IAEA-TECDOC-1518

Retrieval of fluidizable radioactive wastes from storage facilities

IAEA
International Atomic Energy Agency

August 2006

IAEA-TECDOC-1518

Retrieval of fluidizable radioactive wastes from storage facilities

IAEA
International Atomic Energy Agency

August 2006

The originating Section of this publication in the IAEA was:

Waste Technology Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

RETRIEVAL OF FLUIDAZABLE RADIOACTIVE WASTES
FROM STORAGE FACILITIES
IAEA, VIENNA, 2006
IAEA-TECDOC-1518
ISBN 92–0–111106–1
ISSN 1011–4289

Printed by the IAEA in Austria
August 2006

FOREWORD

Temporary storage of unprocessed radioactive wastes at the site of generation is a reasonable, common practice. Temporary storage of unprocessed wastes — also known as "staging" — is intended to place the waste in a safe storage condition pending characterization, classification, pre-treatment, packaging, or accumulation of sufficient quantities to allow for economical transport. Normally, this staging activity lasts for less a relatively short time, thereby having little impact on the waste form, waste containers or other storage vessels, etc. Good operating practices suggest that longer term storage be restricted to those wastes which have been processed for long term storage/disposal, thereby safeguarding against waste form transformation or storage vessel degradation.

Unfortunately, operational, safety and economic considerations sometimes delay waste processing and dispositioning, resulting in the unavoidable, longer term, interim storage of unprocessed wastes. Similarly, processing acceptance criteria or technologies may not be locally available for some wastes, such as sodium, graphite, sludge, or wastes containing a combination of radioactive materials and other hazardous constituents (commonly referred to as a "mixed waste"). Again, in such situations, interim storage in an unprocessed form may be unavoidable.

Large volumes of various types of radioactive waste arising from nuclear energy and nuclear weapon programmes have been stored for many years at some nuclear power plants, nuclear research centres, and other nuclear facilities. Over time, the composition and physical state of much of the waste has changed, sometimes adversely impacting the storage vessel (container, tanks, silos, etc.). The storage facilities and their equipment may also have deteriorated with time. The net result is that the simple removal of radioactive waste from storage tanks, vaults, and silos is often no longer possible. In some cases, the waste must be treated to permit transport and further handling.

Removing stored radioactive waste for transport and further handling has not specifically been addressed in existing International Atomic Energy Agency publications. Only some general aspects are mentioned in publications dealing with decommissioning nuclear facilities and storing radioactive waste, and those discussions focus primarily on solid radioactive wastes. Recognizing the increasing interest in this subject and the potential for more universal application of the document in planning and implementing retrieval of stored radioactive wastes, the IAEA prepared this publication to address strategy and planning of the retrieval of stored fluidizable wastes.

This report provides guidance for strategic planning and implementation of resuspension and retrieval of stored fluid or fluidizable radioactive wastes. The potential risks associated with preparation and realization of these processes are included in the report, and lessons learned from previous applications are highlighted. Technological procedures and equipment used in various countries for resuspension and remobilization of stored fluidizable radioactive wastes are described in the attached annexes as potential options.

Thirteen experts from seven Member States that previously implemented, or have planned for the near future, significant resuspension and remobilization operations were involved in the preparation of this publication. Besides two consultants meetings, a well-attended Technical Committee meeting was also carried out in September 2001. Main outputs from the presentations and conclusions from the meeting are reflected in the publication.

The IAEA wishes to convey its appreciation to all those took part in the preparation of this publication. Special thanks are extended to P. Gibbons from Numatec Hanford Corporation for his systematic review of this publication from its beginning to conclusion. The IAEA officers responsible for this publication were R. Burcl, J.L. Gonzalez and J.J. Kelly from the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

During the history of nuclear energy and nuclear weapons production, radioactive waste has been stored for later conditioning for disposal. In many cases, the conditioning processes had not been developed at the time of waste generation. This resulted in the wastes being stored for an indefinite time pending identification of ways to place the material in an acceptable form for disposal. In some instances, in the early days, the storage vessel itself was considered the final solution.

As environmental concerns have moved to the forefront, many of the original plans for waste disposal have been re-examined. This has delayed plans for retrieval of waste in storage and conditioning. At the same time, many of the current “temporary” storage vessels have been deemed unacceptable, bringing pressure on waste managers to take action.

In addition, at some operating nuclear power plants, radioactive waste processing streams are often directed to concentrators and storage tanks for semi-permanent storage until plant decommissioning. Plant life extension has made these plans unacceptable due to a lack of sufficient storage capacity. Safe and effective waste retrieval is a prerequisite then for restoring power plant operating capacities, transporting nuclear waste to safer storage, and conditioning waste for final disposal.

In retrieving radioactive waste, the primary objective is generally to remove the waste from the operating facilities or storage vessel. Downstream processes for producing a final waste form suitable for long-term storage or disposal are normally secondary — although important — objectives, which are not addressed in this report. The following issues are addressed in this report and are typical for retrieving stored radioactive waste:

— The original waste form may have degraded under storage conditions.
— A retrieval system may not have been included in the original storage system design.
— The retrieval system installed when the storage vessel was constructed, or the standard technologies available and applied at the time of construction, may no longer be appropriate or effective.
— Uncertainties may exist about the waste characteristics (such as physical and chemical heterogeneity, radiotoxicity, etc.).
— Multiple waste types with various radioactivity levels or chemical and physical forms may exist within the same storage vessel.
— The waste form, storage facility, and storage location may no longer meet the evolving or current safety standards.

1.2. OBJECTIVE

The purpose of this publication, which is based on the experiences and lessons learned by particular Member States, is to help managers of stored fluids or fluidizable radioactive wastes to develop and implement effective waste retrieval systems. It describes the development and implementation of a waste retrieval strategy within the larger context of regulated radioactive waste management. Practical experiences and available technologies are also provided. The publication will contribute to the development of the overall waste management plan, including the waste retrieval strategy, provide ongoing programs with information to measure waste retrieval progress, and identify additional resources and related references. To this end, a generic methodology for addressing waste retrieval is presented, along with information on the most commonly used waste retrieval processes.

Waste retrieval encompasses four main functions that are needed to relocate waste:

(1) Access the waste – Bring the mobilisation and removal processes to bear on the waste.

(2) Mobilise the waste – Prepare the waste so that it can be readily removed from the vessel (i.e. place it into a fluidizable state or otherwise prepare it for safe removal).

(3) Remove the waste – Pump or lift the waste from the vessel.

(4) Transfer the waste – Move the waste from the storage vessel location to another location.

For the purposes of this publication, "retrieval" will refer to the use of these four processes in general. The term "vessel" will include a container, tank, silo, or other storage vessel identified in paragraph 1.3.

This publication describes a new, optimally effective waste retrieval program or activity. An ongoing program or activity could also use this material to improve effectiveness and maximize the use of available resources to complete the activity.

1.3. SCOPE

This publication covers the development of onsite radioactive waste retrieval systems, listing available technologies for retrieval of radioactive waste stored in vessels. Those radioactive wastes of interest to this report include liquids, solid-liquid slurries, mixed radioactive and hazardous waste, regardless their activity or isotopic content, and all in a fluid form or a form that can be made fluidizable and can be transferred as a fluid. Vessels include waste tanks, silos, vaults, and basins; buried, drummed, or boxed waste is not considered. Retrieval should be seen as part of the overall waste management plan, which should include the rationale for and alternative scenarios for retrieval, typically culminating in conditioning and interim storage before disposal. Post-retrieval processing, conditioning, storage and disposal are not addressed in this report.

The publication draws on examples of waste retrieval projects in France, Slovakia, Russian Federation, United Kingdom, and the United States of America. An extensive series of annexes are included to provide project-specific examples, technologies applied, and lessons learned on the retrieval of the following fluidizable waste types.

— Sludge.
— Evaporator bottoms.
— Ion exchange resin.
— Dried waste.
— Crystallized salt waste (low solubility).

Each annex provides a statement of the existing problem or waste retrieval challenge, the waste conditions before beginning the project, the reasons or motivation for retrieval of the waste, project objectives, strategy for retrieval, a description of the retrieval technology and processes, and lessons learned. Each annex also has its own topical bibliography. Proposals for future waste retrieval operations at a number of sites are also described.

1.4. STRUCTURE

This publication is structured around the planning sequence for the overall waste management plan (strategy) that will lead to the best retrieval system design. Section 2 outlines each step necessary to develop a successful retrieval system design. Section 3 describes the waste retrieval processes with examples of available technologies. This detailed section is divided into four subsections, each one representing one of the following primary functions in a waste retrieval system:

(1) accessing all the waste within the vessel configuration;

(2) mobilising the waste in preparation for removal;

(3) removing the bulk and residual mobilised waste; and

(4) transporting the waste to processing or treatment equipment, or to storage locations.

As discussed above, extensive annexes are included to describe waste retrieval projects and experiences around the world.

2. METHODOLOGY FOR DEVELOPING WASTE RETRIEVAL SYSTEM DESIGN

2.1. OVERVIEW

When planning to retrieve radioactive material from storage vessels, six key elements should be applied to determine the appropriate retrieval methods. These elements are illustrated in Figure 2.1:

(1) governing policies,

(2) waste management plan (unit waste cleanup strategy),

(3) specific retrieval objectives,

(4) waste and vessel infrastructure characteristics,

(5) downstream waste processes, and

(6) retrieval system design.

The waste management plan (element 2) specific to the target storage vessels is highlighted in the above listing and in Figure 1, because it represents the coordinating activity for the entire retrieval project and ties the six elements together. The retrieval system design (element 6) is highlighted, as it is the end product of the six-element exercise. Starting with the retrieval method design might seem like an intuitive first step, but this often causes extensive problems as the overall project takes shape. Each of the five elements which precede and lead to development of the retrieval system design is dependent on both its predecessors and its successors.

For example, a unit waste cleanup strategy or plan (element 2) that is developed and implemented without considering the national and regional policies (element 1) is vulnerable to redirection. Similarly, the characterization data (element 4) may suggest a need to revise the strategy or plan (element 2) to deal with a surprise waste constituent. Each of the above elements and each stage of the retrieval methodology is described in more detail in the following sections.

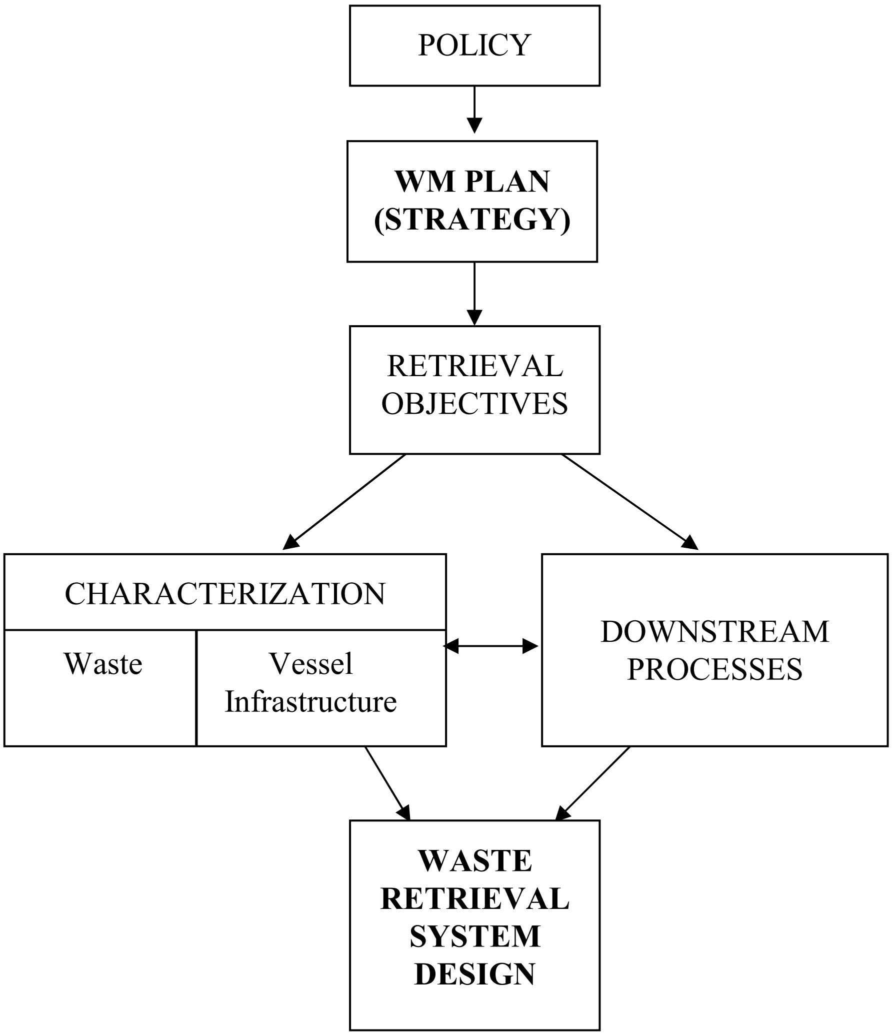

FIG 1. Simplified scheme for determining waste retrieval system design.

2.2. POLICY

Policy is generally defined as a high-level approach to radioactive waste management, including aspects of retrieval, established by one or more agencies or bodies. Policy can be translated into a series of rules. Policies of countries with advanced nuclear programmes often include requirements on retrieval goals (also known as end points or end states), waste disposal; and requirements for communicating with policy developers, waste unit managers, and interested members of the public (often called stakeholders, as they have a claim or stake in waste management).

Ideally, international, national, and regional radioactive waste policies provide the waste manager with information resources that list retrieval goals and guidelines, disposal options, and communication requirements. However, policies may conflict with each other and may be subject to various interpretations. Waste unit managers must propose retrieval goals, disposal options, and technical review requirements, and then make a case that the proposals comply with all governing or controlling policies. This is often a complicated, lengthy and contentious process, as the proposals will also need to comply with any applicable international safety standards and environmental conventions. Understanding international laws, as well as understanding non-binding international agreements and regional agreements on environmental policy, are critical to developing an effective strategy [1].

In addition, Governments play numerous roles in radioactive waste management as well as nuclear energy. These multiple roles often lead to complex relationships among government departments or ministries. The situation can become more complicated when several government agencies have jurisdiction over different (or sometimes the same) aspects of waste management. Furthermore, different levels of government are often involved (for example, local, regional, and national) [2].

2.3. WASTE MANAGEMENT PLAN (STRATEGY)

The waste management plan is the technical approach or strategy for implementing environmental policy at a specific site or waste unit. It identifies:

(1) the overall plan for waste remediation and management of a waste unit;

(2) where retrieval actions fit into the sequence of events in the overall plan;

(3) the performers (participants and working groups) responsible for each set of actions;

(4) interfaces with other functional activities;

(5) the defined and potential downstream processes and storage or disposal criteria for the waste; and

(6) the final vessel and site conditions.

There are many considerations involved in the formulation of a successful site retrieval plan. These considerations include cost, time scales, risk reduction, hazard identification and mitigation, complexity of waste streams, extent of inventory knowledge, scale of task (single or multiple streams to treat), waste types, required conditioning and treatment, and end point definition. As the plan develops, changes will occur because of policy shifts or emerging characterization or process data. Some changes impact only a few elements, while other changes ripple through the entire plan. For each of the larger changes, the waste facility managers must reassess the impact on the current retrieval system design and operations. While the strategy is being developed, and often throughout the entire retrieval effort, waste managers must also communicate with policymakers, regulators, and stakeholders to ensure that the retrieval process remains acceptable.

One common approach to developing a retrieval strategy is to produce a diagram or “route map” for waste streams. This map covers the entire waste management process, identifying process stages — including conditioning plants — leading to a defined final waste state or end state. With the top-level strategy defined in the route map, it is necessary to underwrite the strategy with a technical basis of design. Not every piece of information can be fully underwritten, however.

