator know when to make an addition and how often and how much will he have to add?

A(ASPECT)

Adding salt solution into tank, pos.5, is going on without interruption during the operation of decomposition apparatus, pos.16

j) Which operating parameters and which equipment will be used to control the "dosing" operation from gauge boxes 19 and 20?

A(ASPECT)

The alkali dosage from the tank, pos.19, is controlled by indications of pH-meter, located on the pressure pipe-line of the pumps, pos.9. For dosage from the metering tank, pos.20, see the answer in point (k)

k) How will flow to the settlers from Unit 2 (see 5 below) be controlled?

A(ASPECT)

The procedure of pulp removal is to be set in the time of startup works.

l) Section 2.2 (Page 5) of the Unit 1&2 report states that "cations of hardness in the settlers will be periodically removed from the bottom as sludge". How will the sludge be removed, manually or automatically? If it is automatic which parameters and equipment will be used to control sludge removal? If it is manual, how will the operator know when to remove the sludge and how often will he have to do so?

A(ASPECT) Slime is to be removed from slime condenser mechanically on the regular basis. the procedure of slime removal is to be set in the time of commission.

m) Inevitably there will be some temporary mismatches between NaOH demand at gauge box 18 and the output of the electromembrane unit (16). Is tank 3 of sufficient size to handle those mismatches? Will oversupply from the electromembrane unit be accommodated by dumping to tank 7? Will under supply be accommodated by reducing the feed from Unit 2? If so which parameters and which equipment will be used to control the under supply situation?

A(ASPECT)

The tank, pos.3 is big enough to take excess of alkali. Once the tank is full and the alkali supply stops, decomposition apparatus will cut off.

2. What is the projected need (the annual volume produced at the concentration shown in the mass balance requested in 1.e) above) for the HCl to be used for pH adjustment or other uses? If HCl production significantly exceeds the need, what does Atomflot intend to do with the excess?

A(ASPECT) Estimated need in HCl is shown in the mass balance, point 1-e.

The excess of acid could be used for filter regeneration. That will be shown below.

Verbal Addition:

ASPECT clarified that excess acid will be used for filter regeneration.

3. The only connection from gauge tank 19 is to the pipe to Unit 3. Will this be the only point of HCl injection for pH adjustment? Is the HCl production rate less than or equal to pH adjustment needs? If not, it would seem that a storage tank is required to collect the excess HCl. Is such a storage tank provided?

A(ASPECT) The excess of acid is collected in to tank, pos.4, and periodically pumped out, pos.11, into collectors, provided for in the module of filter regeneration.

4. How does thickener 21 operate? If it uses a dewatering operation there should be a water discharge line from the thickener. Is the arrowhead on the line connecting the thickener to the settler 1-2 pointing in the wrong direction?

A(ASPECT) Water outlet from slime condenser, pos.21, is made into the settler, pos.1,2 (the arrowhead on the scheme is put down wrong)

5. On the flow diagram (965817- , sheet 2) the incoming line to Unit 1 is marked from "From Block 3". Is this correct? Other flow diagrams indicate that inlet flow to Unit 1 is from Unit 2.

A.(ASPECT) point 5. there is incorrectness on the drawing 965817- ,page2. One should read "solutions from Unit 2"

6. Section 1 of the Unit 1&2 report refers to solutions I and II being mixed with sea water. We do not understand this statement. We were told there are only three types of solutions that were to be treated. This is a change from what we have been told in the past. Please explain.

A(ASPECT)Explanation on Solution III Origin

We mean that solutions III come only in the Russian navy. Very often they appear in urgent cases (beside the extraordinary, accidental situations), when normal solutions of I and II type are diluted by sea water to lower the activity beyond $10E-5$ Ci/l. The Navy specialized TNT-8 or TNT-12 tankers cannot ship solutions with activity exceeding $10E-5$ Ci/l. Therefore, as the rule, the solution of composition III is formed in an emergency case, when LRW of composition I and II- the ones with strictly determined chemical composition- get mixed with sea water.

As the result, the Murmansk plant will process only these three types of solutions:I, II and III. Still, we are as sure as ever, that in the future, it would be wise to develop special integrated systems which exclude the possibility of solution III being generated in the Navy at all. We consider this approach be the cardinal solution to the problem of species III processing.

In this case, one can attain quite a tangible reduction (~2-fold) of solid radioactive waste to be buried. Really, the present situation is a paradox: more than one half of salts to be solidified are constituents of sea water.

7. We reiterate our previous request (letter from J. B. Mulligan to R. Penzin dated October 4, 1995) for a more detailed explanation of the operation of the electromembrane softening unit.

A(ASPECT) The answer is our fax on Oct 27, 1995

8. The General Arrangement drawing for Unit 1 and 2 equipment (965817-) appears to be a separate building but the title of the drawing indicates it is in the Repair Technological Building (RTB). Please clarify this point. If it is in the RTB, please show where it is in relation to other LLRW system equipment.

A(ASPECT) All equipment of modules 1 and 2 is at the RTE now. The layout of modules is given in plan (look at Task 7, appendix 4, pp 25-26)

9. We understand the Table on Page 5 of the Unit 1&2 report to say that the maximum settler flow rate is 1 m³/hr. Is this correct? If so, why is pump 9 so large (8 m³/hr)?

A(ASPECT) The pump, pos.9, is intended to have capacity of 8 cubm/h because that is the standard for titanium pumps of commercial use in RF. The needed flow rate is set with the valve.

10. Do the settlers normally operate in parallel or in series?

A(ASPECT) The settlers, pos 1-1, 1-2 can work as in a row, so as in parallel. Optimized mode for different initial LRW is to be picked up in the time of commissioning.

Verbal Addition:

The settlers can work in series or in parallel. This decision will not be made until the time of commissioning.

11. The Unit 1&2 report, page 4 near the bottom states "the hardness of real LRW under treatment dropped from 32 mg- eq./l to 0.1 mg- eq./l in the case of sea water containing no LRW. Thus, the softening factor was of two order magnitude (from 5 mg.-eq./l to .3 mg.-eq./l)." Could you please explain this statement since it does not seem to be either consistent or mathematically correct?

A(ASPECT) The softening effect of sea water without LRW was found to be more than two order value (from 55 mg-equiv/l down to 0.3 mg-equiv/l). These differences, as compared to type III LRW are due to the presence of Trilone B complexons in the latter.

Supplemental Questions regarding Questions B.1 a) through B.1 m) and B.7
(transmitted 12/18/95)

The answers given to several of the sub-questions of question B.1 were not sufficiently detailed to allow the technical team to understand the operation of Unit 1. Also, the technical team had difficulty understanding the basic principles of operation of the electromembrane Unit described in the ASPECT fax of October 27, 1995. Therefore, the Technical Team requests the classifications noted below:

S1 Regarding Aspect's fax of 10/27/95 -Section entitled "Some technological aspects of saline solution decomposition by electrodialysis"

-are the membranes mislabeled in Figure 1? Shouldn't "K" be "A" and "A" be "K" ?

A (ASPECT) we agree that membrane notation on the figure in question is incorrect but we have already informed you about it and sent you revised copy figure.

-what is the meaning of the symbol O_3 ? Shouldn't it be OH^- ?

A (ASPECT) concerning the symbol, some theoretical publications state that apart from OH^- ions, O_3 ions could be generated. In general, that does not matter much because later ion recombination processes will follow in the solutions. Actually, OH^- ions are to be produced as the final stable species in the solution.

-Figure 1 appears to show four chambers; yet it is identified as a three-chambered cell. Are we misinterpreting the diagram ? Please explain.

A(ASPECT) this figure shows membrane assemblage with multiplied electrodialysis cells consisting from two compartments, the fact that has been stressed in process description.

-Figure 1 appears to show only three solutions (concentrated NaOH and HCl and NaCl working solution) passing through the electromembrane device; yet drawing 965-817-OP shows five solutions passing through Unit 16. Please explain how Figure 1 corresponds to drawing 965-817-OP. In particular, if drawing 965-817-OP is correct, please revise Figure 1 to show all five solutions. Also, please provide a thorough discussion of the basic principles of operation of the unit which is consistent with the new diagram.