The waste manager and other involved parties must have reviewed the strategy and be confident that the overall strategy is robust. Ongoing development work and testing can progressively increase confidence in the strategy. A flexible strategy that the waste manager, policymakers, and stakeholders support guides the development of the objectives for the retrieval. If the parties involved can gain consensus and are confident in their strategy, the development of objectives will be strengthened.

2.4. RETRIEVAL OBJECTIVES

To the extent that there is a defined and stable waste management plan, retrieval objectives can be defined. The retrieval objectives will determine the most appropriate retrieval technologies and methodologies.

Clearly defined retrieval objectives that consider schedules and schedule permutations are essential. The most common retrieval objectives help prepare for site closure by reducing the volume of waste in the vessel, the activity of the waste in the vessel, and the radiation hazard from any residual waste remaining in the vessel at completion of the project.

The optimum approach in scheduling retrieval is to plan the effort in phases and to include a re-evaluation after each phase. This allows the objectives and the retrieval strategy to be evaluated when new information becomes available. An example might include the discovery during the initial retrieval phase that the waste contains unknown objects, thereby suggesting a re-evaluation of the objectives and retrieval strategy.

The schedule also should allow for a learning curve, and contingency plans should be at least partially developed. This is especially important when working on projects with insufficient characterization data or technologies that have not been used by the operators before.

2.4.1. Underlying principles (drivers)

In determining the objectives, the underlying principles or reasons for the objectives and the associated priorities need to be clearly articulated. The reasons (often called drivers) for undertaking retrieval may include the following:

— Reducing the safety hazard to the public and workers posed by waste in the storage vessel, including chemical and radiation hazards.
— Reducing or removing potential impacts to the environment.
— Meeting regulatory requirements.
— Allowing facility decommissioning to commence.
— Preparing waste for treatment or conditioning.
— Treating or conditioning waste for storage or disposal.
— Creating capacity for further storage.
— Facilitating accurate characterization of the waste for assessment of downstream process compatibility and final vessel condition.

In some cases, the safety considerations (for employees at the site and for the surrounding public) may require some wastes to be retrieved ahead of others and before downstream processes are available. Although adding cost and complexity, this is often the most practical or pragmatic approach.

2.4.2. Relationship to other elements of the overall waste management plan

Retrieval is one on the key elements in the overall waste management plan, as was illustrated in Figure 2.1. While the necessity of understanding the waste's characteristics is often stressed in developing waste retrieval strategies, the necessity of understanding the waste's ultimate form and destination should not be overlooked. In developing the retrieval objectives, downstream processes must be clearly understood and articulated. The following questions should be answered and considered when determining the retrieval objectives:

— Are there specific physical and chemical parameters (often called waste acceptance envelopes, including waste blending requirements) that must be met?
— What are the minimum and maximum waste volumes accepted per unit of time (throughput requirements)?
— Does the downstream process accept the waste in batches or in a continuous supply?
— For the entire remediation process, what are the treatment and processing schedule limitations?
— Who is responsible for the downstream processes and ultimate waste storage or disposal?
— For the entire remediation process, what are the treatment and processing requirements?
— What are the interfaces with other systems and functional activities?
— What technologies and processes are available?

Failure to understand the downstream processes and the associated management systems can result in expensive changes to the retrieval system. (See Section 2.7 for more information on downstream processes.)

2.5. WASTE CHARACTERIZATION

2.5.1. Purpose of waste characterization

The general purpose of waste characterization is to provide the necessary data to resolve technical issues related to storage, retrieval, and waste processing. The specific objectives may include the following:

— Define the physical, chemical, and radiological properties of the waste that are necessary to select and develop the retrieval system, downstream treatment processes, and conditioning.

— Define the conditions that the retrieval systems will have to overcome. For example, for sludge or slurries, analyse rheological behaviour (waste deformation and flow characteristics), identify an appropriate agitation and pumping system, predict pressure drop during transfer, and determine the needed dilution factors.

— Establish the final waste form specifications that are necessary for waste acceptance. This applies to the receiving vessel, subsequent package acceptance criteria, waste processing criteria, final waste form for storage, and final storage or disposal acceptance criteria.

— Identify the changes in properties in a vessel due to layer effects, dead zones, etc. This will be used to define the need for a flexible retrieval system, flexible downstream treatment, and a large range for final waste specifications.

— Evaluate the changes in properties compared to what was expected from historical records or paper evaluations, especially due to waste ageing. This is particularly pertinent for reactive materials in wet environments, although material in dry storage can also deteriorate.

  - Predict the additional changes in properties and waste characteristics which will result from preparations for transfer, such as the fluidisation of solid or semi-solid material (e.g. higher flow rates, lower radiation dose rates).

  - Predict the changes in properties and waste characteristics which will result immediately following transfer (e.g. higher radiation dose rates following dewatering operations, potential exothermic reactions while dewatering wastes containing nitrates).

— Provide additional data to identify the hazards associated with future operations (retrieval, treatment, storage) and to develop safety requirements. Again, this is particularly important for reactive materials.

— Contribute to cost projections and cost-versus-risk-reduction scenarios.

Waste characterization is also important for retrieval system design. There is a tendency for waste management programmes to characterise waste only for safety, downstream processing (treatment and conditioning), and storage or disposal. Unfortunately, waste characterization is not always conducted for chemical and rheological properties specific to waste retrieval, both of which are critical to projects for the retrieval of fluidizable wastes. A sampling and characterization campaign that will provide a more precise view of the stored contents, as well as extrapolation of the data and characterization results, is also advised for confirming historical record accuracy and for determining the physical properties of the waste. It is also likely that a re-characterization effort will be needed at multiple points in the project, such as at the end of the retrieval project in preparation for processing, and whenever an unexpected change in waste conditions emerges (e.g. unexpected solids in the fluidizable waste).

2.5.2. Waste characterization programme

The necessary characterization phase may be a significant part of the overall cost of the project, especially if it is necessary to develop new tools to obtain characterization data. So, it is of critical importance to establish a waste characterization programme. The basic steps involved in optimising the waste characterization programme are as follows:

(1) Identify operating risks.
(2) Formulate a list of technical issues from the risks.
(3) Determine how the technical issues will be resolved (i.e. create a resolution strategy).
(4) Identify the data needed to carry out the resolution strategy.
(5) Carry out a “gap analysis” to identify which of the required data are already available and which need to be obtained.

(6) Formulate a characterization plan that will propose how to obtain the required data (i.e. define the methods that will be used to obtain the needed data).
(7) Identify any known re-characterization needs and at which points in the project they will be implemented.

2.5.3. Waste characterization method

(a) Record analysis

The primary information sources for the original content (inventory) of the vessel are the previous technical and operations records. This source must be used and, most of the time, provides enough data for initial feasibility studies for planned retrieval and treatment processes.

Nevertheless, this type of information source presents several difficulties. Older logbooks may not be easily accessible, missing, or difficult to locate. Once located, the records may be difficult to interpret, possibly requiring the assistance of staff with operational experience. Some materials added to the vessel may not have been recorded; some waste transfers and other events also may not have been recorded. Finally, chemical reactions, leak mitigation efforts, waste reduction efforts, and other activities may have dramatically changed the waste composition. While logbooks and records can provide useful planning data and show the variability of the waste, the data provided may not be complete. Talking to experienced operators and gathering more information may help. It may even be necessary, and certainly helpful, to interview some former employees who may have further knowledge on the waste or wastes within the vessel or who may be better able to decipher historical records.

(b) Additional studies

In addition to historical record analysis, it is possible to make additional studies or perform tests with nonradioactive products for the purpose of evaluating the behaviour of “real waste” in the vessels (e.g. actual waste samples). For instance, it is possible to calculate chemical reaction kinetics to predict the types and quantities of reaction products present in the vessel after a certain number of years. This is a way to characterise the waste content, but it can be also a preliminary activity, before sampling and analysis, to identify what has to be researched.

(c) Sampling

Preparation for sampling – If a sampling method has been selected, the characterization programme is developed at a more detailed level, that is, an analytical programme. This analytical programme involves defining the following:

(1) Volume of the sample
(2) Location of the sample
(3) Number of samples.

A sufficient quantity of waste must be collected to perform all of the necessary analyses, including quality control analyses. The volume collected depends on how much waste is needed to answer the specific characterization objectives. In certain cases, a good composite sample can be built from individual samples. This may be necessary because of the vessel’s configuration or the type and volume of waste. Because some wastes cannot be homogenized inside the vessel, the number and location of the samples needed for statistical analysis are important factors when the waste is heterogeneous.

For example, at the Hanford Site (USA), experience has demonstrated that the waste may vary not only from tank to tank but also from place to place within each tank. The waste in these underground tanks may contain various layers, including rock-like salt masses, viscous sludge, and free-flowing liquids as well as miscellaneous foreign objects. Each layer of waste may have different chemical and physical properties. Thus, samples must be taken from the different layers and difference tank locations to determine both the location-specific and the aggregate properties of the waste.

The sampling challenge is further compounded by access restrictions. For radiation shielding, the Hanford Site tanks were built approximately 1 to 2 m below the ground surface. The contents of the tank are accessible through access ports, called risers. The number of risers in a tank and the diameter of the risers vary significantly from tank to tank. Internal obstructions, such as in-tank equipment, restrict the movement of sampling equipment. Therefore, to sample waste not located directly under a riser, the sampling technology must be capable of moving 2 to 4 m through a small-diameter pipe into the tank. Then, the technology must safely manoeuvre within the tank, retrieve a representative sample (which could vary from the consistency of cement to that of syrup) at a variety of depths, and return to the operators without exposing workers to excessive radiation levels or possibly damaging the tank. This activity may have to be repeated numerous times based on the heterogeneity of the waste and the data needs.

When both solid and liquid wastes are present, sampling all the waste forms is critical to developing a retrieval strategy. In many cases, non-soluble radioactive material is associated with solids at the bottom of a vessel. While difficult to acquire, this information is important.

Sampling technologies – Sampling technologies are selected according to the nature of the waste (rheology, density, particle settling rate, activity, etc.), the configuration of the vessel, and the nature of already implemented sampling systems. New sampling technologies may need to be developed, or existing equipment may need to be severely modified.

— The most common sampling technologies for low viscosity liquids are those used to transfer liquids: pumps, air-lifts, ejectors, vacuums, etc.
— For viscous liquids, available technologies are core sampling, auger sampling, grab sampling, and vapour sampling.
    - Core sampling is used to obtain solid or supernate waste samples. The sampler's drill bit is pushed or rotated through the waste, often passing though overlying liquid.[1] Each sampler is approximately 2.5 cm in diameter and 50 cm in length. Only the area entered into by the sampler is sampled.
    - Auger samples are taken using a stainless-steel, hand-turned auger bit contained in a sleeve. Auger sampling is generally used to sample the first 20 cm of solid material on the waste surface.

[1] When analysing samples of solid waste, decant as much liquid as practical before beginning the analyses.

- Grab sampling is used to sample liquid or soft slurry. Samples are taken using a special sampling bottle that is lowered into the waste, opened remotely, closed after waste has flowed into the container, and then removed.
- Vapour sampling is used to detect the flammable and noxious vapours and gases in a tank. Several vapour sampling methods are available, including sorbent tubes, combustible gas meters, and organic vapour monitors.

2.5.4. Waste characterization results

Once the samples are collected, they are analysed and results are recorded. The analyses performed will depend on the waste type, the vessel, the retrieval strategy, and the regulations involved. After the analyses are performed, it may be beneficial to compare the results of the sampling with the results of the historical records. Determining the cause or causes of discrepancies between these reports can help uncover "surprises," such as solids found in what was expected to be 100% liquid, or unrecorded foreign objects (e.g. steel measuring tapes or gloves). The accurate recording of the characterization data is a critical task. The data should be recorded in an easy-to-understand fashion. This can be done by developing key definitions early in the process and acquiring agreement on these definitions from key parties. An independent assessment of the clarity of new retrieval records can be beneficial.

Waste managers must keep in mind that even after achieving the characterization programme, the need for defining a flexible retrieval system remains. Characterization analyses will provide an envelope of the known and expected properties pertaining to the waste. To ensure a robust retrieval system, the retrieval technology and methodology must be prepared to deal with a wider range of properties than indicated by the characterization results. Variations in the consistency of the waste and limitations of the sampler may prevent a representative sample from being obtained. Furthermore, unexpected and uncharacterised conditions, including unknown objects and materials (from pine needles to steel measuring tapes), are likely to emerge during actual retrieval operations. These surprises can incapacitate a retrieval technology. Therefore, while surprises, by their very definition, cannot be anticipated, systems can be designed to respond to a wide range of in-tank conditions. This broad view–often called flexibility of design–can be critical to a system's success.

2.6. STORAGE VESSEL CHARACTERIZATION

2.6.1. Purpose of storage vessel characterization

There are three primary objectives in characterising a vessel and its associated waste-handling infrastructure.

- — The vessel parameters must be determined.
- — The operational safety parameters of the vessel must be determined.
- — Following the waste retrieval system design, the retrieval system and processes must be assessed for compliance to technical requirements and to safety limits. Any issues (for example, airborne solids, hydrogen concentration) must be identified.

2.6.2. Required information

The amount of data required to characterise the vessel may vary according to the vessel; nevertheless, the following are commonly needed:

— Vessel construction characteristics (volume, dimensions).
— Nature and location of process and mechanical equipment (transfer, handling, sampling, ventilation, weather protection, etc.).
— Piping isometrics.
— Access systems (openings, overhead clearance, load limits, etc.).
— Civil engineering specifications (seismic behaviour, capability to accept new structure or equipment).
— Radiation protection conditions.
— Equipment degradation and structural degradation due to stored waste, aggressive conditions, or normal ageing.

2.6.3. Methodology for vessel characterization

The process of assessing the vessels is similar in principle to that of waste characterization. The results of this assessment will be to:

— define issues,
— develop a resolution strategy, and
— define tasks to accomplish the work.

Available documentation should be used to characterise a vessel. The work involved may include use of as-built documentation and verifying or enhancing the knowledge of vessel and infrastructure characteristics. Begin with those documents originally prepared for construction, with original construction blueprints or Piping and Instrumentation Drawings (P&IDs) being of primary importance. Next, the documents that have been updated and/or established during the operating time of the facility should be used, again focusing on engineering copies of P&IDs.

Waste managers should exercise caution when relying on such documentation for three reasons:

(1) The documentation may be out of date or unavailable.

(2) The vessel and its internals typically correspond to an old design. As vessels were constructed to the standards of the time, they may not be equivalent to modern standards and may not behave in the manner expected of modern designs for vessel construction materials, internals, and included equipment operating parameters.

(3) Third, many of the vessels, internals, and included equipment have been in use longer than called for in the original plans and have exceeded their design life. These structures may be degraded or no longer functional. There is also the possibility that the vessel was not always operated properly. Ageing vessels tend not to function according to the design intent and may have to be removed.

After the as-built documentation is exhausted, additional efforts may be necessary to verify or enhance knowledge of the vessel. Methods of verifying or enhancing vessel-specific knowledge include:

— Inspection or field surveys (for example, checking drawings against the actual vessel by visual examination of the vessel).

— Discussions with system engineers or operators, possibly including former employees.
— Nondestructive examination (ultrasonic, radiography) of confinement systems.
— Destructive examination (for example, taking core samples of the vessel's concrete for strength testing).
— Measurement (for example, building movements, corrosion losses of vessels, and pipe work).

2.6.4. Additional evaluations

In addition to the vessel characterization itself, which consists of defining as precisely as possible the current conditions, it may be necessary to evaluate the capability of the system to accept new conditions added by the retrieval and treatment operations. For example:

— The protection of the workforce could involve installing containment and biological shields, depending on the waste activity levels. Installation of heavy shielding could present a challenge to vessel loading. The capability of the vessel's existing structure to accept heavy loads, such as containment systems, under normal and seismic conditions must be determined. This may lead to the need to evaluate the reinforcement of an existing structure to ensure loads are distributed and maintained within safe design limits. In some circumstances, either an upgrade or the construction of new structures around the existing vessel is required to accommodate the retrieval system load.

— The process of retrieving waste will present safety and environmental challenges dependent on the waste characteristics. The ability of the existing vessel infrastructure to meet these challenges will need to be assessed. For example, the demands on an installed ventilation system may rise significantly as more entrainment is needed. This may occur when moving from a position of quiescent storage over many years to one where waste is being mobilised and transferred. Other issues may also arise, such as the need to manage hydrogen concentrations and the requirements of current environmental regulations.

2.7. DOWNSTREAM PROCESSES

Downstream processes include treatment in preparation for shipment or storage, volume reduction processing, conditioning for disposal, and creation of a final disposal waste form. The operating parameters of the downstream processes must be considered when determining how waste will be retrieved. In some cases, advantageous selection of a retrieval method may simplify the next processing step. An example of this is the selective dissolution of salts to concentrate nitrates.

It must be recognizes that a retrieval process may complicate or defeat a treatment or conditioning process by introducing chemicals or simply by providing inconsistent feed. The objective is to balance the cost of the retrieval system against its impacts on subsequent processes. In many cases, the final packaging and waste form for disposal are not yet defined. In these cases, assumptions must be made to avoid interfering with future final conditioning.

Downstream processes may vary and have several stages of treatment or conditioning of the waste after retrieval, and each stage may have specific conditions for acceptance of the waste. These criteria need to be understood when determining how the waste will be retrieved. For example, can the downstream process handle large volumes of water? Varying particle sizes? Varying chemistry? When the downstream process is not clearly understood, retrieval systems, retrieval strategies, and downstream processes may need to be redesigned. Conversely, accurate waste characterization will ensure that downstream processes are properly selected and minimize the uncertainties, surprises, and changes in strategy.

To help ensure waste acceptance, certain key parameters may need to be controlled as waste is moved into the downstream processes. Examples include:

- Segregating solid and liquid waste.
- Separating sludge from solid waste.
- Keeping solid and liquid contents of sludge and slurries within specified ranges.
- Controlling the pH.
- Controlling the concentration of specific chemicals or classes of chemicals (for example, hydroxides).
- Controlling radioactive species concentrations.
- Controlling the temperature.

In addition to waste acceptance criteria, there may be other process requirements. To understand the process requirements, look at the route map developed during the site strategy from the viewpoint of the waste characteristics, vessel characteristics, and downstream processes. In retrieving the waste, has the overall water balance and solids content changed, and how will that impact downstream processes? How do vessel parameters and waste characterization fit together? Have technologies or methodologies been incorporated to handle possible pipeline plugs or waste transfer issues? Will an intermediate downstream step be needed (for example, pipe flushing)? What types and volumes of secondary waste will be generated? How will they be treated? Where will they be sent for storage? How will they be transported? Is there available storage or will additional capacity be needed? These questions and others need to be carefully considered and the results of the questions managed when considering the processes downstream of waste retrieval.

Ideally, all the downstream steps should be known before the retrieval design is optimised and finalised. Strategies may need to evolve along with the actual retrieval process, resulting in different downstream constraints. However, it is important to minimize the addition of chemicals in advance of or during the retrieval phase so as not to further complicate downstream processes.

To minimise the impacts of strategy changes, the retrieval system design itself should be as flexible as possible, that is, the system should operate satisfactorily over a wide range of waste parameters and still produce an acceptable output. For example, where minimal, questionable or limited characterization data are available, the system should not be locked into one waste type, such as liquid. In retrieving aged sludge, which may have a wide range of properties, a retrieval technology that encompasses both mechanical and hydraulic methods may be more flexible and thus, more effective.

2.8. WASTE RETRIEVAL SYSTEM DESIGN

Using the gathered information, the retrieval system is designed. Who should design the retrieval system? Experience shows that effective design teams should be led by retrieval system specialists who understand downstream processes. These teams work closely with system specialists, operators, and maintenance representatives, integrating their ideas and addressing their concerns. Other opinions and experiences are sought throughout the design process as needed.

In developing a successful design, the two primary rules are to keep it simple and to keep it flexible. Technical complexity should be added only when it is needed to answer a specific parameter. In some cases, the retrieval system is over-designed based on a misunderstanding of the objectives or based on a perceived need to match the design life of the vessel. Clear objectives and information are needed to ensure that the system is designed for the lifespan of the appropriate retrieval effort, not necessarily of the vessel.

Flexibility, both in initial capability and in ease of modifying the system, should be considered in regards to the vessel and waste conditions. Since characterization efforts may not provide a complete view of the waste, systems that can handle a variety of waste forms are more likely to succeed. Of importance is an understanding of what is realistically to be expected from the retrieval technologies in the way of retrieval objectives. Flexibility requires a strong understanding of the available technologies and proper waste retrieval planning. For example, the plan could call for a system designed to retrieve only the bulk of the waste, rather than perform both bulk and residual waste retrieval. The residual waste by its very nature may require a different retrieval approach. Using such an inflexible approach could dramatically increase the cost of removing the residual waste by necessitating a full additional waste retrieval campaign. A flexible retrieval system has much in its favour, as does a flexible plan.

A thorough evaluation of the proposed retrieval system design is essential to ensure its success. Both the normal function of the equipment and possible failure modes and effects must be evaluated. This evaluation normally involves the retrieval system designer, the vessel owner, the retrieval equipment operator, and the downstream processor. Evaluations or tests should be conducted throughout the design process. Prototypes and process tests can be constructed and tested at various scales. During the development phase, easy-to-implement retrieval systems can be used to prove the effectiveness of the retrieval system design. Generally, evaluation culminates in full-scale, nonradioactive testing (also known as cold testing). Full-scale testing can use a prototype or mock-up to test design assumptions before finalizing the design. Alternatively, full-scale testing may use the final system to validate construction and procedures, as well as train operating personnel. These tests also can determine the effectiveness of the technologies at removing simulated waste, determine how the retrieval method will interact with the vessel, and assess the possibility of the technology damaging the vessel.

Reliability tests can identify and rectify weak points in the design. In full-scale and reliability tests, the careful selection of simulated waste is required to achieve accurate results. Simulates can be designed to mimic particular parameters of the waste for particular tests. Once active, repairs and alterations to the system are extremely difficult and costly.

After the retrieval system design is accepted and operational, the designers should continue to be involved with the retrieval system. In some cases, operators deviate from the design intent, and their inventiveness can expand the flexibility of the system. While properly planned retrieval operations tend to run smoothly, conditions will change with even the best of plans, and surprises are almost certain to occur. When conditions change, project managers must be prepared to accept and manage the change. In addition to information gained on the technology, vital characterization data can be obtained during operations on the waste and its behaviour. This information on the physical behaviour of the waste needs to be captured and provided in a coherent fashion to those operating and developing downstream processes. In addition, the information should be provided to appropriate parties for waste acceptance.

With the inputs described in previous discussions, successful retrieval systems can be designed and tested. While a comprehensive and effective design is often more difficult than first imagined, following the sequence and elements set forth in Figure 1 can make the process easier.

3. WASTE RETRIEVAL PROCESSES

As discussed earlier, retrieval systems must include the following four functions. Limitations on any one of these functions affect the whole process.

(1) Accessing all of the waste within the vessel configuration;

(2) Mobilizing all of the waste, freeing it up for removal;

(3) Removing the bulk and residual mobilized waste;

(4) Transferring the waste to processing (treatment and conditioning) facilities, storage or disposal.

This section categorises (according to primary function) and briefly describes many of the currently available retrieval and transfer processes. Additional information on many of these systems and their past use is described in the annexes at the end of the document.

3.1. ACCESS WASTE

Access to the waste is the first function to be considered in the actual retrieval process. Accessing the waste generally involves the insertion of tools into the vessel, often through narrow confined spaces, and moving the appropriate mobilisation or removal tools to the optimum locations near the waste.

Accessing through the civil structure that was initially provided around the waste, mainly for waste containment and radiation protection, may be accomplished using existing openings, such as through risers or access ports in a tank’s roof. Using existing openings needs to account for a variety of infrastructure issues, such as the opening’s diameter, possible obstructions within the opening, and general safety issues (see Section 2.6). New openings may also be created using standard civil work technologies can be used; the following precautions apply:

— The new or modified openings must not jeopardize the overall structural behaviour of the storage vessel.

— Access through the upper slab, or roof, is usually preferred. Nevertheless, access through the sidewalls or through the storage bottom may be envisaged according to the storage environment and the nature of the waste.

— Construction work must be done with full knowledge of containment and/or radiation protection implications. Additional protection for the environment and the workers may be necessary.

Once a retrieval system or subcomponents have been installed in the vessel, they must be able to reach the waste within the vessel, or the waste must be able to flow to the retrieval components. The system to be implemented depends mainly on the nature of the waste. Consider the following:

— Liquid waste is able to flow by gravity to a single point where the retrieval system can be installed.

— Sludge or viscous liquid cannot be retrieved from a single point. (Viscous liquid, by definition, has an inherent resistance to flow.) A mobilization system with dilution can be enough to modify the waste properties within the entire vessel. Examples of this are bulk waste mixing pumps and high-volume sluicing equipment described in Section 3.2.
— Very viscous liquid (very high flow resistance) cannot be retrieved from a single point, even by use of a dilution or mobilization system. An additional deployment system is necessary to move the retrieval system to locally access each part of the waste vessel (including, if necessary, a local dilution and mobilization system).

In this section, three categories of local access technologies are described:

(1) long-reach manipulation (Section 3.1.1);

(2) remote-controlled vehicles (Section 3.1.2); and

(3) cable positioning systems (Section 3.1.3).

3.1.1. Long-reach manipulation

Local placement of retrieval processes to access all of the waste in the vessel can be accomplished using a manipulator arm from one or more fixed locations. This provides positioning without necessarily being supported by the waste surface. As the equipment does not contact the waste surface, removing the manipulator for maintenance is simplified. In addition, work can be performed high on the vessel walls and throughout the vessel storage volume. However, such systems require an extensive support infrastructure and a large initial investment. Descriptions of several long-reach manipulation technologies follow.

Modified Light Duty Utility Arm (MLDUA) – This system uses a seven-degrees-of-freedom robotic arm capable of moving through 30 cm (27 cm actual clearance) access openings or risers to deploy a variety of retrieval tools. The arm was deployed in seven underground tanks at the Oak Ridge Reservation (USA) [3]: two 7.5 m diameter vessels, five 15 m diameter vessels. The arm reaches 15 m vertically and 4.5 m horizontally, and it is capable of picking up a 90 kg payload [4]. Because of the MLDUA's limited horizontal reach, four placements were required in the 15 m tanks to achieve complete coverage. (See Annex US(1) for more information on this project and retrieval equipment.)

Advanced Waste Retrieval System – This system consists of a retrieval arm with a 4.5-m reach. It is mounted on a tool deployment mast that extends from tank floor to tank top. The system is remotely operated, with the arms and other tools mounted on carriages that can be raised and lowered along the mast. This system can be inserted through a 60 cm access port and is designed to support several tool configurations. Originally designed to vacuum sludge residue from a tank floor using a steam jet eductor pump (see Section 3.3.1), this system was used with gamma survey tools and sluicing jet nozzles at the end of the retrieval arm to characterise and clean tank walls. It was used in two tanks at the West Valley Demonstration Site, USA. (See Annex US(11) for more information on this project and retrieval equipment.)

Another example of this type of remotely operated manipulator system is the sludge removal system planned for use in retrieving sludge from a series of tanks at Nuclear Power

Plant A-1 in Slovakia. (See Annex S(2) for additional information on the DENAR System and the related waste retrieval project.)

A final example is the Commander Manipulator developed by BNFL for use at Sellafield, UK. This manipulator arm was designed as a compact version of complex manipulator models with the objective of improving accessibility. As of the writing of this report, development of the Commander Manipulator was reported as complete, but it had not yet been engaged for any specific waste retrieval project.

3.1.2. Remote-controlled vehicles

Waste retrieval with remote controlled vehicles involves the local placement of a vehicle that manoeuvres across the waste surface or vessel bottom. While the ability to successfully move through and across the waste is an issue, it is not the most significant issue in designing and deploying these systems. The more challenging issues are umbilical management and recovery of the vehicle for maintenance. Descriptions of several remote-controlled vehicle deployment technologies follow.

Houdini Vehicle – This 450 kg, 1.2-m by 1.5 m tracked vehicle folds to fit through a 60 cm access riser. It has been used successfully in conjunction with the MLDUA (see Section 3.1.1) to clean out seven 4.5-m and 9.0 m-diameter tanks at the Oak Ridge Reservation, USA. The Houdini Vehicle uses a small plough blade to move sludge inside the tank to a pumping system for removal. The plough blade can be used for a variety of other activities, including scraping dried waste from the vessel floor. The vehicle also has a small manipulator arm that can lift, position, and use mobilization and removal tools, such as a small sluicer. (See (Annex US(1).)

TRACPUMP™ Vehicle – This deployment system was considered but not selected for non-technical reasons for sludge retrieval from a 23 m-diameter tank with about 2.5 m of sludge (Hanford Site, USA). The system has a hydraulic-powered pump mounted between crawler tracks to pump out sludge as water is added to form a slurry. The vehicle produced by Environmental Specialties Group, LLC, was contracted to perform a Phase II demonstration of a Vehicle-Based Waste Retrieval System (VWRS) for underground storage tank waste retrieval at the Hanford Site (USA). The testing demonstrated the effectiveness of water jetting for waste movement using the manipulator arm. The manipulator arm was also used for grinding and milling, although water jetting was demonstrated as the more successful technique. At the time of publication of this report, a sufficiently detailed analysis of the project was not available for inclusion as an Annex.

ARD Crawler – This wheeled vehicle produced by ARD Environmental, Inc., was designed for use in tanks containing radioactive sludge and was tested by the Hanford Site (USA) [23]. During the test project, the ARD Crawler vehicles were fitted with a variety of dislodging devices, including a rotary cutter, scabbler, and jackhammer, to test their abilities to break up and convey various simulated wastes developed by Hanford. Both air conveyance and a positive displacement pump also were tested as a means for moving the material.

The off-the-shelf equipment used to dislodge the simulated wastes all worked to some extent. The ARD cutter head, although designed specifically for hydrocarbon sludges and moderately compacted sediments, was moderately effective at breaking up the high-strength salt cake, highly effective at dislodging and moving the low-strength salt cake, and effective at breaking up the two hardpan simulated wastes. It also easily dislodged the original sticky, wet sludge, but diluent water was required to assist in the transfer of material. The scabbler was quite effective at powdering (pulverizing) the high-strength salt cake, but it was not useful in the dried or wet sludges. The jackhammer easily broke up the salt cake into large chunks and, with a modified tool, was able to pulverize the salt cake into small pieces for easier transfer. The testing was performed by Hanford in 1996, and the results are reported in Reference [19]. A key design innovation since the Hanford test project is the addition of large rubber tires that provide the ability to right itself if the Crawler is tipped over.

Sludge Walker – Using four specialized wheels with independent movement, this 230-kg remote-controlled vehicle was used at Nuclear Power Plant A-1 (Slovakia). The Sludge Walker moves across sludge, sand, gravel, and slurried waste. This semi-robotic system, operated remotely, can be used to deploy a variety of tools inside the tank, such as a shovel, rotating brush, and pumping system. Unlike the Houdini system discussed above, the tools are mounted onto the Sludge Walker before it is deployed. (See Annex S(1) for additional information on this vehicle and the waste removal project.)

Guepard Carrier – The Guepard is a tracked vehicle weighing 230 kg, which is driven using two independent, sealed motors. It has a 61.5 cm by 80 cm platform set 30 cm above floor level that contains an adaptable mount to receive, hold, and position the required tools. The Guepard is operated by remote control from an operator station using a 100 m-long cable. This tracked vehicle can be completely submerged in liquid, can be decontaminated for conventional use, and can negotiate 60% slopes. This system was used at the La Hague Reprocessing Facility (France) to remove contaminated concrete rubble from a room and to remove a sticky residue found on the floor of another room. (See Annex F(3) for additional information on this vehicle and the waste removal project.)