A (ASPECT) Figure 1 above explains how the electrodialysis unit works as part of the Unit 6. Actually, fig.1 for the Unit 1 shows 3 prime solutions, circulating through the electrodialysis Unit for decomposition and these solutions are determinants for the mass balance of the Unit. apart from these supporting streams contributing to the unit efficiency are shown on the drawing 965-8177-OP.

S2 ASPECT's answer to question B.1 a) gives the concentration at the outlet of device #16. However, our question asked for the range over which NaOH could vary and still get an acceptable precipitation rate in the settlers. Please provide this range.

A (ASPECT) NaOH concentration value is not essential, because the finality of precipitation depends on stoichiometric ratio of precipitated product and added reagent, the optimal concentration is 90-100 g/l, as was stated earlier.

S3 Questions B.1 c) and d)- ASPECT's answers to these questions seem to indicate that the electromembrane unit can be controlled in a very small range around 100 g/l and that flow will vary from 30 and 60 l/h. however, ASPECT provides no discussion about how this level of control is to be achieved. Please explain what operating parameters affect NaOH concentration and flow rate at the outlet of the unit, and explain how these parameters will be measured, what control signals will be generated from these measurements, and what equipment will be controlled with these control signals. Also, please relate your discussion to the basic principles of operation given in response to Supplemental question 1. above.

A (ASPECT) Concentration of NaOH solution produced is determined mostly by membrane quality and operating current, the latter is the very technological determinant allowing to vary in NaOH concentration. Given the actual range of NaCl concentration (200-260 g/l) with operating current being constant, NaOH concentration is expected to be optimal (90-100 g/l). No other control factors are intended.

S4 Please indicate specifically what equipment will be controlled by each tank-level signal from each tank.

*A ******

S5 Questions B.1 i) We don't understand how NaCl can be added continuously at a constant rate. It would seem that it should be controlled to match the demand for NaOH. Please explain how NaCl flow is controlled in response to changes in demand for NaOH.

A(ASPECT) As shown above, the operation of the electrodialysis decomposition unit (pos. 16) is based on destruction of the salt solution (200-260 g/l) pumped through the unit from the tank 8 on its way through the heat exchanger (pos.17-3).

The compensation of NaCl deficiency out from decomposition in the apparatus is going through the steady refill with "fresh" NaCl solution from the measuring vessel (pos. 20); solution quantities are controlled by rotameter in line with operational mode.

S6 We do not understand ASPECT's answer to question B.1j)- it refers to the alkali dosage from tank 19 yet tank 19 contains the acid HCl. Also, in response to our question regarding tank 20 ASPECT refers us to point k; however, we see no relationship between the answer given in point

k and our question. Please provide an answer to our question regarding tank 20.

A (ASPECT) Here is the error of translation: measuring tank 19 is used for acid dosing. The dosing of NaCl from the measuring tank 20 has been described above.

S7 ASPECT's answer to B.1m) indicates that when tank 3 is full the decomposition apparatus is cut off. It would appear that other equipment needs to be shut off also (e.g. pumps 12,13 14 and 15). Please explain what equipment will need to be shut down or valves shut and what parameters will be used to control this equipment.

A (ASPECT) Automation scheme secures synchronized operating mode of pumps and valves: once the unit powered, pumps (pos.13-15) would respond then simultaneously valves (pos.9-11) would go open. The stoppage begins with valves cut off whereafter the pumps go down.

C. Unit 2

1. If the Electrodestructor capacity is only .8 - 1 m³/hr why is pump 24 so large (8 m³/hr)?

A(ASPECT) The answer is similar to that of point B.9

2. What gasses are produced in the degasser and how are they handled? Is the vent system active or passive? Since the vent system is a safety system for hazardous gas removal will vent system failure be alarmed? Will it be interlocked to halt processing?

A(ASPECT) Chlorine and hydrogen evolving from the degassing apparatus are to be dumped in atmosphere via exhaust ventilation system. Working floors are equipped with sensors and alarming devices.

3. In the Unit 1&2 report, near the middle of page 9 it states that " the equipment of the Electrochemical destruction module is technologically related to the settlers of the electric membrane module for desalination ...".

The electric membrane module for desalination is in Unit 6 and has no settlers; so, we do not understand this statement? Could you please clarify this point indicating how they are related. Also, what material is the settler made from (titanium?) and has a corrosion evaluation been done? If, so what is the result of the evaluation?

A(ASPECT) The settlers used in Unit 1 and this settlers would be made from titanium after conclusion of the corrosionist.

4. What causes pulp formation in the Electrodestructor? According to the reactions, only gases

such as CO, CO₂ and N₂ are produced by the Electrodestruction Unit.

A(ASPECT) Pulp in electrodestructor could be generated under effect of electrochemical field on micell generating.

5. In the Unit 1&2 report, page 7, in the equations near the bottom, Chloramine (NH₄Cl) is written as one of the reactants for C. However, the actual reactants are substances containing amine groups, ammonium salts and ammonia. Could you please write the equation using these substances and reactants?

Specifically, the first two equations are oxidations. What reduction reaction(s) occurs? Is H₂ formed? If so, how is it vented?

Also the next three equations are indicative of "destructive processes". However, equation 5 doesn't have "active chlorine" involved. Do these types of reactions take place on the electrodes?

*A(ASPECT) **We do not quite understand the meaning of your question. On given page 7 there was an example of ammonium ion decomposition in that module. properties are rather important for the process.*

Verbal Addition:

Specific equations relating to reactions was sought. ASPECT believes this information was provided in a recent transmittal.

6. On the top of Page 8 of the Unit 1&2 report, what are the units mkm?

A(ASPECT) Unit mkm means 10E-6 m conventionally

7. What is "ORTA"?

A(ASPECT) ORTA denotes an anode made of titanium and coated with ruthenium oxide (trade mark of catalytically active anode)

8. We do not understand the last paragraph of section 3.2 of the Unit 1&2 report. Please explain in more detail.

A(ASPECT) The meaning of the last paragraph in Section 3.2 is as follows. In low alkali solutions the catalytic destruction reactions would run with minimum output of active chlorine surplus.

D. Units 3, 4, 5

1. In the Unit 3, 4, 5 report, in the second paragraph of the Introduction, there are two phrases we had difficulty understanding. The first is "of specially designed filter with flexible there as hold characteristics imbedded directly into cisterns with initial solution". The other is "there is inclosed abridges flow-diagram of initial solutions going - Hirounh to the Unit 6". Would you please clarify or rephrase these statements?

Here is the meaning of the first phrase. As a by-product of chemical reactions in the Units 1 and 2, the sediments (secondary impurities) are being generated. They should be extracted from solutions.

Here is meaning of the second phrase. Responding to corrosion active environment, there should be equipment from titanium.

2. What are the origin and constituents of the "slime" sediment mentioned in the second paragraph of the Unit 3, 4, 5 report?

A(ASPECT) Concerning the origin of "slime" sediments. These sediments appear under conditions when primary solutions of different composition are fed into one and the same tank for a lasting time. As time goes, fine-grain sediments, incorporating actually all radio nuclides (sometimes Cesium 137, as well), are being accumulated at the tank bottom.

3. What is the efficiency of the Polysorb (-TM) oil removal? What is the concentration of oil in the waste water leaving the column containing the Polysorb?

A(ASPECT) The efficiency of oil (non-polar organic) compounds) extraction on POROLAS resin comprises ~99.9 per cent. Its adsorptive capability is 70% by weight. the oil concentration at the exit will not exceed 0.005 mg/l.

4. We do not understand the meaning of overlapping factor number 2 at the top of the second page of the Unit 3, 4, 5 report. Please clarify.

*A(ASPECT) ***Regretfully the meaning of the question is unclear.*

Verbal Addition:

The current response is not formulated well in English. ASPECT will work up a revised response soon.

5. Please provide instrumentation and control diagrams for Units 3, 4, and 5 as you did with for other units.

A(ASPECT)

The Units 3-5 are to be controlled through LRW rate flow and pressure gradient. Measurements are made sporadically so there is no need for control automatization. Tracking of

quality indicators, if necessary, is to be carried out by laboratory tests.

6. Please describe how the sorbent material in the columns will be removed when it is expended for the all of the columns in Unit 3 as well as in other units.

A(ASPECT) The absorbents are removed from the columns by hydraulic means. The operation foresees the removal of the absorbent by a flow of service water. The RTE utilizes just this system of unloading, the operating personnel being well acquainted with it. That is why we had decided to apply this unloading system.

7. Please provide sketches showing the internal structure of the columns. Are all columns of the type used in the existing facility or are some of the newer cartridge type going to be used.

A(ASPECT) According to the customer (the RTE) wish, we had accepted the same type of columns they use nowadays (head-type column with slot drainage) The initially designed cartridge-type columns, unfortunately could not be implemented in the final design.

Verbal Addition:

An amplification to the response is available and will be provided quickly.

8. Is it possible to backwash the sorbents to "clean" the sorbent of loose particulate?

A(ASPECT) The columns are suitable for back-wash of adsorbent. In this case the charge should be some 70% by volume. The operation is a customary one at the RTE.

9. The sulphate masses are not given after stream #3. What are the masses in subsequent streams?

A(ASPECT) The sulphate mass in current 3 will not be altered, comprising the same 680 kg (see Material Balance of modules 1-5)

E. Unit 6

1. Please explain how the unit is started up. In so doing please answer the following questions:

(a) When the unit is shut down will it be flushed and filled with salt-free water? If not what effect will the stagnant salted water have on the membranes and other equipment in the system?

A(ASPECT) All start up[operations at Unit6 are to be done with processed solutions. there is no need to flush the equipment with fresh water, membranes should be kept in ion equilibrium with solutions.

Verbal Addition:

Processed solutions are really process liquids or working liquids.

(b) What will be in each of the tanks when the system is started up? Do the relative salt concentrations in these tanks have any affect on the ability of the system to make good water ($< .02$ g/l salt) when the system is first started? If so, how will the bad water be handled since the diluate side of the cycle is once-through from Tank 3 to Tank 8? Will the bad water be dumped to the drainage tank? Is this drainage tank shown on any of the flow diagrams? Can water, sent to the drainage tank, be recycled back to tank 3 for treatment?

A(ASPECT) At the beginning upon start-up the Unit6 is to run under circulation mode and then, after the intended salt the Stage 2 output has been achieved, the solution starts into the Unit 7.

Verbal Addition:

When in startup mode, a recirculation approach is necessary in order to meet water specification requirements. Drainage tanks are used as discharge collectors in the recirculation mode, but are not shown on the drawings. The fluid is reintroduced into the system via the "Filter Tank", item number 3 on the Flow Diagram.

ASPECT indicates that the Flow Diagram needs to be clearer in this regard and may be modified in the future to reflect the recirculation mode.

2. The following questions all deal with control of Unit 6:

(a) It is assumed that during equilibrium operation the waste water on the diluate side is passing once-through the four dilution units (1-1 through 1-4) but on the brine side it is cycling until the salt concentration reaches the desired level. Then once brine concentration reaches the desired level, the brine in tank 5 is dumped to tank 6. Is this correct?

If our assumption is correct, how is the salt concentration of the diluate at Tank 8 controlled to less than $.02$ g/l. It would seem that diluate flowrate could not be allowed to exceed about $2.7 \text{ m}^3/\text{hr}$ ($2550 \text{ m}^3/958 \text{ hours}$) for Solution 2 or $.5 \text{ m}^3/\text{hr}$ ($1700 \text{ m}^3/3220 \text{ hours}$) for Solution 3 in order to ensure minimum residence time within the dilution units. Is pump speed controlled or is flow throttled. What parameters are used to control flow?

Which parameters and what equipment are used to control the dumping of brine from tank 5 to tank 6. Once the dumping of brine from tank 5 to tank 6 occurs is the brine volume in the dilution unit brine loop restored by adding makeup waste water from the previous sorption unit (4/5) outlet tank? Which parameters and what equipment are used to control this waste water addition to the dilution unit brine loop?

If our assumption is not correct please explain the cycle in detail and explain how it is controlled.

Verbal Addition:

Regarding the diluate loop in question, the process is once through. On the brine side, the operations are cyclical in nature and when the brine reaches the required concentration, it is discharged to Tank 6. When the diluate reaches 10 g/l, it is sent back to the first stage.

(b) We are not sure that we understand the flow path through the Electromembrane dilution unit. Our understanding is as follows. Circulation flow on the diluate side passes through Tank 6 and pump 12 and then through the lines which are shown passing through the right-hand side of the membrane devices (2-1 and 2-2). When the diluate concentration reaches 2g/l, flow is diverted to tank 3 and tank 6 is emptied. On the concentrated brine side there would have to be a slow bleed through the parallel branches shown passing through the left-hand side of the membrane units. The concentrated brine exits through the bottom of the electromembrane units to tank 7.

If our understanding is correct, how is the flow through the concentrated brine flow path controlled? What parameters and equipment will be used to control the diversion of diluate flow to tank 3 and to empty tank 6?

If it is not correct please explain the cycle in detail and how it is controlled.

(c) How will the levels in each of the tanks be controlled? What parameters will be sensed and what equipment will be used to control these levels?

A(ASPECT) (a,b,c) Control and automation system of the Unit has been designed to account for specificities of the process, major of them listed below:

**electrodialysis apparatus are to be run at the fixed speed in the operating chambers. i.e. under the stable flow rate through the apparatus with flow meters;*

** current value through the apparatus is another important parameter, its magnitude for every Stage is to be determined on the basis of start-up results, according to depolarization mode in working chambers;*

**to ensure the projected salt content at the Unit output in response to variable salt content of initial solution, the particle recycling mode is used dictating the part of the output solution to be sent to the input of the Stage 1. So is the way to secure the stability of the hydraulic and electrical modes of operation to simplify the processing;*

**tank levels are under control of the local level locating systems with initial solution refilling periodically the moment level goes down to some intermediate position.*

**drainage of the brine tank is to be done with the similar system but for additional salt content*

control; present value achieved, the brine is pumped to the tank 6, followed by refilling with initial solution.

Verbal Addition:

There will be level sensors for level control. The sensors will either be conductivity or capacitance types.

3. In the communication of 2 August, 1995, from Dr. Penzin to Dr. Mulligan (before Report on Redesign Project of Liquid Radioactive Waste (LRW) Refining Installation at the RTP "Atomflot", Murmansk), the List of Equipment requests delivery from the USA, of an IBM 486 DX2 computer. However, in none of the other documentation is there mention of the need for a 486 computer. Only 286 or 386 computers are mentioned on pages 14 and 15 of the Unit 6 report respectively. Please clarify which computer is being requested and specifically what it will be used for.

A(ASPECT) Coming to the type of computer, in the first instance we meant the PC intended for the automization of the installation as a whole, other instance - the PC for the stand-alone Unit was meant. If the automization system on the basis of programmable controllers and PC is to be accepted, we think it reasonable to use 486 X2 PC for the entire system.

4. On page 5 of the Unit 6 report the specific costs given for pattern 1 are 3000 kwh whereas those for pattern 2 are 49000 kwh. What is the principal factor that makes the difference so large?

A(ASPECT) the difference in question is caused by the value of specific power consumption the table in Appendix 2 for electrodialysis show $10\text{kW}\cdot\text{h}/\text{cubm}$ (close to the peak value, see Point 2) and for evaporation- $185\text{ kW}\cdot\text{h}/\text{cum}$ (assumed to the average value, see Point 3). Even under these conditions, the total power consumption for concentrating one and the same amount of brine (300 cubm) well be at $3000\text{ kW}\cdot\text{h}$ (Scheme 1) and $49500\text{ kW}\cdot\text{h}$ (Scheme 2).