3.2. WASTE MOBILIZATION

Waste mobilization is defined as changing waste properties or waste form to allow removal from the vessel, including making it fluidizable. It entails breaking down solids into a removable size and form. This includes size reduction for mechanical removal, mixing liquids with solids to create a pumpable slurry, and dissolving salts into a pumpable solution. Mobilization systems may also be defined as an adjunct to retrieval access systems — rather than moving the retrieval system into the waste area, the waste can be moved into the retrieval system's range.

In this section, six categories of mobilization technologies are described:

(1) mechanical stirrers (Section 3.2.1);

(2) mixer pumps (Section 3.2.2);

(3) hydraulic sluicing jets (Section 3.2.3);

(4) pneumatic systems (Section 3.2.4);

(5) crushing and digging by mechanical methods (Section 3.2.5); and

(6) chemical and thermal methods (Section 3.2.6). All of these technologies change the properties of the waste so that it can be retrieved.

3.2.1. Mechanical stirrers

The most common technology used to mobilize waste in tanks or silos is mechanical stirrers. While mechanical stirrers are produced in a variety of configurations, the technology, in general, can be described as a series of large paddles connected to a central pole that turns relatively slow (reminiscent of a ceiling fan). Stirrers are usually incorporated into the initial design of a waste vessel. Nevertheless, it may be possible to add one at the time of retrieval.

At the La Hague Reprocessing Plant (France), a mechanical stirring system, combined with a dilution jet and a pumping system, was used to remove thixotropic sludge from waste silos. The mechanical stirrer was designed to comply with the critical shear tension of the sludge. The dilution jet was used to add water when needed to reach the appropriate concentration. A progressive cavity pump system was used to pump the stirred waste out of the tank. (See Annex F(2) for additional information on this equipment and project.)

3.2.2. Mixer pumps

Mixer pumps agitate liquid to mobilize and entrain (resuspend) previously settled solids so that they can be pumped out of a vessel. Several types of mixer pumps are available. Heavier solids may settle again before they can be pumped from the vessel and may have to be removed using a different process.

Mixer pumps are categorised as global systems. A “global” system is one that can mobilize waste throughout a vessel from a fixed location. A “local” system is one that can only mobilize waste in a small area and must be moved to each area in the vessel. Mixer pumps generally have sufficient energy to mobilize waste in a vessel which is dispersed across an extended area. They generally do not need to be relocated to be effective, unless the vessel is partitioned or contains significant internal obstructions which interfere with the jet streams.

Long-Shaft Mixer Pumps – Generally, a long-shaft mixer pump is a centrifugal, dual-jet pump located beneath the liquid surface and near the solid waste, with a drive shaft connected to a motor above the storage vessel. The pump bodies are rotated in a manner which causes the jet streams to sweep across the vessel floor, thereby mobilizing waste across the entire effective range of the jet streams. These systems are effective for bulk waste retrieval. However, at times, the long shaft has resulted in vibration-induced bearing and seal failure, as is discussed in the project review in Annex US(4). One possible alternative is a submersible mixer pump, which is described below.

Submersible Mixer Pumps – This mobilization system is powered by close-coupled submersible motors and includes either a centrifugal pump or horizontal ducted turbine. The pump bodies may be rotated or used in a fixed position. Submersible mixer pumps have been used to mobilize supernate, salt, zeolite, and sludge from a 4.9-million litre capacity tank at the Savannah River Site (USA) [5,6]. Limitations involved with this technology include limits on motor size when the system is placed inside the tank (due to limited access port sizes in the tank), limitations regarding tank configuration, and flammable gas ignition concerns. (See Annexes US(5) and UK(2) for information on two example projects.).

3.2.3. Hydraulic sluicing jets

A hydraulic sluicing jet — also referred to as a hydraulic water jet — uses water or another motive fluid (such as the vessel supernate) to mobilize waste. The jet directs a pressurized stream of liquid through the air, water or waste, breaking the solids apart or sweeping them to a different location.

The two defining characteristics of hydraulic jets are pressure and volume. Generally, the effective range is inversely proportional to pressure. Low-pressure, high volume systems usually have sufficient range to be categorized as "global" systems, meaning they can mobilize waste throughout a vessel from fixed locations. High-pressure systems (350 to 3500 bar) are generally locally deployed because of the short effective ranges. The volume of liquid used by the hydraulic jet to deliver mobilization energy is also inversely proportional to the pressure. Low-pressure systems use high volumes of liquid. High-pressure systems use lower volumes of liquid. In the case of high- and low-pressure systems, immediately removing the added liquid is an important consideration under certain conditions, such as leaking or potentially leaking vessels and policy requirements for minimizing resident liquid time.

(Note: water jetting systems up to approximately 2800 bar are commonly available. When approaching 3500 bar, they are no longer capable of providing a continuous flow stream, converting to a pulse-pressure system. These pulse-pressure systems are rare, although they reportedly have been tested for various non-nuclear applications in Russia and the USA. However, as an indicator of the net force of these very high pressure systems, water jetting at 2800 bar combined with an abrasive media has been demonstrated to cut through a 2 m diameter concrete column and more than 15 cm of steel. This underscores the need for careful personnel safety considerations and a careful evaluation of the potential impact on the infrastructure of the storage vessel.)

Confined Sluicing End Effector – Deployed on either a manipulator arm or a remotely controlled vehicle, this technology combines a high-pressure water jet with immediate removal of the slurried waste to minimise the resident water volume in the vessel during retrieval. This is especially important when the vessel is suspected of leaking. The system is equipped with three rotating jets mounted 120 degrees apart. As the jets rotate, a short-range stream of water is focused on and dislodges the solid waste. The rotating jets deliver water with a pressure of up to 700 bar. An electric motor rotates the jets at variable speeds from 0 to 500 revolutions per minute to cut hardened sludge [7]. This technology was used at the Oak Ridge Reservation (USA) and is described in the project documented in Annex US(1).

Light Weight Scarifier – This tool is a combination of very high pressure (at least 2800 bar) water jet mobilization system and a high-velocity air conveyance waste removal system. While tested extensively in the USA for conventional waste removal purposes, it has not been used in an actual nuclear waste vessel.

Low-Pressure Sluicing Jets – Both global and local mobilization can be accomplished using low-pressure jets, which can take a variety of configurations. Four low-pressure sluicing jets are discussed in the annexes.

— At The Mining and Chemical Combine (Russia), hydro-monitors used two sluicing jets mounted at opposite ends of a vertical shaft to remove sludge and solid waste from a vertical tank, with a capacity of approximately 3,200 m^3. In this system, the lower jet was designed for immersion, while the upper jet was through-the-air. Sluicing was powered by a pulsating pump [9] (Annex RU(3)).

— A low-pressure commercial pan-and-tilt through-the-air sluicer was used to mobilize sludge in a tank at the Savannah River Site (USA) [8] (Annex US(6)).
— A similar unit was used at the Hanford Site (USA), also for the purposes of mobilizing tank sludge (Annex US(8)).
— A low-pressure through-the-air spray ball and low-pressure steerable sluicers were used to remove simulated waste in a mock tank at the Idaho National Engineering and Environmental Laboratory (USA) (Annex US(7)).

High-Pressure Sluicing Jets – Far-reaching water jets, or sluicing jets, have one or more through-the-air water jet nozzles with water supplied by a local or remote pump. An example of a high-pressure sluicing jet is the Borehole Miner with an extendible nozzle used at the Oak Ridge Reservation (USA) [24]. This technology is a specially designed, mast-mounted sluicing jet that uses higher-than-normal pressure (70-200 bar versus 10 bar). It is coupled with an extendible nozzle (~3 m long) to increase the effective range sufficient of access across the tank volume.

3.2.4. Pneumatic systems

While hydraulic systems use water or another liquid, pneumatic systems use pressurized air in mobilizing waste. Air may be used directly as an air jet or indirectly as a means to create a liquid jet. Note that it is also possible to add an abrasive media to the air jet stream, thereby creating a more aggressive force for breaking down solid wastes. The downside of adding an abrasive media is the increase in net waste volume; yet it may be a reasonable option for some leaking vessels.

Air Lance Excavation – Commercial air lances are available for loosening soils for dry soil excavation. Theoretically, these lances can be adapted for remote use inside radioactive waste vessels. By using air lances to mobilize wet sludge, water levels would be kept to a minimum, reducing the potential for leaking waste. This research area has not been fully explored.

Pulsating Mixers – Compressed air is discharged in a small tank located in the waste vessel, while simultaneously expelling a liquid jet from a secondary nozzle. A vacuum cycle then refills the small vessel with liquid waste. This relatively low energy technology can keep waste that has a low settling rate in suspension, but it is not powerful enough to remobilize aged waste. An example application of this technology is provided in Annex US(1).

Air Buoyancy Mixers – The buoyancy of air bubbles in liquid is used to establish bulk convection flow. This system supplies air bubbles which rise through the liquid and mix the surrounding waste. For example, the PulsAir system provides discrete pulses of air or inert gas inside the vessel. This is accomplished through the underside of an array of horizontal, circular plates, positioned a few inches from the tank floor. The air pulses rapidly create bubbles that quickly rise to the surface, mobilizing soft to moderately strong cohesive sludge, ranging in consistency from syrup to peanut butter [10,11]. This method was used successfully at the Oak Ridge Reservation (USA) to mobilize lighter weight sludge for pipeline transfers. (See Annex US(1) for additional information on this project and technology.)

3.2.5. Mechanical methods: Crushing and digging

Mobilization by mechanical means is excavation adapted to waste mobilization. For example, dried waste or sludge adhering to the vessel floor can be crushed and then removed, as was done with the Houdini vehicle in the USA (Annex US(1)). Generally, where mechanical technologies have not been developed or planned for nuclear waste vessels, it is due to concerns regarding vessel integrity, complex internal geometry, and tool deployment, when compared to global hydraulic methods.

Crawlers and Vehicles – Crawlers can deploy digging or ploughing tools as well as use the weight of the equipment to crush hardened sludge. For example the 450-kg Houdini vehicle used its plough blade to loosen 5-cm to 10-cm-thick plates of dried sludge in underground tanks at Oak Ridge Reservation (USA). Next they simply drove the heavy vehicle over the loosened sludge, crushing it. The plough of the Houdini vehicle was then used to push the loosened sludge to the removal tool location (Annex US(1)). Other crawlers and vehicles also use various tools to crush or dig waste from a vessel. These include the ARD Crawler [23], Sludge Walker (Annex S(1)), and Geupard Carrier (Annex F(3)).

Arm – An arm can be equipped with digging tools — such as grabs, shovels, and buckets — that are used in a waste vessel in a manner similar to earth excavation equipment. Examples of such equipment are the Modified Light Duty Utility Arm (Annex US(1)), Mast Mounted Tool Delivery System and Advanced Waste Retrieval System (Annex US(12)), and Long-Reach Manipulator (Annex S(2)).

3.2.6. Chemical and thermal breakdown

In addition to water dilution, chemicals, such as acids, can be used to mobilize waste. For example, chemical softening of sludge was performed at the Savannah River Site (USA). Similarly, salt waste can be mobilized by heating (thermal conditioning). Of course, it must be recognized that chemical treatment of any wastes is likely to impact the waste characterization considerations applicable to downstream processing (treatment and conditioning), storage and disposal. Consider the following examples of this mobilization approach.

Acid Sludge Softening – Often, retrieval systems cannot mobilize and retrieve residual waste, hardened sludge, or salt wastes located in difficult-to-access vessels. Water or a weak acid (such as carbonic acid) could be used to partially dissolve salt wastes. For example, 30 g/L, or 0.5 M, nitric acid was added to a tank at The Mining and Chemical Combine (Russia) through a sluicing jet. The nitric acid reacted with sludge, breaking down its structure so that the jets could form a slurry that was pumped out of the tank. The solids were transferred to another location, and the liquid was returned to the tank with additional acid. This process was repeated over the course of a year or more [12].

Similarly, at the Savannah River Site (USA), some high level waste tanks contain support columns and cooling coils that interfere with certain waste retrieval systems [13]. This situation is further complicated by hardened sludge arising from plutonium-uranium extraction methods. Currently, operators at the site use oxalic acid (and are considering a mixture of oxalic and citric acids) to partially dissolve the hardened sludge. Combined with bulk agitation, this method creates a slurry that can be pumped from the tank. (See Annex US(10) for additional information on this approach and project.)

Thermal Conditioning of Salt – Heating water can increase its ability to dissolve salt-containing waste. Similarly, heating brine can prevent the formation of a solid phase. In the RBMK and WWER types of reactors in Russia, thermal conditioning is being considered to mobilize selected radioactive wastes. (Annexes RU(1) and RU(2) provide additional information and discussion on thermal condition technologies.)

3.3. WASTE REMOVAL

Removal of waste is simply acting on mobilized waste to take it out of the vessel. The most straightforward and inexpensive method is pumping using one or more of the commercially available or specialized pumps (Section 3.3.1). Two other approaches are air conveyance and mechanical conveyance. Air conveyance or entrainment in an air stream is especially valuable when adding water or other liquids is undesirable, such as in a possibly leaking vessel (Section 3.3.2). Mechanical conveyance can be used in certain situations; however, mechanical systems under certain conditions have a low tolerance to objects in the waste, such as level measuring tapes, and have contamination confinement issues (Section 3.3.3).

3.3.1. Hydraulic–liquid pumps

Several types of pumps are listed in this section. In addition, the TORE® solids fluidisation and transportation device is discussed. This new technology enhances the performance of hydraulic-liquid pumps to entrain solids.

Centrifugal Pumps – This is the most common type of pump. Centrifugal pumps come in two basic configurations. The pump can use a long shaft driven by a motor external to the tank, or it can use a close-coupled submersible system. At the Savannah River Site (USA), the bulk of the sludge was removed from a 3 000 m^3 capacity tank using four long-shaft vertical centrifugal pumps [14]. These 110 kW pumps used a combination dual-jet and pump system to mix the waste. The pump, located at the centre of the shaft, pulled waste in. The waste was then forced out through two jets located on opposite sides of the pump. This system rotated inside the tank, mixing solid waste with supernate [15] (See Annex US(4) for additional information on this project and pumping equipment.)

Water-Jet Eductor – Water-powered jet pumps range from low-pressure drives (7 bar) to high-pressure (700 bar) drives. High-pressure systems add less water during pumping but require more sophisticated drive pumps and generally need to use clean water. Lower pressure systems are less expensive and are more amenable to using recycled contaminated liquid (See Annex US(1) for additional information.)

Steam-Powered Jet Pump – A standard for years in the USA, the steam-powered jet pump's high specific drive energy results in minimum net water addition during pumping. A local pump is used to move the slurried waste to the destination if it is more than 100 m. A steam-powered jet pump (also known as a steam-jet eductor) generally requires a separation tank to vent off entrained gasses. (Annexes US(7) and US(11) discuss two projects involving steam-powered jet pumps.)

Double-Diaphragm Positive Displacement Pumps – This simple, air-operated positive displacement pump has relatively low pump rates but can lift waste more than 18 m. (This can be an important capability when retrieving waste from tall structures or vessels located deep underground.) It is rugged and reliable; but it is susceptible to fouling from heavy, solid material (sand and gravel). An air-operated double-diaphragm scavenging pump with a 12 m head at 0.5 m^3/min [16] was used to remove more than 7.5 m^3 of sludge and almost 1100 m^3 of tritiated water in a tank at the Savannah River Site (USA) [17] (Annex US(6)).

For another project, a simple and inexpensive displacement pump, manufactured by IDEX Corporation, was used to pump sludge and liquid from an underground tank in Iraq. This system was designed to work around infrastructure limitations: the site did not have electricity, water, or other utilities, and access to the tank was restricted [18].