Verbal Addition:

Regarding the physical difference that causes the large power differential between Pattern 1 and 2, Pattern 1 energy is used for anode, cathode and pumps, while Pattern 2 energy is used for evaporators.

5. In part 4, Technological Equipment, of the Unit 6 report the description of the Electrodialysis dilution apparatus (EDMS-3170) makes no mention of the membrane size whereas the description for the Electrodialysis concentration apparatus (EKDSP-3286) gives a membrane size of $460\cdot 740$. It is stated that the same membranes are used, but how do their sizes differ?

A(ASPECT) Apparatus model of EDMS-3170 is membrane-like with near circular configuration and to be made from the job item dimension of $500\cdot 500$

Verbal Addition:

"Circular Configuration" means spiral. EDMS stands for Electro Dializer Membrane Spiral. 500 * 500 means mm.

6. In the description of the Electrodialysis concentration apparatus one of the parameters listed is the width of dilution cells. To what does this refer? How is this related to the working cell height of 1.2 mm for the Electrodialysis dilution apparatus?

A(ASPECT) As stated in the report, electrodialysis device for concentration has no pumped-through brine line. Its double cell consists of the dilution chamber, similar to the chamber in the dilution unit, and of the close-in brine chamber with contacting membranes. Due to the fact, the height of the dilution chamber is only cited.

Verbal Addition:

Regarding the Electro Dialysis apparatus, " width of cell" is the distance between the membranes-for one cell.

7. On page 15 of the Unit 6 report the paragraph that starts "The system of programmed controllers move in by American party seems " is very difficult to understand. Could you please clarify the meaning.

A(ASPECT) This part of the report should be understood as follows. The automization system to be established in RTP is planned to be developed on the basis of Russian automization components, controllers inclusive. Nevertheless, the completing elements for this system (detectors, microprocessors, PCs) are supposed to be supplied with assistance from BNL and Mr. Dyer from USA. This is true not only for the Unit 6 but for the entire installation. we believe it wise to solve the problem along the way of step-by-step designing with cooperation of specialists from both sides.

Verbal Addition:

PCs is meant to be PLCs.

8. The Electromembrane concentrator device (ECD) now includes a "remote stack replacer" which appears to include/require a hydraulic system for final compression of the stack. What experience exists with these components? What is the estimated does rate from the ECD device? Is the remote capability just for ALARA purposes or is it essential in order to replace the stack? If the remote stack replacer fails during a replacement operation how will you complete the operation without high radiation exposure to workers?

A(ASPECT) On the grounds, stated in point E9, we will not use the remote stack replacer albeit it is principally part of initial design. Radiation level in the process of stack replacing is low enough so there is no need special contrivances. That is also the reasonable way to spare extra capital funds.

9. Will the Electromembrane concentrator device membranes degrade from exposure to radioactivity? If so, how long will they be expected to last?

With radiation doses of the solutions processed on the concentrator, no sensitive degradation of membranes has been noted. It should be noted that unit 6 membranes are designed for radiation dose up to 6×10^8 rad without any degradation in their characteristics. These radiation levels are thousands times as much as that of actually assumed in our process.

10. Penzin letter to Mulligan dated 9/22/95, Attachment entitled "General information on Electrodialysis Process" - In Figure 1 it shows the cation Na^+ passing through a membrane labeled A. We assume "A" means anionite. However, at the bottom of page 4 it states that "anionite membranes.... provide passage to anions only". Similarly Figure 1 shows the anion Cl^- passing through a cationite membrane. Please clarify.

Also, what are the reactions at the electrodes? Are Cl_2 , H_2 or OH^- formed? If one or more of these are formed are there provisions to safely vent this gas?

*A(ASPECT) Membrane labeling in fig 1 is incorrect. ***Here is enclosed the revised figure. Electrode reactions run, actually producing reaction products named by you. The actual quantities of these species produced under pre-calculated current densities are to make of solution and to be moved away as dissolved components into tanks. From there gases evolved from the solution are to be removed through ventilation system.*

11. The effluent Ferrum for Stream 7 is not given. Subtracting gives an estimate of .026 Kg. Is this correct? If so it does not match the input for Unit 7 which is given as .226 Kg. Which is the correct value?

A(ASPECT) The current exiting from module 5 (see Material balance of modules 1-5) will contain only 0.226 kg Fe. This value is already below the permissible one, considering both the electrodialysis standards and its standard contents in waste waters. Therefore, any further balance of the elements has no physical sense.

F. Unit 7&9

1. In the Unit 7&9 report, near the middle of page 4, there is a statement "including mechanical filtration with inorganic sorbents selective to the ammonium ions. " Are inorganic sorbents actually used as mechanical filters? If so, which sorbents are these?

A(ASPECT) Kn is used in the Unit 9 as a mechanical filter. Simultaneously, it makes a good sorbent material for ammonium ions. Its exchange capacity is around 0.8 mg-equiv NH_4 /g of sorbent. It is the combination of these Kn features and, in parallel, its ability to filtrate solutions 1 from cesium and partially from strontium that make it superior for our process.

Verbal Addition:
Kn means clinoptilolite.

2. In the Unit 7&9 report near the bottom of page 4, it is stated that the latter unit is considered auxiliary and is used for prolonging service life of the ionites. This apparently refers to the regeneration unit and seems to imply that the regeneration feature might not be used. Will the regeneration unit be used? What will determine if it is used or not?

A(ASPECT) The meaning of the phrase is that the ion exchange decontamination Unit in question (decontamination on ionates and ion exchange resins) is intended to be a by-stand one. It is to be used only under conditions when radio nuclides or chemical impurities concentration goes higher than Ultimately Admissible Concentration (UAC). This is relevant to Units 7 and 9. regeneration modules in these Units are also used as a reserve.

3. In the Unit 7&9 report, on page 5, the paragraph that starts "Besides the units in question will provide water quality" contains the parenthetical phrase (the latter is determined by the oxidability of the filter). This phrase is unclear. What does "the latter" refer and what is "oxidability"? Please clarify these points.

A(ASPECT) (look at F.17)

Verbal Addition:
See response to F-17.

4. In the Unit 7&9 report, on page 6 the term "modified clinoptilolite" is used. How has it been modified and what is the purpose of the modification.

A(ASPECT) Modification of clinoptilolite (CL) proceeds in accordance with the Russian patent by treatment with alkaline solutions followed with calcination. their purpose is to increase the Cl adsorption of metal ions, such as ammonium ions and improve mechanical stability. Both

5. In the Unit 7&9 report, on pages 8 and 11 it states that solutions of 1 N HCl and NaOH are used to regenerate columns. Are these reagents generated by the electrosoftening device? Also, if NaOH and HCl are used, how is a waste of nitric/sulfuric acid generated as stated at the bottom of page 4. We hope that Atomflot is not proposing to use a mix of nitric and sulfuric acid which has caused many explosions in resin columns in the past.

Report of task N7 , Sections 2.16 and 2.2 state that nitric acid is used to regenerate the columns. Please resolve these contradictions.

A(ASPECT) In principle, one can use NaOH and HCl, generated in module 2 for this purpose. It is especially so in regards of HCl, which is generated in excess. The excessive HCl quantity is supposed to be directed for the regeneration of cationites, used not only in modules 7

and 9, but also in other processed of water pre-treatment utilized at the RTE.

Verbal Response:
Answered in F-8.

6. In the Unit 7&9 report on page 14, calculations using the data given show only 178,704 rubles for RTB renovation, 8,760 rubles for TSSL renovation and 9,745 rubles for TSSL shed construction. Could you please show in more detail how you arrived at the figures of 223,000, 10,800 and 14,550 respectively.

A(ASPECT) There should have been some technical misunderstanding. Considering the reconstruction cost of the RTE ATOMFLOT, we would ask you to take as official document only Report on Task 7 (i.5)

Verbal Response:

The cost figures were calculated by two groups- Design Bureau and VNIPIET. The "official numbers" are in the Unit 7/9 report, 223,000, 10,800, and 14,550.

7. In the Unit 7&9 report, in Sections 2.1.6 and 2.1.9, it says that zeolite (CMP) removes salts. Please explain how this occurs. Are both anions and cations removed?

A(ASPECT) Zeolite like CL, removes only cations. Just that was the meaning of the term for the removal of metal salts.

8. Why are separate anion and cation beds used? Why is the cation column made of titanium?

A(ASPECT) By no means will we use mixtures of any acids to regenerate the ionites. For this purpose, the solutions of various acids will be selected on the basis of the conclusion, made by the specialists. Their prime consideration at the stage of contractor design (construction) will be corrosion resistance. Considering i.8 it has to be noted, that in the case of using HNO_3 , and accounting for the stainless steel instability, we propose to use columns of titanium (which are already available at the RTE and did not appear in the cost calculation.

Verbal Addition:

Separate anion/cation resin beds are used because its easier to regenerate separate beds as compared to mixed beds. Titanium is used for corrosion protection as 1 molar HCl is used for cation regeneration.

9. The flow diagram refers to the Sb-18 Type 1 container being used for spent sorbents. It was our understanding that the smaller, more heavily shielded container ($.3 \text{ m}^3$) was to be used for sorbents; however, the Unit 8 report designates the $.3 \text{ m}^3$ container as Type 2. Also in the Report on Task N6, page 8 it is stated that the Type 2 container will be used for sorbents. Further confusing the issue are the statements in Report N7 (pages 11 and 12) that sorbents will be put in

a High Integrity Container (HIC) which will then be put into a Type 2 container. Please clarify this your intent on the matter of containers for sorbents. Also, specifically what must you do to resolve the issue of concrete versus HICs containers?

A(ASPECT) Our project foresees only two types of protective containers with identical external dimensions. The internal dimensions differ in the thickness of concrete. all the dimensions and substantiation of necessary protection are given in report on Module 8. As it is, the smaller one should be used for the absorbent burial (actually, for all solids with activity exceeding 5×10^{-2} Ci/kg). Just that value was used by the specialists calculating necessary thickness of the protection screen. This protective container is used for housing of HIC container (or a similar one) loaded with dewatered adsorbents. there have been no other variants foreseen in the project.

Considering assembly-18, the given "non-standard" method for storing spent adsorbent is used by RTE at the present moment, since the storage room is well adjusted for the assembly-18 size. The design mentions this method as an alternative in case the construction of the temporary container storage is behind the schedule.

Naturally, this solution to the problem is not the best one, since the present storage has been already filled up. To my mind, you had become acquainted with the adsorbent storage system used presently at RTE, so it should not be news to you. Besides, we would like you and your experts be ultimately understandable: we cannot choose between a cement container and HIC-type one. It is against our legislation in management of radioactive waste. we can only combine them. That is, we have chosen the only possible variant of the HIC container utilization viable at the present moment under our conditions.

10. In Appendix 1:

(a) please explain why the resin beds cause a decontamination factor (DF) of 2 for insoluble particulates between points 13 and 15. Shouldn't .1 kg. be accounted for in stream 14.

A(ASPECT) Concerning Mass Balance Unit 9

a) Insoluble particles coming with the Stream 13 are referred to as the secondary impurities i.e. tiny particles size of 15-60 mkm that can result from hydromechanical wear-out of inorganic sorbents. Sorbants YMP and Kn are the granules of irregular shape the different case from H<KA type that is spherically shaped. Part of these mechanical impurities will be sorbed in the columns with organic ionites, the rest of them will be held on the final microfilters. this is also the explanation for the need in microfilter at the end of the line (answer on Point F.16)

Verbal Addition:

H<KA is a typo. It should be the symbol for ferro-cyanide.

(b) the DF for Cs-137 across the clinoptilolite filter (points 1 to 3) is 10. This seems too

low. In contrast, the DF for Cs-137 for the Potassium Ferrocyanide absorber (points 5 to 7) is 1000. Are these DF's correct?

A(ASPECT) The pointed out cleaning coefficient of Cs137 belongs to the solutions where besides cesium, an ammonium ion is present; its ionic radius is proximal to that of cesium. therefore, cleaning coefficient (DF) of cesium in CL under given condition is rather low (~10%). At the same time, ferrocyanide adsorbents (FA) adsorb cesium according to crystalline/chemical mechanism, and their selectivity for cesium is better than that of all other type of adsorbents.

I have mentioned before, the we had been well acquainted with the FA chemistry. In the middle eighties a whole complex of research was carried out on ca. 30 types of inorganic adsorbents. After that, FA had been introduced for LRW treatment at the Navy and for commercial production of cesium at radiochemical plants.

The presence of salt background has about no influence on cesium adsorption by these adsorbents. Therefore, Df~1000 for FA, in comparison with Df=10 for CL, are in fine agreement with the adsorption relationship.

11. In the Unit 7&9 report on page 5, Line 10 says the design throughput of Unit 9 is 9-11.5 m³/hr. yet the pumps are rated at 6 m³/hr and later design descriptions say the flow is 1.3 m³/hr. Which is correct?

*A(ASPECT)**Concerning the projected capacity of Unit 9.*

Verbal Addition:

The correct throughput is 0.9 to 1.15 cm/hr. The 1.3 cited should be 1.1 cm/hr.

12. Please clarify the statement at the bottom of the Unit 7&9 report, page 5, last line which states "Ion exchange resins..... above the Maximum Permissible Concentration" We do not understand the meaning of this statement.

A(ASPECT)To put things right we suggest to replace the opaque term with "ionites"

Verbal Addition: The Maximum Permissible Concentration (MPC), is a term used by the Russian NRB and sets the concentration requirements target. When it appears that the MPC will not be able to be reached, then ion exchange beds are put into service and used to achieve more decontamination.

13. In the Unit 7&9 report, page 6, in section 2.1.3 it appears that the LRW activity should be 2.8×10^{-7} rather than 1.8×10^{-7} .

A(ASPECT) We agree that the LRW activity should be 2.8E-7

14. In the Unit 7&9 report, page 9, section 2.1.19 discusses the dilution of Solution 1 to reduce Tritium concentration to below 10^{-6} Ci/l. The dilution factor to attain to this level must be between 100 and a 1000 overall. If a factor of 10 dilution is available in the aeration tanks a factor of 10 to 100 must be available by mixing with water from the processing of Solutions 2 and 3. Thus, even in the best case where tritium levels are at 10^{-3} Ci/l., 7500 m³ of dilution water must be available from the processing of Solutions 2 and 3. However, only a little over 4000 m³ is available from this source. What will Atomflot do with this water if sufficient dilution water is not available from Solutions 2 and 3? If cementation is the alternative then the interim storage facility will become filled within one year.

A(ASPECT) You are absolutely right pointing out that we have never materially accounted for the activity of tritium. Nevertheless, as you rightly point out in i.14, that the final calculated concentration of tritium in the cleaned solutions should be below 10E-6 Ci/l. Still the following route of you(r) thought considering the dilution is not quite correct.

The RTE removes radio nuclides not only from solutions I-III. The most quantities of LRW relate to another type- effluents from special laundries which were described in the project in detail.

Without going deep into the problem, I can say, that the amount of such solutions considerably exceeds those 7500m³ per year, formally to be diluted.

Verbal Addition:

Both purified water and laundry water can be used to dilute tritium. Laundry water has less than 10^{-9} Ci/l.

15. Why are tank 9-3 and 7-9 required?

16. Why are microfilters 9-13 and 7-14 required?

A(ASPECT) The microfilter 9-13 and 7-14 at the exit serves for trapping the secondary contaminants. They may arise due to hydromechanical destruction of inorganic and carbonaceous adsorbents in the current of the fluids. The technological solution to this is the use of adsorbents Kn and UMN of irregular shape. the H>KA-type adsorbents are spherical grains and can hardly be destroyed hydromechanically.

17. Typically total organic carbon (TOC) constituents of the LRW solution need to be 5 ppb or less in order to achieve proper operation of the filtration units. How is this design requirement to be met?