Pitbull™ Pneumatic Pump – This pump, an adaptation of a commercially available pump, consists of a chamber with a foot check valve. A foot check valve is a valve located at the bottom (or foot) of the pump that lets water in but not out. A vacuum is placed on the chamber as it draws liquid and slurry into the chamber. The chamber is then pressurized, closing the foot valve and forcing the liquid in the chamber up a tube that extends to the bottom of the chamber, up and out of the tank. A check valve in the discharge line keeps that material from falling back into the chamber. The pump is designed to sit on the bottom of a vessel and vacuum sludge through a 1-in. gap between the vessel bottom and the inlet. The Pitbull™ was tested in a 5000 m^3 capacity tank (Savannah River Site, USA) [19] This unit has not been used in the field, but it has been extensively tested for pumping capability and resistance to plugging (as compared to the double-diaphragm pump). It is also more robust than the double-diaphragm pump when moving granular or gravel-like solids. (See Annex US(5) for additional information on this type of pumping technology.)

Fluidic Pumps – These pumps use either a fluidic check valve or a fluidic amplifier to fill a charge vessel under vacuum and discharge the liquid under pressure. This system allows pumping to occur without introducing moving parts into the tank. Two types of fluidic pumps are common in radioactive waste retrieval: the fluidic diode pump and the reverse flow diverter. The fluidic diode pump is similar in function to the Pitbull™ pump (see previous paragraph), except that the system check valves are fluidic diodes with no moving parts (mechanical check valves as used in other systems). The diodes are full flow in one direction and 25% flow when reversed. The reverse flow diverter draws liquid into the charge vessel through jet pump suction. When the charge vessel discharges, the jet pump pulls in more liquid increasing the flow. This type is limited in pump discharge head. Both were developed by AEA Technology. (See Annexes US(2) and US(3) for two example projects.)

Special Purpose Pumps – There are several special purpose pumps, such as the Moyno pump. The Moyno pump is a positive displacement pump based on a wobbling drive plate. It effectively removes slurries but cannot handle larger materials. This is a commercially available unit. No annexes discuss special purpose retrieval pumps, although in several cases the pumps used were commercially available systems selected and modified for the radioactive and caustic environment. (For an example, see Annex F(2).)

The TORE® Solids Fluidization Device – This device is a hydraulic fluidiser of solids that can be added to a hydraulic-liquid pump suction to enhance its ability to remove solid materials from the bottom of certain vessels. The TORE® creates a precessing vortex core under the foot of the central suction tube to mix the solid material. The mixture is drawn into the TORE® and discharged. With no moving parts, this technology could assist in the removal of solids in waste tanks and other vessels that ordinarily mound near the pump interface during retrieval [20]. For more information on this technology, see http://www.merpro.com/.

3.3.2. Pneumatic system: Air conveyance

Air conveyance is a process that uses a rapid flow of air to entrain liquid and solid wastes and carry them off the vessel floor or out of the vessel. These systems have the advantage of scavenging free liquid, reducing the potential for vessel leakage. However, these systems add a significant complexity to the retrieval system support equipment. Note: The TORE® system described in Section 3.3.1 can also be driven by air and used with similar effect to enhance solids pickup by the suction air stream.

Blower-Driven System – Using a blower mounted externally to the tank, this type of system can achieve exceptionally high flow rates resulting in excellent retrieval effectiveness, but it requires significant ex-tank de-entrainment facilities with shielding.

Eductor-Driven System – Eductors generate less air velocity than blowers but require less containment infrastructure outside the tank. However, eductors still require the use of a de-entrainer. Water-driven systems can be used for short transfers as is, but for longer transfers, they require an air separator and booster pump. (See Annex US(1)for additional discussion of an eductor project application.)

3.4. WASTE TRANSFER

Waste transfer is simply the process of moving waste that has been removed from a vessel to a destination vessel or facility. This can be accomplished using the in-tank removal system or a separate out-of-tank system. Several methods exist for transferring retrieved waste; the decision regarding the optimum method is based on the waste characteristics, infrastructure requirements, distance to destination vessel or facility, government policies, and regulatory requirements. This section will discuss the more common methods of waste transportation:

(1) pumping (Section 3.4.1);

(2) liquid vessels (Section 3.4.2);

(3) dry solids vessels (Section 3.4.3); and

(4) slurry vessels (Section 3.4.4).

3.4.1. Pumping and transport lines

Pumping waste liquid and slurries through transport lines to move them to a destination is the most common approach, as many types of pumps are readily available, and piping systems are easily controlled and shielded. Other means must be used when the waste is not pumpable or is in too small a quantity to justify the expense of a qualified radioactive waste transport line. Pumping for transport is done directly from the storage vessel or indirectly from a transfer staging tank.

Direct Pumping – A removal pump in the vessel is used to move the waste through the pipeline to the destination in one operation. This is the most straightforward method, but longer pipelines require higher pressures and greater pumping power.

Indirect Pumping – Waste is delivered to a staging vessel, where a dedicated transfer pump moves the waste through the transfer line. More than one stage may be needed to move the waste to its final destination.

When radioactive waste is transported through a pipeline, solids can precipitate during an inadvertent pump shut down and form blockages in the pipeline. Furthermore, chemical reactions or saturated salt precipitation can occur and cause solids to form. Plugged pipelines, especially buried pipelines, present severe financial and scheduling problems [21]. The plugged pipelines could be flushed with large volumes of water or other chemicals; however, this creates large volumes of secondary waste, which is not always desirable. The pipelines could be cut and the plug removed; however, the high radiation levels and often insufficient knowledge about the location or nature of the plug make if difficult, if not impossible, to cut into the pipeline and remove the plug. When it is possible to cut out a plug in a location which is difficult to access, the cost can be extremely high. One such example for cutting into an evaporator drain line at the Savannah River Site is discussed in Reference [22]. Recently, four pipeline unplugging technologies were tested at the Hemispheric Center for Environmental Technology at Florida International University. (See Annex US(9) for additional information on this project.)

In addition to concerns about plugging transfer lines, concerns often exist about the lines themselves. At some installations, the transfer pipes have passed their design life and may no longer be able to safely move radioactive waste. When the expense of installing a new permanent pipeline is not justified, a temporary, high-pressure hose-in-hose technology can be installed for a safe conventional transfer. Such an approach is described in Annex US(9). Either direct or indirect pumping can be used to move the waste through either temporary or permanent pipes.

3.4.2. Liquid transportation vessels

For processing some radioactive wastes, it might be necessary to transport it off site to specially dedicated facilities. A liquid transfer cask can be used to transfer retrieved radioactive materials. Many have been used in the USA for high-activity wastes; however, these vessels are no longer licensed. In Europe, some such shipments have taken place for processing waste liquids in facilities located outside the generating country.

LR-56 (French) Tank Truck – This truck-mounted shielded cask was developed by the CEA, the French Atomic Energy Commission. The primary feature of the system is a liquid transportation cask mounted on a trailer. The cask is a horizontal tank-within-a-tank design, which provides shielding and environmental protection. The usable volume of the cask is about 4,000 L. It has provisions for rinsing the cask after transfer, but it cannot be used for transferring solid material.

Low-Activity Vessels – Liquid waste that does not present a direct high-radiation hazard has been transferred by lightly shielded vessels located on a truck or trailer bed. At the Oak Ridge Reservation (USA), a high-integrity container (HIC) was used for transferring waste from 20 m^3 tanks to a remote receiving tank.

3.4.3. Mixed liquid and solids transportation vessels

Transporting a mixture of liquid and solid wastes in a vessel is challenging due to the possibility of leakage during handling and the difficulty of removing solids from a closed vessel. Except for the low-activity vessels described previously, no vessels designed for solid-liquid slurries have been identified. This capability will be required for final retrieval of sludge from high-radioactivity vessels with a remaining volume too small to justify a pipeline.

4. SUMMARY

Waste retrieval is a maturing technology of major importance now that Member States are moving forward in the responsible management of wastes by removal to safe interim storage or disposal. Retrieval of fluidizable wastes is a four-phase operation:

(1) access to the waste;

(2) mobilize the waste;

(3) remove the waste; and

(4) transfer the waste.

This report divides successful retrieval of radioactive waste into two areas. The first area applies the *concept* of the waste retrieval as being the final component of a systematic process of old waste management. It also encompasses characterization as it applies to waste retrieval and downstream processes, including acceptance of wastes for treatment, conditioning, storage or disposal. This retrieval stage or concept is summarized in Figure 2. It should be in conformity with national policy, as well as complying with international safety standards and environmental agreements.

The second area of the report focuses on *implementation* of waste retrieval in a wide range of scenarios and using a wide range of retrieval approaches, equipment and technologies. Technical processes are further explained as part of the experience gained in advanced countries on the subject. A set of detailed retrieval technology descriptions by country is included as Annexes to this report.

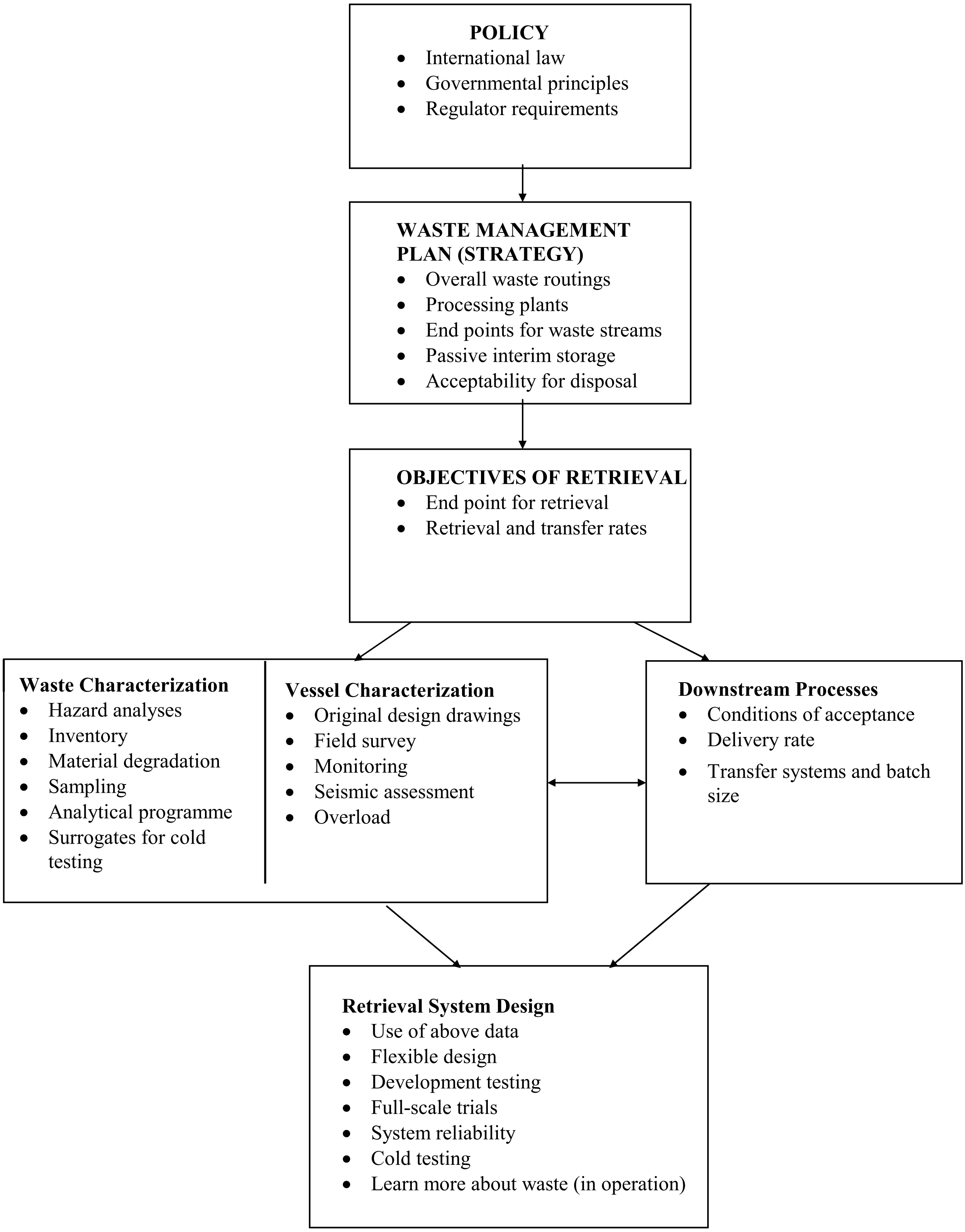

FIG 2. Summary of significant issues affecting waste retrieval system design.

REFERENCES

[1] LINSLEY, G., and TONHAUSER, W., "An expanding international legal regime: Environmental protection and radioactive waste management." IAEA Bulletin, Quarterly Journal of the IAEA, 42(3):24–2 (2000).

[2] HERNE DATA SYSTEMS, Ltd., "Government." Available: http://www.radwaste.org/gov.htm. (2 September 2004).

[3] GLASSELL, R.L., BURKS, B.L., and GLOVER, W., "review of the Modified-Light Duty Utility Arm after the completion of the removal of nuclear waste from the Gunite and Associated Tanks." In Proceedings of the 9th International Topical Meeting on Robotics and Remote Systems [CD-ROM]. March 4–8, 2001, Seattle, WA. American Nuclear Society, Seattle, WA. Available: http://www.robotics.ost.doe.gov/reports/glassell.pdf.

[4] WASTE POLICY INSTITUTE (WPI), "OST dovetails technologies for remote tank cleanup." Initiatives Online. Volume 4. Waste Policy Institute, Blacksburg, VA (April 1997).

[5] U.S. DEPARTMENT OF ENERGY, High-level waste tank closure draft environmental impact statement: Summary. OE/EIS-0303D. U.S. Department of Energy, Washington, D.C. (November 2000).

[6] KEILERS, C.H. and DAVIS, R.T., SRS report for week ending August 4, 2000. Available: http://www.dnfsb.gov/weekly/sr/2000/sr080400.pdf. (12 June 2001).

[7] LLOYD, P. D., FITZGERALD, C. L., TOY, H., RANDOLPH, J. D., DePEW, R. E., FALTER, D. D., BLANK, J.A., "Performance assessment of the Waste Dislodging and Conveyance System during the Gunite and Associated Tanks Remediation Project." In Proceedings of the 9th International Topical Meeting on Robotics and Remote Systems [CD-ROM]. March 4–8, 2001, Seattle, Washington. American Nuclear Society, Seattle, WA.

[8] U.S. DEPARTMENT OF ENERGY, Innovative technology summary report: SRS tank closure. DOE/EM-0449, U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (August 1999).

[9] U.S. DEPARTMENT OF ENERGY, Tank Retrieval and Closure Demonstration Center workshop. U.S. Department of Energy, Augusta, GA (January 2000).

[10] U.S. DEPARTMENT OF ENERGY, Innovative technology summary report: Pulsed-air mixer. U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (August 1999).

[11] TANKS FOCUS AREA (TFA), Focus on: Closing the gunite tanks: Oak Ridge Reservation takes big steps forward in closing gunite tanks, Available: http://www.pnl.gov/tfa/tech/techlist/gunitebroc.htm. Pacific Northwest National Laboratory, Richland, WA (1 June 2001).

[12] ALBERT, T. E., BARAKOV, B., and GIBBONS, P. W., "Russian technology advancements for waste mixing and retrieval", In Proceedings for Waste Management 2001 [Web Site]. February 25 – March 1, 2001, Tucson, AZ. WM Symposia, Inc., Tucson, AZ.

[13] ROUSE, J. K., McLAUGHLIN, T. J., AIRHART, S. P., JENSEN, E. J., LINDBERG, S. L., ROBINSON, D. D., and CRUSE, J. M., Underground Storage Tank-Integrated Demonstration participant site characteristic summary, WHC-EP-0566, Westinghouse Hanford Company, Richland, WA (1993).

[14] McNATT, F.G., Annual radioactive waste tank inspection program – 1998. WSRC-TR-99-00069, Westinghouse Savannah River Company, Aiken, SC (1999).