A(ASPECT) In the Russian practice, different criteria are generally used, but in their

nature they are identical to those mentioned by you. We apply the notion "filtrate oxidizability". The parameter is not considered as State standard on "Water", though in practice it is accepted as concentration 1-3 mg/l. Just this value do we plan to obtain at the exit of modules 7 and 9. There it should be mentioned, that in the report on modules 7 and 9, page 5 we were meaning just that term.

The above modules shall provide additional cleaning of water from organic carbon: that is they reduce "filtrate oxidizability".

Evidently, the meaning of the expression was lost for adequacy of translation.

Projected capacity of Unit 9 is 1, 3 cubm/year. It is identified not only on the basis of the formal flow rate of the columns and pumps capacity but with regard to the column sorption materials used. Given all characteristics, the optimal yield of this Unit can be estimated as 1.3 cubm/h.

Verbal Addition:

US micro filters are only used to process stream 1, which has no TOC. Russian filters of a new design are used for streams 2 and 3. The new Russian filters use a non-organic material which they contend is not susceptible to organic fouling. If this equipment tests out, this may be an appropriate item for technology exchange.

18. The input of oxalates to Unit 7 is given as 18 Kg., whereas the output from Unit 6 appears to be 1.8 Kg. Which is correct?

A(ASPECT) We are sending you the revised table with mass balance figures to the Unit 7. Also enclosed is the corrected mass balance table to the Unit 6.

G. Unit 8

1. What instrumentation is used to determine when the waste/cement container is full?

A(ASPECT) We use radio tracer sensitive elements to determine when the waste/cement container is full.

2. In order to ensure that the cement matrix sets up properly, with no free liquid and no matrix degradation, a Process Control Procedure is required under U.S. practice. The purpose of this procedure is to provide testing of typical waste streams on a bench-scale basis to determine an acceptable range of cement-to-waste ratios and the correct admixture type and quantity. These parameters are then used in waste solidification.

Will such a procedure be utilized at the LLRW facility? Given the difficulty in achieving a dry stable waste form using cement use of such a procedure is highly advisable.

A(ASPECT) There is not free liquid in our original technology mixing and we have no

problem with matrix degradation

Verbal Addition:

The Russians do not plan on cementing resins, but will either use HICs or will store the resins for 2-3 years. The pH will be in the slightly basic range and will not likely be a problem for solidification. Regarding salt waste effects on mixing operations, ASPECT agrees that it could be a problem but their research indicates that the time for mixing is only about 10 seconds and is too fast to allow setup. They have a report that defines the tests performed for solidifying brine waste and will send it.

3. What are the construction materials proposed for the major pieces of equipment?

A(ASPECT) We use 316L steel for pieces equipment which contact with LRW, for all other pieces we use carbon steel.

4. Please provide a much more detailed description of how the cement and wastes are mixed. It appears to be a magnetic process but there is not enough detail for us to review the method.

A(ASPECT) These method and device are patenting now. If you have the professional interest we are ready to give away possible information.

Verbal Addition:

The mixing process uses an external magnetic field to rotate metal balls in the cement-waste mixture. These metal balls are held in the field and do not fall into the container. This is a proprietary and patented process and has been tested for over a year.

5. What experience is there in Russia with in-line mixing such as that proposed for Unit 8? Experience in the U.S. and elsewhere worldwide is poor to the extent that, virtually, it has been abandoned in favor of mixing directly within the waste container. With in-line mixing, the equipment requires a thorough flushing creating a large amount of secondary waste which must then be processed. If the equipment is not thoroughly flushed the unit will jam when it is used again. The latter was a frequent problem with this type equipment.

Has the mixing equipment shown been used successfully elsewhere? If so how much flush water will be required after each operation and how does Atomflot intend to handle this potentially contaminated water?

A(VNIPIET)

**Perhaps water purified from radio nuclides is meant.*

A radio nuclide concentration in the purified water determined by the material balance makes up to $1-3 \times 10^{-10}$ Ci/l which, pursuant to our regulation, corresponds to the permissible concentration in water for category "B" individuals from a limited part of the public. therefore this water can be used (and basically will be used) for proper production needs and partly

discharged into the gulf water area due to the stated quota of the total maximum permissible discharge.

Verbal Addition:

The mixing apparatus is rinsed after use. The water is then filtered/settled and reused in the cement process.

6. Where will the waste containers be stored while the cement/waste mixture sets up. Is the storage area heated? What is the maximum estimated dose rate in the area where the waste containers are temporarily stored while the cement is setting up and how will workers be protected from incidental exposure from these containers.

A:(VNIPIET)

During waste and cement mixing operation the container is in a special tight room and personnel access to this room is impossible. The protective lid is remotely put on the container in the next room of similar type.

Maximum dose on the container surface is up to 10 mrem/h

Containers with the closed lid are moved to the accumulation platform in the same heated building and since the protective lid on the container is closed, a worker seeing the joint has no direct contact with the container contents.

Containers on the accumulation platform are kept for approximately 3 days till the cement mass solidifies.

7. Please identify which operations are done automatically and which are manual?

A:(VNIPIET)

Only operation of sealing the container lid gap is performed manually, the rest operations are performed automatically or remotely.

8. In the unit 8 report, near the bottom of page 5, it is stated that "Attending operator comes to the side of the casket, lid shut, and does encapsulating of the lid." What is the expected total exposure to an operator while performing this operation?

A:(VNIPIET)

This is a mistake, see item 6

H. Report on Task N6 - Radwaste Reprocessing Complex of 5000 cum /year Capacity

1. Throughout the document it seems that all of the radioactivity data is missing the exponent. Please provide a new document with all of the proper exponents filled in.

A:(VNIPIET)

Misprints?

p5 PC- 2E-15Ci/l PC-5E-17 Ci/l

p18 of -2.5E-3 Ci/kg; totally -5 E-3Ci

p20 equals -2E-12 Ci/cum; of -6.7E-7 Ci/cum

2. This report, page 3 references PNAG-01-11-89 (OPB-88) and PBTRB-73). How specifically do these documents affect or classify containers?

A(VNIPIET)

The PNAG-01-11-89 standard states safety guidelines for NPP designs and contains definitions and classifications of systems and system components being designed in view of their impact on radiation safety both in normal operating regimes and accidental situations.

The PBTRB-73 standard states safety rules during transportation of radioactive materials and identifies requirements for packages and containers depending on radiation characteristics of materials contained in them

3. What is the definition of Category "A" and Category "B" persons?

A(VNIPIET)

Class 3H is specified for the container storage system according to PNAG-01-11-89 and means that the storage system refers to normal operating systems important for safety and accordingly, other standards specify, by this classification, specific storage design requirements and consider safety issues but the report version for BNL comprises no list of these standards since they are not helpful for BNL without detail explanations.

Category "A" (by definition of the HPB-76/78 standard) comprises individual or personnel (professional workers) who constantly or temporarily work with sources of ionizing radiation.

Category "B" comprises a limited part of the public which does not work directly with sources of ionizing radiation but by residence condition or location of working places can be affected by radioactive materials that are available at immediate enterprises.

4. Is the Category "A" person permissible dose of 5 rem/year a whole body dose limit?

A(VNIPIET)

A maximum permissible dose of 5 rem/year for category "A" workers is maximum permissible for exposure of the entire body

5. What regulations set the various limits stated on Page 5 and what is their basis?

A(VNIPIET)

The established limits are identified by the HPB-76/78 standard and have a basis of not exceeding a dose limit of 5 rem/year both at normal operation and accidental situations.

6. The permissible contamination of skin surface is 20 part./sqcm*min. How is such a low level of contamination to be measured?

A(VNIPIET)

A KPAB-3 radiometer is used in the airlock to monitor personnel skin to the norm of 20 beta-particles/sqcm.min

7. On page 8 of this report it states "the storage facility is designed to receive containers during 8-10 years of operation with a 1200-1400 cum/yr. throughput of reprocessed liquid radwaste". However, the LLRW Facility upgrade and expansion project is to accommodate 5000 cum/yr. Does this mean the waste storage facility will be full in 2-3 years?