[15] TANKS FOCUS AREA, “Technical highlights period ending March 31, 2000.” Available: http://www.pnl.gov/tfa/hilight/back/31mar00.stm. Pacific Northwest National Laboratory, Richland, WA (29 June 2001).
[16] U.S. DEPARTMENT OF ENERGY AND RUSSIAN ACADEMY OF SCIENCES (DOE-RAS), Collaboratory agreement (contract) between the U.S. Department of Energy and the Institute of Physical Chemistry of the Russian Academy of Sciences, U.S. Department of Energy, Washington, D.C. (1 August 1999).
[17] FORTENBERRY, J.K. and SANDERS, J., Defence nuclear facilities safety board memorandum: SRS activity report for week ending January 31, 1997, Savannah River Site, Aiken, South Carolina (31 January), Available online: (1997).
[18] RINKER, M. W., HATCHELL, B. K., POWELL, M. R., LEE, J. H., HEALY, G. and GIBBONS, P. W., “Retrieval of uranium sludge from an Iraqi tank.” In Proceedings of American Nuclear Society’s 8th Topical Meeting on Robotics and Remote Systems [CD-ROM], April 25–30, 1999, Pittsburgh, PA. American Nuclear Society, Pittsburgh, PA (1999).
[19] HATCHELL, B.K., POWELL, M.R., COMBS, W.H., RINKLER, M.W., HYMAS, C.R., and WHITE, M., Performance evaluation of the PITBULL pump for the removal of hazardous waste, PNNL-11968, Pacific Northwest National Laboratory, Richland, WA (September 1998).
[20] MEPRO LTD., MEPRO limited — Process & Products Division: The TORE® solids fluidisation and transportation device. Bulletin 03, MEPRO Limited, Montrose, Scotland (2001).
[21] HUNT, R. D., BEAHM, E. C., CHASE, C. W., COLLINS, J. L., DILLOW, T. A., WEBER, C. F., Prevention of solids formation: Results of the FY 1999 studies, ORNL/TM-1999/263, Lockheed Martin Energy Research Corporation, Oak Ridge National Laboratory, Oak Ridge, TN (1999).
[22] HUNT, R. D., McGINNIS, C. P., WEBER, C. F., WELCH, T. D., JEWETT, J. R., FY 2000 saltcake dissolution and feed stability workshop. ORNL/TM-2000/202, UT-Battelle, Oak Ridge, TN (2000).
[23] Berglin, E.J., Acquire Commercial Technology for Retrieval Fiscal Year 1996 Summary and Highlights, Revision 1. WHC-SD-WM-RPT-269, Westinghouse Hanford Corporation, Hanford, WA (October 1996).
[24] US Department of Energy, Borehole Miner Task Focus Area. DOE/EM0492, Oak Ridge, TN (November 1999).

ANNEXES

ANNEXES

Annexes sorted by waste type

Waste type	Annex
Sludge	I-2, II-3, III-1, V-1, V-2, V-3, V-4, V-5, V-6, V-7, V-8, V-9, V-10, IV-1, IV-2
Sorbent resin	I-1, V-5, V-11
Dried waste	V-1
Evaporator bottoms	II-1
Crystallized salt waste (low solubility)	II-2

Annexes sorted by action

Action	Annexes
Access waste	
Long-reach manipulation	V-1, V-11
Remote-controlled vehicles	I-2, I-3, V-1
Mobilize waste	
Mechanical stirrers	I-2
Mixer pumps	IV-2,V-4, V-5
Hydraulic sluicing jets	II-3, IV-1,V-1, V-6, V-7, V-8
Pneumatic systems	V-1
Mechanical methods: Crushing and digging	I-3, V-1, V-11
Chemical and thermal breakdown	II-1, II-2,V-10
Remove waste	
Hydraulic-liquid pumps	I-1, I-2, IV-1, V-1, V-2, V-3, V-4, V-5, V-6, V-7, V-11
Pneumatic system: Air conveyance	V-1
Transport waste	
Pumping and transfer lines	V-9
Liquid transportation vessels	None
Vessels for liquid and solids	None

ANNEX I
FRANCE

I-1. INNOVATIVE WASTE SAMPLING SYSTEM AT LA HAGUE REPROCESSING PLANT

1. STATEMENT OF PROBLEM

At the La Hague Reprocessing Plant in France, waste generated by fuel treatment has been interim stored since 1966, until the implementation of conditioning facilities. Still, some waste is in tanks or silos. In 1992, COGEMA started to study the retrieval and conditioning of this waste. The first steps are sampling and characterization, to define the best strategy and appropriate technology for downstream operations. In this annex, two innovative systems that have been developed to mix liquid and solid waste will be described.

1.1. Waste type

(a) Spent resins stored in settlers

Several settlers contain a slurry composed of the following:

— Spent ion exchange resin generated by fuel storage pool water treatment. It consists of suspended bead or crushed resins, which varies in density between 0.3 to 1.6 mm for the beads and 5 to 130 µm for the crushed resin. Their density is 1.1.
— Zeolites (grain size: 0.4 and 3.2 mm, density = 1.9)
— Diatometer (grain size: 10 and 80 µm, density = 1.06)
— Graphite powder generated by GGR fuel core drilling (grain size: 1 to 50 µm, density = 1.2).

This slurry has settled and supernate has periodically been removed from the settlers to introduce more waste. The total amount presently stored is around 350 m^3, with a radioactivity level between 0.2 x 10^{12} and 20 x 10^{12} Bq/m^3.

(b) HAO silo

The HAO silo was filled with different solid wastes generated during reprocessing of spent light water reactor fuel from 1976 to 1988. They include the following:

— 90% hulls (diameter ≈ 10 mm; length = 35 mm) and end-fittings
— 2.5% dissolution and chopping fines (1 to 4 mm diameter)
— 0.5% spent ion exchange resins (5 to 130 µm)
— 7.5% technological waste including carrier lids, pumps, etc.

All of this waste is stored underwater. The estimated activity ranges from 40 x 10^{12} Bq/m^3 for the resins to 400 x 10^{12} Bq/m^3 for the fines. The total amount is approximately 1,500 m^3.

1.2. Current storage arrangements

The resins are contained in nine rectangular settlers of 25 to 75 m^3; five are equipped with stirring rings. They are covered by a 1-m-thick slab.
The HAO silo is a rectangular silo, 15 m x 15 m with a 10-m inner height. The water depth in the silo (about 9 m) is sufficient for the waste to be submerged.

1.3. Reasons for retrieval

The objective of COGEMA is to condition all the intermediate waste presently stored on the site and reduce the safety hazard associated with present interim conditions.

1.4. Objectives

The objective of the first step, i.e. the sampling phase, is the characterization of the different waste. With samples, it will be possible to evaluate the variety of waste in the silo, the need to implement pretreatment processes (sorting, cleaning, decontamination) to reach final waste specifications, and select the adequate conditioning process.

2. RETRIEVAL STRATEGY

Sampling:

(a) Spent resin settlers

The suspension is pulled out by a hydroejector located in a mobile, shielded box installed as close as possible in an accessible room above the settlers. Solution from the settlers is lifted out of the tank and recirculates back to the sampled settler. A sampling vial is installed on the suction part; during the hydrojet operation, the sampling vial is an integral part of the circuit. As a consequence, after recirculation in the loop, the sampling vial contains a solution representative of the content of the settlers at the level where the suction nozzle is located.

An air vent interlocked with the hydrojet stopping command breaks the vacuum in the suction pipe. This immediately drains the pipes to the settlers, except the solution contained in the sampling vial.

The vial, which is also located in the shielded box, is disconnected, tightly sealed, and placed in a transfer cask through the docking system. The cask accommodates three 100-cm^3 vials that are sent to the laboratory.

(b) HAO silo

Samples are taken at different altitudes in the waste heap using a corer to collect samples with various compositions and various ageing.

The sampling system is in two main parts:

— leak-tight enclosure with biological shields for safe sample handling, installed on the silo opening

— glovebox mounted on top of the enclosure, with glove parts and a viewing panel through which all handling operations of the corer and associated items can be performed.

2.1. Infrastructure upgrade

There was no need of infrastructure upgrade for sampling operation. Such need will be re-evaluated for retrieval operations.

2.2. Downstream process

The downstream process will be evaluated considering the process already used at La Hague.

— Spent resins: cementation
— Dissolution fines: vitrification
— Hulls and end-pieces: compaction
— Technological waste: grouting

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Process

Engineering studies to evaluate and select retrieval processes are ongoing.

I-2. SLUDGE RETRIEVAL FROM LA HAGUE STE2 SILOS

1. STATEMENT OF PROBLEM

At the La Hague Reprocessing Plant in France, sludge has been generated by liquid waste treatment between 1966 and 1989 and temporarily stored in adjoining STE2 silos until the availability of a conditioning process. In 1992, COGEMA started to study the retrieval and conditioning of this sludge. The sampling phase was implemented in 1992. A retrieval system adapted to the specific need is currently being developed (prototype phase), and studies are being conducted related to the conditioning process.

1.1. Waste type

The chemical composition of the sludge results from the chemical co precipitation reagents used in the STE2 facility and the ions present in the effluents and likely to precipitate during co precipitation treatment. Their activity ranges as follows:

— up to 40E+12 Bq/m^3 for β, γ emitters
— 0.1 to 1.E+12 Bq/ m^3 for α emitters.

Their density varies from 1.1 to 1.45 kg/L, and the dry extract content varies from 150 to 600 g/L. The total amount of sludge is 9,400 m^3.

Simulations on inactive sludge showed that the sludge is thixotropic and could occur in fluid, viscous, or plastic form. Moreover, it had been stored since 1966, which induced significant settlement. This was enhanced by the fact that supernate was regularly withdrawn.

1.2. Current storage arrangements

Silos and tanks have very different dimensions and installation constraints. The sludge is stored in as follows:

— Five rectangular silos 16 m x 14 m x 11 m with a volume up to 2,200 m^3; some are in raw concrete, others are covered with Zebron or polyurethane.
— Two cylindrical stainless steel tanks, 12 m in diameter with a volume of 1,000 m^3, installed in concrete bunkers.

A 1-m-thick concrete slab, whose the upper surface is in direct contact with the environment, covers tanks and silos. Direct vertical access is possible.

1.3. Reasons for retrieval

The sludge stored in the STE2 silos was generated during the first years of operation of the La Hague plant, a time when no conditioning process was available.

Retrieval and conditioning of this waste is part of a general strategy engaged in 1992 by COGEMA in La Hague to minimise the amount of nonconditioned waste stored on the site. Moreover, some conditioning processes are now available and can be envisaged for providing a better form for this waste.

1.4. Objectives

The objectives of the retrieval activity are to mobilize, remove, and transfer the maximum amount of sludge from the silos and put it under an acceptable conditioned form. There are no predefined criteria for sludge amount removal. Cleaning activities with other tools may be envisaged after the removal of the majority of the silos' content.

2. RETRIEVAL STRATEGY

2.1. Sampling

Taking an "intact" and representative sample in a loose terrain is extremely difficult because the medium is easily disturbed by the coring operation. An inventory and assessment of the different sampling techniques used in geotechnical drilling led us to use an Osterberg-type corer as the sampling probe. This instrument is based on the principle of sampling by a thin wall core barrel and a stationary piston.

After the penetrometer tests, gravity penetrations by the corer by wireline were discontinued, instead a positive thrust system with the same drill stem type was used. To avoid the loss of the sample due to a lack of cohesion or disintegration of the sludge during pullout in the very dilute phases such as supernate, a diaphragm retainer was added. This arrangement prevented pollution of the sample during the relatively long pullout times for samplings at the silo bottom.

The main operating steps of the probe are as follows:

— Phase 1: penetration of the corer from the top of the tank to a predetermined altitude in the sludge, by adding drill stem elements
— Phase 2: pneumatic pushdown of the core barrel around the stationary piston
— Phase 3: pneumatic closure of the diaphragm retainer below the sample
— Phase 4: pullout of the corer by withdrawing stem elements and placing it on the vial
— Phase 5: opening of the diaphragm and drainage of the sludge into the vial by mechanically lowering the piston. The filled vial can be transported in a shielded cask to a laboratory for content analyses.

This coring probe is part of a system whose nuclearization took into consideration at first the containment of all the sampling operations in two superimposed ventilated boxes. The lower one is shielded specifically for the transfer of samples into the vial.

The sampling units are installed in a ventilated air lock located on the slab covering the silo. This air lock makes it possible to core the 1-m-thick concrete slab and to anchor the connecting sleeve between the sampling box and the interior of the silo.

The first sludge sampling campaign took place in 1992 and concerned a silo containing about 2,000 m^3 of sludge. Representative samples were taken along the entire height of the silo. Currently, more than 70 sludge samples of 400 to 500 g each have been taken.

2.2. Waste characterization

Sludge has been characterised in the COGEMA La Hague analytical laboratories, for the purpose of determining physical, chemical, radioactive, and rheological properties. Characterization of real waste allowed for confirmation or better definition of the properties initially evaluated by simulation.

2.3. Infrastructure upgrade

Sampling equipment and their associated air lock were installed above the silos with a heavy mobile crane. The structural modifications that have already been performed around the silos consist of drilling the upper concrete slab. Structural modifications related to the retrieval system design are not yet defined.

2.4. Downstream processes

The new STE3 liquid treatment station located nearby includes a sludge bitumization unit that would be suitable for STE2 sludge conditioning. Studies, using results of real waste sampling and characterization are currently in progress to qualify the use of this process and characterise the conditioned product that would be generated.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Process

Several systems are currently being considered to access the waste; two of them are described here: the fixed mast system and the cable positioning system. The first one is simpler and will be used first in the real configuration. Then, based on lessons learned from the first experience, a decision will be made whether or not to implement the more expansive, but more efficient, cable positioning system.

- A fixed mast is introduced and fixed in the silo through an opening in the upper slab. The mobilization and removal system is mounted on the mast; it can slide along it or turn around it. The cylindrical volume around the mast axis represents the access range of the system. Even if such a system doesn’t provide access to the whole silo, it may be enough to create such a hole that the sludge would flow by gravity to the removal system.
- A cable positioning system is currently being developed by COGEMA that would allow the access to any part of the silo. For a square or rectangular silo, this system comprises a set of four cables and winches used to move the retrieval tool horizontally and vertically. The four drive systems are placed in housings located at each external corner of a silo. The housing acts as containment when the system is installed and facilitates the transfer in the event of maintenance or shifting to another tank or silo.

Installation of the cable positioning system requires the use of the existing opening or implementing new ones through the upper slab of the silo:

- at each corner of the silo for cables

— at the centre of the silo for waste retrieval, mobilization, and removal system connections (power, water, etc.).

Using a harpoon and net does first entry and connection of the cables to the mobilization and removal system.

3.2. Mobilization and removal system

The mobilization and removal system consists of three devices mounted on a frame with reduced dimensions that can be moved in the silo with one of the access positioning systems previously described:

— a mechanical stirrer, designed to comply with the critical shear tension of the sludge
— a dilution jet used in conjunction with the local stirrer. Dilution is used only if required to reach the appropriate concentration corresponding to the correct operation of the pumping system
— a local pumping system to pump out the sludge. The pump is adapted to the nature of the sludge: in the particular case of the STE2 viscous sludge, it has been determined that a progressing cavity pump (Moyno type) would be appropriate.

3.3. Transfer system

The sludge is transferred by pipe to an agitation tank. A flexible pipe is used to connect the pipeline and the pumping system. A modular enclosure is installed on the top of the tank. It is a small shielded cell equipped with remote handling manipulators for the introduction and maintenance of the retrieval tools. It also houses the specific winches of the retrieval tool corresponding to water and sludge outlet pipes and electrical cables.

3.4. Implementation

The sampling and characterization phase of the project has provided input for designing retrieval and conditioning system. Development of retrieval tool is as follow:

— Mobilization and removal system has been developed, built, and tested. The tool that will be used for real operation is ready to work.
— The cable positioning system is being developed: tests at reduced scale have been performed and tests at real scale are going on. Also, the cable introduction system has been prototyped and qualified for a configuration similar to STE2 silos.

The implementation of the whole retrieval system will be done after the final selection of the conditioning process. The plan is to start the retrieval operation in 2005.