A(VNIPIET)

The storage facility has been designed to accommodate 80-100 containers a year. If up to 20% of radioactive salts are incorporated into the cement mass, then, by our calculation, this figure and storage facility capacity will be kept for 8-10 years.

The production rate of 1200-1400 cum/year on page 8 is determined conditionally with an average salt concentration of 30g/l. And the average salt concentration in the available now solutions is 8.5 g/l

8. On page 11 of this report, what is the term ZPS-1 designate? Also, this page (section 3.3) refers to the "transport and handling flow sheet". However, It does not appear that this flow sheet was provided with the document . Could you please provide this flow sheet?

A(VNIPIET)

The ZPS-1 abbreviation is a mark of the film coating applied for dry decontamination to remove non-fixed radioactive contaminants from surface and it stands for -protective polymeric coating (execution 1)

9. The filtering systems for the different zones are not clearly defined. It is stated on page 13 that zone 2 vented air passes one cleanup stage before discharge above the building roof. Is zone 1 air also filtered? Why is only one filter stage used and not two? Are these HEPA filters?

A(VNIPIET)

There is no air in zone 1 since zone 1 forms the container internal space filled up with radioactive waste.. One air cleanup stage of zone 2 with Kcl=100 is determined in view of aerosol cleanup sufficiency even during an accident. The XXX-15-3 dry filters (t up to 90 C, humidity up to 95%, Kcl=100) filled with Lavsan and Petryanov tissue (not HEPA filters) are used to clean up ventilation air.

10. On page 14, stacking of the containers in the form of a pyramid is mentioned for the first time. When and why would this arrangement be used since it provides much less storage space?

Also on this page is stated that the facility is equipped with a carbon steel pallet. Could you explain what the pallet is and why it is used? What are its dimensions?

A(VNIPIET)

Both the pyramid and the rectangle variants of stacking up were calculated for container stability at seismic impacts and since the latter satisfied calculations it was adopted for further work and only for this reason the pyramid variant is mentioned on page 14. The facility floor is equipped with a carbon steel (not SS) tray over the entire area.

This tray is an additional barrier on the way of radioactive materials penetration into the facility.

Besides, pursuant to our regulations no storage facility construction is allowed on sites having a ground water level of this site is 3.5m. therefore we had to make an additional barrier in the facility to obtain permission for construction.

11. On page 15 it is mentioned that the volumetric aerosol activity in the facility hall and the control room will be monitored. Will it also be monitored in zones 1 and 2 (the volumetric activity in the exhaust ventilation system)?

Also on this page it is stated that the radioactive contamination level (gamma radiation dose rate) on the containers will be monitored. Why is the gamma dose rate monitored but not the beta contamination?

A(VNIPIET)

Yes, the monitoring system will also function in zone 2 and in the ventilation system. The subsystem of item 1 also provides monitoring of beta-radiation on container surfaces.

12. On page 16, Section 6.1 the DBEQ has no units. What scale is used?

A(VNIPIET)

Units on the MSK scale

13. On page 17 what is "a regime of special permit for staff" that is provided to liquidate an accident? Does this refer to some temporary relaxing of the dose limits in emergencies?

A(VNIPIET)

No, this means introduction of limits only for working hours with retaining 5 rem/y dose limit

14. At the bottom of page 18, "the level of territory radioactive contamination can reach 110 part./sq. cm. min." What kind of particles are these? This seems to be a very large number as is the limit of 2000 part./sq. cm. min. given on the following page. Is this correct?

A(VNIPIET)

In case an accidental situation with building collapse described on page 18, contamination of the "Atomfleet" territory on the area up to 1000sqm at the level of 110 beta-part./sqcm.min. The permissible value of territory surface contamination pursuant to our codes makes up 0.1 of the permissible surface contamination for personnel residence rooms which is 2000 beta-part./sqcm.min i.e. this value makes up 200 particles/sqcm.min and these explanations were not available in our report submitted to you.

15. On page 23, should ground water level be minus rather than plus 3.5 m?

A(VNIPIET)

The ground water level is - 3.5 m (this is a misprint)

16. Is closed circuit TV used by the crane operator to observe loading of containers remotely?

A(VNIPIET)

The local TV-network is not used.

17. What method is for determining placement of the containers? Is it indexing on the overhead crane bridge, rails, and trolley, a grid system on the ceiling, or something else?

A(VNIPIET)

A method of reference marks with the use of light sensors across two coordinates is applied for accurate container positioning. One mark is on the facility wall, the other- on the bridge crane.

18. With large arrays of radwaste such as the "massif", "skyshine", or air scattering is a major concern in limiting the dose outside of the storage facility. Monte Carlo computer dose analysis shows roof thicknesses of 7.5 cm to 15 cm are typically required. What analysis of "skyshine" has been done and what were the results?

A(VNIPIET)

The facility "massif" is formed out of concrete shielding containers with a limited radiation level on surface of each container and the gamma radiation level in any point on the "massif" surface due to self-absorption effect will not exceed a radiation level of one container: 10 mrem/h. Taking into account that the roof is at a distance of ~10m from an upper container and roof thickness is 300mm, the Monte- Carlo method was not considered.

19. What is the wall thickness of the facility. What analysis has been done of direct transmission doses through the walls and what are the results?

A(VNIPIET)

The item is missing

20. There appear to be no shield walls for reducing the dose rate in the truck bay. How is the dose

rate in the truck bay to be controlled. Has analysis been done and what does it show?

A(VNIPIET)

Screening walls in the truck bay are actually absent. only a 0.6m high enclosure barrier is provided. The radioactivity level in the truck bay does not exceed the total level in the storage hall. radiation monitoring is performed by a gamma background and aerosol contamination of the air. The driver cab from the body side where the container is placed additionally is shielded with a 50mm thick steel sheet.

Verbal Addition:

If a shield wall is needed to meet GAN dose requirements, then they will add one. GAN has approved the design at this point on a technical basis, but not on a construction basis.

21. In this report on page 9 it is stated that "the handling hall has no space heating". Has the proposed waste form been tested for expected freeze/thaw cycles? This is a requirement in the US. by the Nuclear Regulatory Commission (NRC).

A(VNIPIET)

Tests for freezing and defrosting cycles were conducted with containers by the method used for reinforcing concrete items.

Tests of the cement block with radioactive waste inside the container were not conducted. Freezing and defrosting regimes for the containers were considered when calculating radio nuclide content in the storage room air.

22. The safety evaluation of building flooding assumes waste forms/packages retain their integrity. US. experience indicates that some organic resin/cement waste forms crumble on contact with water . Has appropriate testing been done to demonstrate waste form integrity when submerged in water? This is also an NRC requirement in the US.

A(VNIPIET)

These tests were also not conducted for reasons described in the answer.

I. Report on Task N7 - RAW Reprocessing Complex of 5000 cum/year Capacity

1. Comment H.1 above also applies to this report.

2. On page 12, it is stated that the storage facility can accommodate 900 containers. The diagram is Appendix 3 of the Report on Task N6 clearly shows that 975 containers can be accommodated. Please clarify this point.

3. In the middle of page 14, what are the OTT-87 requirements? On this same page what are

"montejuses"

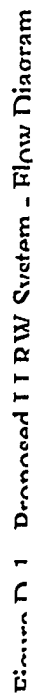
4. On page 18 several Gosstroy decrees (N79, 49) and letters (N 52-D, 14D and a-4-2374-8/1) are mentioned. What significance so these have? Are they legally binding procedures, guidelines or recommendations?