3.5. Progress and experience to date

The experience gained to date mainly concerns real operation of sampling tools but also prototype tests done on access, mobilization, and removal equipment.

BIBLIOGRAPHY

[1] TCHEMITCHEFF, E. (SGN), DOMAGE, M., BERNARD-BRULS, X. (COGEMA), Sampling of Charged Liquid Radwaste Stored in Large Tanks.

[2] International Conference on Radioactive Waste Management and Environmental Remediation (ICEM), September 3–8, 1995 (Berlin, Germany)

[3] TCHEMITCHEFF, E. (SGN), Retrieval of Liquid and Solid Radwaste Stored in Large Tanks, Seminar Obninsk Feb-March, 1996 (Obninsk)

I-3 USE OF THE GUEPARD VEHICLE FOR CLEANING CONTAMINATED CONCRETE, LA HAGUE

1. STATEMENT OF PROBLEM

The COGEMA-La Hague facilities extract reusable materials, uranium and plutonium, from spent nuclear fuel and condition the waste into suitable final form. In doing this work, it is sometimes necessary to conduct cleanup work in hostile environments (such as highly radioactive areas). In these areas, it is frequently necessary to operate equipment remotely. Suitable equipment may not be readily available because of certain constraints, such as access to the area or the task that needs to be performed. In two rooms in the Cogema reprocessing facilities at La Hague, the existing cleanup methods were found to be inadequate (stability problems and incompatibility between tools and carrier). Thus, special remotely operated equipment was developed to perform the cleanup. Development work on the equipment began in 1983, and it was in service from 1989 to 1992. It was designed to clean the floors of two rooms with high-activity contamination levels. One, Room A, was in the fission product concentration and storage facility, and the other, Room B, was in a facility designed for the chemical treatment of spent nuclear fuel.

1.1. Waste types

The initial waste in Room A consisted of acid-degraded concrete floor contaminated with fission products. The gamma radiation level was greater than 0.1 Gy/h. After a surface erosion operation, the waste was in the form of rubble consisting of particles of different sizes, ranging from dust to pieces 1 cm in diameter. Approximately 5 m^3 of contaminated rubble needed to be removed.

The waste to be removed in Room B consisted of a sticky residue caused by a solvent reacting with an acid-resistant paint; the residue was contaminated with fission products, uranium and plutonium. The gamma radiation level was greater than 0.1 Gy/h, and the volume to be removed was estimated at 1 m^3.

1.2. Current storage arrangements

In both cases, part of the waste was ingrained in the floor. Room A is essentially a long corridor, 5 m wide and 20 m long, with a narrow access. Room B is a large room, 7 m by 20 m, with three levels separated by 1.5-m steps.

1.3. Reasons for retrieval and objectives

The goal in Room A was to reduce the ambient radiation to a maximum of 5×10^{-2} mGy/h to allow personnel passage for work on nearby piping. The radiation levels before cleanup prevented humans from being in the room.

The goal in Room B was to reduce the ambient radiation to less than 2 mGy/h to make direct human access to the room possible. It was established that cleanup of the floor would provide the desired radiological conditions.

2. DISTRIBUTION OF RETRIEVAL PROCESS

2.1. Development methodology

The first step was to design and construct the carrier vehicle (1983 to 1984). This was called "Guepard," and care was taken to use the experience gained from attempts to use an existing carrier. Next (1985), work began on the design and construction of the tools necessary to remove the contaminated materials from Room A, particularly the bush hammer. During this step, particular attention was paid to the choice of remediation processes, their compatibility with the carrier, and the specific requirements regarding remote operation of the tools. Finally (1988), design and development of the containment system and waste collection system took place. Before work in Room B was started (1992), a washing/scrubbing system was added to the range of tools for the Guepard carrier so that the system could do final cleanup.

3. DESCRIPTION OF THE SYSTEM

3.1. Carrier

The Guepard is a tracked vehicle that weighs 230 kg. It is driven using two independent, sealed motors. It has a 61.5 cm x 80 cm platform, set 30 cm above floor level, that contains an adaptable mount to receive, hold, and position the required tools. The Guepard is operated by remote control from an operator station using a 100m long cable. This tracked vehicle can be completely submerged in liquid, can be completely decontaminated, and can move up and down 60% slopes.

3.2. Operator station

An easily transported 2 m x 2 m cabinet was developed to centralize the controls and displays required for operation. From this station, the operator can control both the Guepard carrier and its tools, as well as see the display monitors. In addition, the operator can manage the waste removal system and see the indicators showing the radiation readings of onboard and fixed sensors.

3.3. Tools

The following tools were developed or adapted to meet the requirements of the two work areas:

- Bush hammer for cutting back and breaking
- Jack hammer for work on the bottom of walls
- Vacuum nozzle for picking up dust and small pieces of rubble
- Washing/scrubbing system for work on floor paint without erosion
- Romain-50 electric arm for inspecting and taking samples (the arm has three degrees of freedom, 50 N capacity, and is joystick controlled).

3.4. Containment and collection of waste

The waste recovered by the Guepard's onboard equipment was transferred from the work area to the collection area by a special vacuum system generating a suction of 9 m water gauge. Filters were then used to separate the waste. Cogema has patented this exclusively dry process.

3.5. Cold tests

To confirm the performance of the equipment, full-scale tests were carried out, including the waste removal system. Although the tests covered all operational aspects of the equipment, its endurance was not tested.

To prepare for operations in Room B, where access constraints necessitated the installation of ramps, special additional tests were conducted that confirmed the carrier's ability to negotiate up and down ramps, with a maximum incline of 15 degrees, when the carrier was fully laden (weight in excess of 400 kg).

4. DISTRIBUTION OF RETRIEVAL PROCESS

4.1. Tools used in Room A and cleanup constraints

Apart from the waste collection and packaging system, the following tools were required for cleaning up Room A:

— Bush hammer, for removing a 5-cm layer of concrete, which had been shown to have the necessary penetration
— Jack hammer
— Remote-controlled arm
— Guepard carrier was also used for radiological reconnaissance of the room.

At the entrance to Room A, headroom and side clearance were both greatly reduced (650 mm and 800 mm respectively), requiring significant driving skills.

4.2. Scheduling for Room A cleanup

The work took place in two sessions. The first session occurred in 1989. Some 30 m² of the central part of the room was cleaned up. Operation planning lasted 6 weeks, and the work itself took an additional 3 months followed by 2 more months to close the work area. The second session began in 1990. In this session, the remaining 70 m² were cleaned up. Operation planning lasted 5 weeks, the work itself took 25 weeks, and closing of the work area took another 2 months as in the previous case.

4.3. Performance of cleanup system in Room A

The gamma radiation dose rates recorded during the work ranged from 6 to 60 mGy/h. After the work was completed, the gamma level did not exceed 5 x 10^{-2} mGy/h. The goal was met.

Tools used in Room B and cleanup constraints: The tools used in Room B included the brush; the system for vacuuming up, filtering out, and collecting the waste; and, as in Room A, the Guepard carrier to make a radiological reconnaissance of the room. The carrier could not negotiate the 3-m difference at the entrance to the cell and the 1.5 m one inside it. Ramps were installed in advance.

4.4. Scheduling of Room B

The Room B floor cleanup operation took place in 1992. During the initial planning phase, 4 months were devoted to additional studies and procurement, and 2 months to planning of the operation itself. Operations lasted for 3 months, and closing the work area lasted another 2 months.

4.5. Performance in Room B

The gamma radiation dose rate recorded at floor level before work began was greater than 0.1 Gy/h. After the work was completed, the dose rate at floor level was less than 40 mGy/h due to the ambient radiation in the cell.

4.6. Progress and experience to date

The Guepard vehicle and tools met the requirements concerning breaking up concrete flooring and vacuuming up waste in the form of dust and small pieces of rubble. It also met the endurance constraints associated with remote operation in a hostile environment. The system was operated for more than 500 hours and enabled radiation levels to be reduced by factors of up to 100.

No maintenance was necessary during operations. After each operation, the carrier was decontaminated by washing. Changing the seals and tracks, which required hands-on maintenance, was then possible.

4.7. Lessons learned:

This type of carrier proved useful for remote operations, and further development work was carried out to allow

- Removing thin layers of materials with a scraper
- Brushing and suction under water for pond cleaning
- Adding a lifting platform for use of tools at higher levels
- Utilizing a 200 N electric arm with force feedback
- Determining and documenting the systems' limits of operation in the field.

Some improvements were made to the Guepard carrier, including modifications to the tracks and the suspension, and changing the location of the umbilical cord attachment as needed (that is, attaching the cord to either the right or the left side based on the waste storage area configuration).

ANNEX II
RUSSIAN FEDERATION

II-1 RETRIEVAL OF WWER AND RBMK-TYPE REACTOR EVAPORATOR BOTTOMS

1. STATEMENT OF PROBLEM

Until recently, Russian radioactive waste, both liquid and solid, was stored at nuclear power plant (NPP) sites without treatment, that is, in raw 2005-08-25 11:09:20unconditioned form. Annual radioactive waste generation and some typical characteristics of waste are presented in Table I. The availability of and demand for radioactive waste processing techniques at the Russian NPPs are reflected in Table II.

According to information from Rosenergoatom [1], at the end of the year 2000 the cumulative volume of liquid waste at eight Russian NPPs was 78,500 m^3, solid waste was at 113,300 m^3. Storage tanks for evaporator bottoms have been filled with concentrates up to 80 to 96%; solid waste storage facilities up to 80 to 89%. Such a situation is typical for Ukrainian reactors and for the relatively old V1 NPP in Slovakia (storage capacities for evaporator bottoms - 4,150 m^3; volume of concentrate in storage 3 200 m^3).

Only evaporator bottoms will be considered in this annex as the waste representing the most actual problem.

TABLE I. ANNUAL GENERATION OF WASTE IN NPPs WITH VARIOUS TYPES OF REACTORS IN RUSSIA

Type of waste	**WWER-440**	**WWER-1000**	**RBMK-1000**
Evaporator bottoms, m^3/year Average salt content of evaporator bottoms, g/dm^3 Total quantities of salt, t/year Specific activity of evaporator bottoms, g/dm^3	120-170 300-400 50 $5 \cdot 10^{-5}$	220-300 300-400 90 $5 \cdot 10^{-5}$	1000-1200 200-250 250 $5 \cdot 10^{-5}$
Low-activity sorbents, m^3/year Specific activity, Ci/kg	8.0 $3 \cdot 10^{-3}$	16 $1 \cdot 10^{-3}$	62.0 $1 \cdot 10^{-3}$
High-activity sorbents, m^3/year Specific activity, Ci/kg	3.0 $5 \cdot 10^{-2}$	5.3 $5 \cdot 10^{-2}$	22.0 $5 \cdot 10^{-2}$
Perlite, m^3/year Specific activity, Ci/kg	- -	- -	9.0 $2 \cdot 10^{-3}$
Solid radioactive waste, m^3/year	200	300	400

TABLE II. RADIOACTIVE WASTE TREATMENT TECHNOLOGIES AT THE RUSSIAN NPPs AS OF THE BEGINNING OF 2000

NPP	Cementation	Compaction	Incineration	Bitumization	Vitrification	Radionuclides isolation	Metals melting
Balakovskaja		D	D	W		D	
Belojarskaja	D	W/D	W			D	D
Bilibinskaja	D	D	D				
Kalininskaja	D	D	D	W		D	
Kol'skaja	D	W/D	W/D			D	
Kurskaja	D	D	D		D	D	
Leningradskaja		D	D	W		D	D
Novovoronezhskaja		W/D	D		D		D
Smolenskaja	D	D	D			D	

W = in place
D = intended to be introduced in practice

1.1. Waste type

WWER Reactors[1]*:* Aged evaporator bottoms of the Russian WWER-type reactors, as a rule, represent crystalline phase and high-density liquid in relation 0,9:0,1 or more. The solid phase is formed mostly by low soluble meta and tetraborates, as well as sodium nitrates and carbonates in comparable concentrations. Specific activity varies from 5 x 10^{-5} to 5 x 10^{-4} Ci/dm^3; pH varies from 11 to 13.

In the supernate, the whole spectrum of corrosion products is detected; iron and nickel are dominant. Critical radionuclides are cesium-134, -137, cobalt-60, silver-110, and manganese-51 (whole isotopic composition can be presented, if necessary).

RBMK Reactors[2]*:* Evaporator bottoms of RBMK-type reactors represent a combination of supernate and very dense ("cemented") sludge. The main macrocomponents of the solid phase are sodium oxalates and sulphates, and MnO_2, with some possible addition of perlite and diatomite. Specific activity and isotopic composition of concentrates are very similar to those for WWER reactors. Concentrations of corrosion products are essentially higher than in evaporator bottoms containing borates.

Both types of radioactive waste contain very high (100 g/dm^3 and more) concentrations of organic compounds coming with laundries waters, decontamination solutions, floor waters, and washing fluids from the steam generator.

[1] A WWER or water water energetic reactor is a pressurized water reactor with a core composed of low enriched uranium dioxide fuel rods, enclosed in zirconium cladding, in a hexagonal geometry [2].

[2] An RBMK reactor is a boiling-water-cooled channel type, graphite-moderated reactor. The core is composed of fuel rods of low enriched uranium dioxide pellets in zirconium cladding. The rods are arranged in hexagonal fuel assemblies and placed inside pressure fuel channels in a graphite matrix. The channels are cooled by water that boils as it passes through the channels [3].

1.2. Current storage arrangements

Evaporator bottoms from WWER reactors are stored in stainless steel vessels located in concrete containments with 460 to 500-m3 capacity; evaporator bottoms for RBMK, 5,000-m3 capacity. WWER tanks are placed vertically, RBMK, horizontally. The tanks contain access ports. At many NPPs, the distance between the upper opening and the containment is not enough for employment of "standard" sampling, analytical, and retrieval equipment.

1.3. Reasons for retrieval

There are a number of serious reasons for retrieving evaporator bottoms from the storage tanks. First, availability of storage capacities is an absolutely inseparable component of the existing energy production cycle. Second, on-site storage of the large volumes (thousands cubic metres) of chemically active unconditioned radioactive concentrates increases the risk of accidental situations with all that it implies. Third, according to the national regulation, to obtain the license for facility life extension or decommissioning (both are actual options for many reactors), it is necessary to demonstrate that all the radioactive waste accumulated at the reactor's site are removed or transferred in an environmentally safe form, and all the waste expected to be generated during decommissioning process will be managed adequately.

1.4. Objectives

The objective of the retrieval activity is to remove the predominant (if not all) share of evaporator bottoms from the tanks for on-site deep treatment of concentrates, aiming at obtaining an essentially reduced volume of conditioned waste applicable for temporary storage and further transportation to a centralized disposal site.

2. RETRIEVAL STRATEGY

2.1. Sampling and waste characterization

Regular sampling and analysis of evaporator bottoms are part of a NPP's routine activities. Access to the tanks is limited because of the tank design and worker safety issues. This limited access as well as the absence of "standard" analytical procedures, directly related to retrieval-processing requirements, restrict the number of the samples taken and the information received. In specific, the information on physico-chemical characteristics and on the nature of organic compounds presented are very limited.

The analyses performed included the following:

— Boric acid determination
— Metal analyses (epizodically)
— pH determination
— Cations and anions determination
— Radioisotopes determination
— Densities
— Main organic compound determination
— Unsoluble remainder
— Viscosity.

For more information, some data from Kalininskaja, Leningradskaja, and South Ukrainian NPPs can be presented, if necessary.

2.2. Infrastructure upgrade

Significant infrastructure upgrades will be needed, including access to the tank and connections with the processing facility, adding engineering communications that exist both in and out of the tank, unloading structures, and electrical systems. The final solution will be accepted after pilot-scale testing of waste processing equipment and selection of optimal technology for waste conditioning.