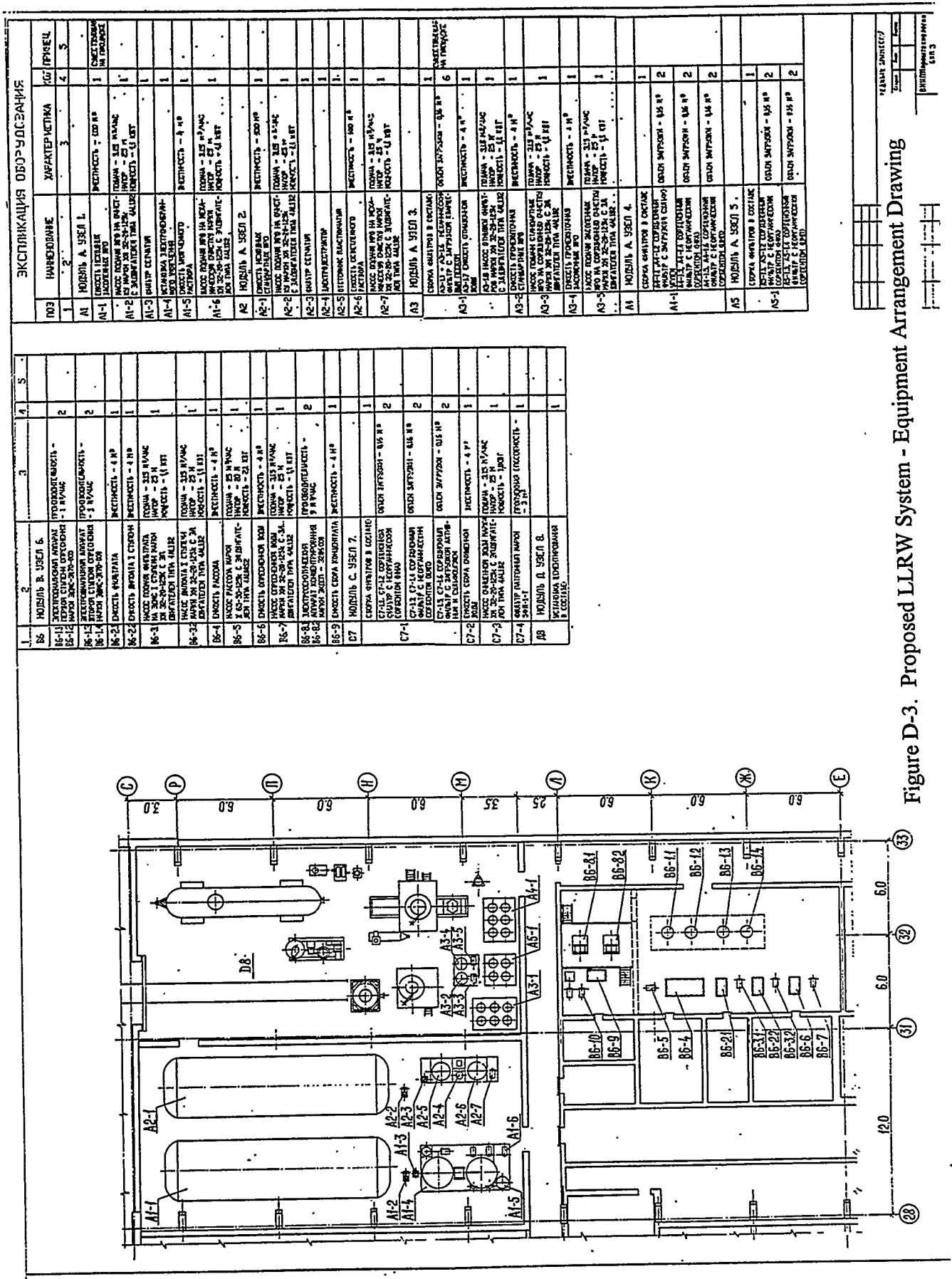
5. On page 21, the table lists 302.7 thousand 1991 rubles of other works and expenses. What types of things are included in these expenses.

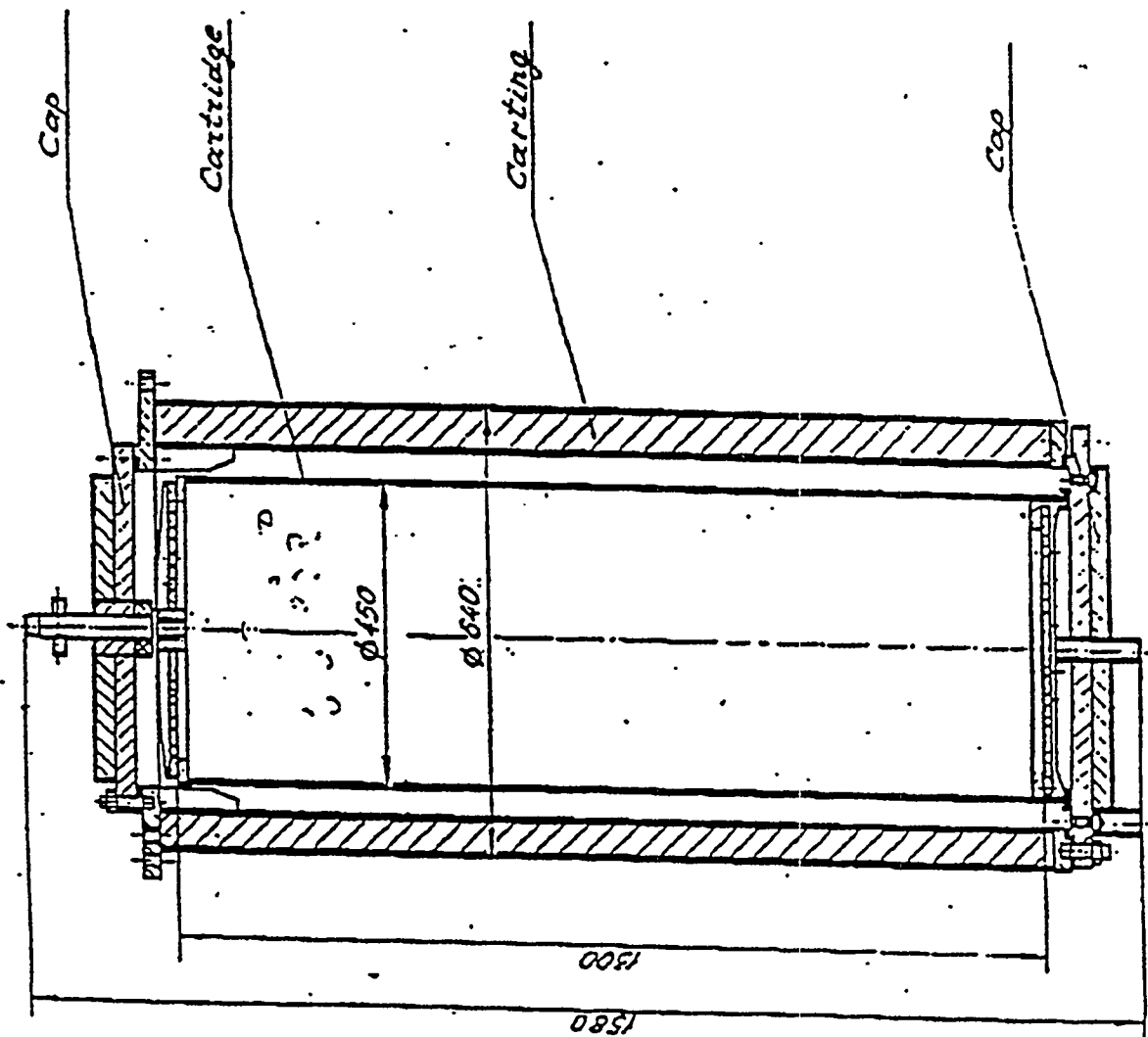
6. What is block 10? It is referred to several times in the text and shown on the diagrams on pages 22 and 23. What is it? Is it part of the cementation facility?

APPENDIX D

FLOW BLOCK DIAGRAMS







Working medium - waste water.
 Working pressure - 3 kg/cm^2
 Flow rate - $15 \text{ m}^3/\text{h}$
 Working temperature - $10+10^\circ\text{C}$

Figure D-4. Proposed LLRW System - New Sorbent Column Design