2.3. Downstream process

In accordance with a concept recently accepted in Russia (see [4-6]), retrieved evaporator bottoms are intended to be treated with separation of macrocomponents (salts and water) in such a form that allows storage without special precautions (preferably as nonradioactive waste) or reuse in technological processes, and concentration of radioactivity in the smallest reasonably achievable volume in a form ensuring further reliable isolation of activity. The key elements of a retrieval technology are 1) removal/destruction of complexing organic constituents, and 2) employment of highly efficient selective sorbents “thermoxide”. Pilot-scale trials have clearly demonstrated applicability of this technology for WWER evaporator bottoms and prospects of the method proposed for the processing of evaporator bottoms from RBMK reactors.

In Slovakia and the Czech Republic, evaporator bottoms are subject for solidification in bitumen and cement.

For more information, a number of references, including patents, can be presented.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

To mobilize the borate-containing radioactive concentrates of WWER reactors, it is intended to use the following combination of factors: suspension, heating, and dissolution. For RBMK evaporator bottoms, the most prospective technology is suspension combined with chemical reduction of Mn(IV) to Mn(II).

For removal of mobilized concentrates from the tanks, there exists a broad spectrum of commercially available and specially designed equipment.

In Slovakia, NPP-A1 evaporator bottoms are re-pumped by technological pipeline to bituminization or a cementation unit (in the treatment centre).

Evaporator bottoms from NPP-V1 and -V2 are re-pumped from storage tanks into the transport container (volume 2.5 m^3) by a vacuum system. After the transport at the bituminization plant, evaporator bottoms are re-pumped from container by pressurized air in technological vessels.

In the Czech Republic NPP-DUKOVANY, evaporator bottoms are re-pumped from the storage tank directly by pipelines to the bituminization plant.

3.2. Process

All the stages of the overall technology (from mobilization to deep processing of radioactive waste) are based on an indisputable principle, "the processes, which if anything, decrease total waste volume, do not add new chemicals which can create potentially worse problems, and can be run in low cost facilities for low cost, if not in existing facilities themselves".

For mobilization with subsequent removal of waste the following processes were or are intended to be tested:

— dissolution with utilization of evaporator's condensate or "floor waters". Disadvantage: equilibrium between solid and liquid phases requires 5 to 10 days, even under intensive mixing.

— dissolution with utilization of steam (P = 0.6 MPa; T = 150-170°C) for theown needs of the NPP. Mechanism: "melting" of the salts in crystalline water with subsequent dissolution by the steam condensate. Successfully tested at Kalininskaja NPP.

— employment of hydrodevice (water jet equipment) for suspension and dissolution of the solid phase. Method was tested at radiochemical combine "Mayak"; there are no data for NPP concentrates. Potential disadvantages: increasing waste volume (alternatively, additional equipment for water recirculation and separation of small size crystalls are required). For RBMK, concentrates water jet equipment seems to be an appropriate option, but "hot" tests are required.

3.3. Progress and experience to date

The specific downstream process predetermines both the technology of radioactive concentrates retrieval and the data required at the beginning of retrieval operations. This is because:

— there are no onsite capacities for even temporary storage of evaporated bottoms after retrieval
— there are no techniques for onsite processing of retrieved concentrates to minimise volume of waste
— there is no centralized storage facility able to accept concentrates for treatment and storage/disposal, as well as there are still no special containers for transportation of unconditioned concentrates.

Thus, the progress of retrieval operations strongly depends on how unobtrusively and how successfully the technology of the deep processing of evaporator bottoms will be introduced into practice. At present, such technology is tested with very promising results. In particular, after processing, the specific activities of caesium, cobalt, iron, and manganese in a water stream are below the detection limit of standard NPP's analytical equipment; more than 70% of separated crystalline dry salts (including 99.95% of boric acid) had specific activity less than the bottom limit for low-level solid waste and could be stored in a drums without special precautions. The volume reduction factor varies from 200 to 500 or more, depending on acceptable specific activity of spent selective sorbents.

In October 2001, it is planned to put into operation a pilot facility in Obninsk to demonstrate effectiveness and reliability of processing technology on a semi-industrial scale. Success of this project will open the door for the full-scale retrieval operation at the Russian (and maybe Ukrainian) NPPs with WWER and RBMK reactors.

3.4. Lessons learned

- Deep evaporation of radioactive concentrates as an enforced measure to diminish the waste's volume is not justified based on the efforts and resources needed for retrieval and processing at the further stages of the waste management cycle. Optimal concentration of boric acid should be around 100 g/dm^3 but, in any case, not more than 120 g/dm^3 under pH is approximately 11 to 13.
- Downstream process could essentially be simplified if organic compounds (floor waters, laundry waters, decontamination solutions, and washing fluids from steam generators) would be directed after evaporation into a separate tank. At new NPPs, this concept could be realized at the design stage; for old NPPs, comparative techno-economical analyses would clarify the proper choice.
- As experience has shown, it would be highly advisable to provide new storage tanks with in-tank mixing equipment and in or out-of-tank heating devices. It is also advisable to provide any new tanks with the necessary infrastructure for retrieval operations.

REFERENCES

[1] ROSENERGOATOM, Annual Report, 2000.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Improvement of radioactive waste management at WWER nuclear power plants, IAEA-TECDOC-1492, IAEA, Vienna (2006).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, RBMK Nuclear Power Plants, http://www.iaea.or.at/worldatom/program/safety/nens/rbmk.html, 3 December 2001.

[4] NECHAEV, A.F., TCHUGUNOV, A.S., DMITRIEV, A.S., et al., "Processing of Intermediate Liquid Radioactive Waste from NPPs with WWER-type Reactors", Proc. Intern. Topical Meeting on Nuclear and Hazardous Waste Management, Seattle, August 18-23 1996, ANS Inc., Vol. 1, pp. 111–115.

[5] TCHUGUNOV, A.S., NECHAEV, A.F., SHIBKOV, S.N., et al., "Processing of High-Salted Low and Intermediate Levels Liquid Radioactive Waste: First Principles of Technology Organization and Experimental Substantiation", Proc., ICEM'97, Singapore, October 12–16 1997, ASME, pp. 527–529.

[6] TCHUGUNOV, A.S., NECHAEV, A.F., SHIBKOV, S.N. et al., "New Technologies for Processing of Evaporator Bottoms as One of the Aspects of NPPs Safety Increasing", Proc., Conf. on Nuclear Power Development and Possibilities of Plant Life Extension, St. Petersburg, May 24–26 1999, RNS, pp. 46–47.

BIBLIOGRAPHY

[1] TCHUGONOV, A.S., DMITRIEV, S.A., LIFANOV, F.A., NECHAEV, A.F., et al., Method of NPPs Liquid Radioactive Waste Treatment, RF Patent N2066493 of 10 September 1996.

[2] TCHUGONOV, A.S., NECHAEV, A.F., SHIBKOV, S.N., Method for Processing of Liquid Waste Containing Radionuclides, RF Patent N97117372 of 28 May 1998.

[3] TCHUGONOV, A.S., NECHAEV, A.F., SHIBKOV, S.N., et al., "New Technology for Processing of Concentrates form the Systems of Liquid Radioactive Waste Utilization", Proc. 2nd Intern. Conference on Radiation Safety, St. Petersburg, November 9–12 1999, RESTEC, p.111.

[4] TCHUGONOV, A.S., NECHAEV, A.F., SHIBKOV, S.N., Method of Liquid Waste Cleaning from the Ions of Heavy Metals and Radionuclides, RF Patent N2127459 of 10 March 1999.

II-2 SALT CONCENTRATES MANAGEMENT AT WWER-TYPE REACTORS

The limited free capacity of liquid radioactive waste storage vessels and the lack of conditioning facilities led to the necessity to use deep evaporation units (DEUs) for liquid radioactive waste treatment at some of nuclear power plants with WWER reactors in Russia.

The product of the DEU is a wet mixture of salts with a residual humidity of 15 to 20%. The main macrocomponents of the salt mixture are $NaNO_3$ and $Na_2B_4O_7 10H_2O$. The DEU product is discharged into 200-L-capacity steel containers and is delivered in these containers to on-site storage.

During cooling, the DEU product is being crystallized with water forming $Na_2B_4O_7 x 10H_2O$. The resulting product is a dense substance - the so-called “DEU product”. This DEU product can dissolve when in contact with water and does not have the properties required of conditioned waste.

The use of the DEU is an interim and forced measure. It is assumed that in the future, the DEU product will be subject to conditioning.

For retrieval of the DEU product, it is proposed to warm up the container to 120°C. In the process, the salts are being dissolved in the residual and crystalline hydrate water present in the container.

The resulting solution is poured out of the container and delivered to conditioning by one of the available methods (cementation or vitrification). The container is subjected to washing (decontamination) and is used for packing conditioned waste.

A special facility for DEU product treatment can be erected (if necessary) to serve simultaneously several NPPs; in this case, the containers with DEU product will be used as transport packages.

NPP operational experience shows that:

— newly designed NPPs and those under construction should be provided with the equipment for trapping slurry and precipitates from receptacles and salvage water tanks and for their transportation to conditioning
— the NPP start-up equipment set should include radioactive waste conditioning facilities that would allow slurry processing. This will preclude risk of residue precipitation in liquid radioactive waste storage facilities and exclude the need to take urgent measures and look for interim technical solutions on slurry and residue retrieval out of process vessels.

II-3 RETRIEVAL FROM TANK 8301/3 AT ZHELEZNOGORSK

1. STATEMENT OF PROBLEM

The radioactive waste in Tank 8301/3 needed to be removed for decommissioning plans to continue at the Mining and Chemical Combine (Russia). The tank is located inside the Zheleznogorsk complex (also known as Krasnoyarsk-26), which was built inside a mountain, placing the complex 250 to 300 m underground [1]. The plutonium-uranium extraction process used at the reprocessing facilities at the site produced the radioactive tank waste.

1.1. Waste type

Some time ago, the supernate was removed from Tank 8301/3, leaving sludge and solid materials. This sludge separated into three layers. The top layer could be stirred and had a solid phase concentration of 60 g/L. The second layer was more dense and viscous, having the consistency of fruit jam. The solid phase concentration was 120 g/L. The final layer was strongly dehydrated and structured, with a solid phase concentration of 600 to 800 g/L [2]. Studies indicated the uppermost phase contained hydroxides. The solid phase of the sludge contained metal hydroxides (steel corrosion products, aluminium), polymerised forms of silicic acid, niobium and magnesium oxides, nickel and cerium ferrocyanides, and ion-exchange resins. In addition, the sludge contained significant concentrations of uranium and plutonium. However, because of changes in the processing of the nuclear materials, the waste characterization information on the sludge was not comprehensive [2]. The waste had a pH of 12 [3]. The temperature at the solid-liquid interface was 75 to 108ºC, depending on the depth of the upper layer of sludge [2].

1.2. Storage arrangements

Tank 8301/3 is a vertical tank, approximately 30 m in height and 12 m in diameter, with a capacity of approximately 3 000 m^3. Carved out of the rock floor of the complex, the tank was reinforced with concrete and lined with stainless steel. Retrieving the waste was not an issue when the tank was built. It was built with a single 159-mm-diameter access port (called a backup well) to place equipment [2]. Because the tank is inside the complex, retrieval and characterization equipment can be used without regard for the weather; however, large-scale equipment cannot be used because of the height of the complex's ceiling, 4 m [2].

1.3. Reasons for retrieval

Plans at the Zheleznogorsk complex call for the waste to be removed to 0,05 mSv/hr, also known as maintenance levels [4]. Once the waste is removed, the tank could be dismantled and the rock cavity used to store materials generated by other activities [2].

1.4. Objectives

There were two objectives for removing the waste from Tank 8301/3. The first objective was to demonstrate the effectiveness of several waste retrieval technologies in a vertical tank configuration. The second was to remove enough waste to reach maintenance levels for the tank.

2. RETRIEVAL STRATEGIES

2.1. Sampling

The waste was sampled and provided for characterization. Information is not available on the sampling campaign.

2.2. Waste characterization

The waste was characterised before it was retrieved. The characterization analyses included the following:

- Metal analyses
- Radionuclide analyses
- Beta activity
- Mercury analyses
- Solids concentration [2].

2.3. Infrastructure upgrade

Shielded access ports, each 10 cm in diameter, were added to the top of the tank. In addition, shielded transfer lines were arranged on the hall floor. Video cameras, an eductor to provide rarefaction, an air distributor with slide valve, pipelines, armature, and filters to clean discharge air were installed [5].

2.4. Downstream process

Once the sludge was removed from the tank, it was chemically treated to extract uranium and plutonium. Plans call for the treated sludge to be immobilized as borosilicate glass, although grout or deep well injection could be used [2, 4].

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technology involved

Hydro-monitors and hydro-elevators were used to remove waste in Tank 8301/3. The hydro-monitors, which are similar to some sluicing jet systems used in the USA, use two sluicing jets mounted on opposite sides of a vertical shaft. The lower jet is designed for immersion in the waste. The upper jet is not. A pulsating pump powers sluicing. Supernate can be used as the motive fluid [5]. The hydro-elevator is similar to a conventional axial jet pump, used in the USA [6]. The pump consists of a vessel; intake and discharge check valves; a working air supply pipe; and discharge pipe. Intellectual property issues prevent a full description of the equipment used [4].

3.2. Process

Ten hydro-monitors and four hydro-elevators were installed near the centre of the tank. To remove the waste, supernate from an adjacent tank was forced through the immersed jet and agitated the waste in a circle approximately 4 m in diameter. Periodically, the waste was pumped out using the hydro-elevators. When the cleared area reached 2 m in depth, the lower jets were closed and the upper, non-immersed jets were used to create a pressurized stream of liquid. This method effectively mobilized waste at a 16 to 24 m radius. This process mobilized the uppermost layer of sludge [5].

After the upper layer was removed, one of the hydro-monitors was removed and replaced with a hydro-monitor with four horizontal jets at the lower end. The jets were effective near the hydro-monitor but left thick sludge several feet deep in the tank.

Next, 30 g/L or 0.5 molar nitric acid was added to the tank through a hydro-monitor at 5 to 6 atm. The nitric acid reacted with sludge, and acidified sludge was pumped out of the tank and separated. The solids were transferred to another location; the liquid was returned to the tank with additional acid. This process was repeated over the course of a year or more.

3.3. Implementation

A pulsating mixer pump is being developed to have better effect on the hard sludge. The unit consists of an integral pulsating pump that discharges either through lower nozzles, under liquid directly at the sludge, or a steerable sluicing nozzle in the air above the waste. The through air nozzle has a greater effective range than the submerged nozzles. It will be tested in the next tank to be retrieved.

3.4. Progress

Approximately 75% of the 380 m^3 of sludge was removed from the tank by this retrieval process. This did not meet the objective of reducing the radioactive contamination to maintenance levels. However, it did show that the sluicing and pumping equipment used was effective at removing hydrated sludge.

3.5. Lessons learned

- *Closure requirements*: It is not technically possible to remove all of the heavy residues from the tank bottom with the current retrieval technologies.
- *Dehydrated sediments*: Chemical treatment removed some of the dehydrated sediments at the bottom of the tank. These sediments need to be removed before the rest of the waste because the waste, which has temperature readings in excess of 100ºC, could boil if the more hydrated materials are removed first [2].
- *Sluicers*: Liquid can be replaced with supernate, water, or peptizing agents, based on chemistry concerns [5].

REFERENCES

[1] BELLONA FOUNDATION, Zheleznogorsk. Available: http://www.bellona.no/imaker?sub=1&id=8225, Bellona Foundation, Oslo, Norway (11 July 2001).

[2] RUSSIAN FEDERATION MINISTRY FOR ATOMIC ENERGY (RFMAE), Activities for Establishing at Mining and Chemical Combine a Demonstrations Center for Handling Radioactive Waste Accumulated in Storage Tanks of Nuclear Weapons Industrial Complex of Russia and USA. Attachment 6. Augusta, GA (January 2000).

[3] U.S. DEPARTMENT OF ENERGY (DOE), Russian Chemical Cleaning - Russian Tank Meeting Held in Augusta, Georgia. U.S. Department of Energy, Augusta, GA (September 2000).
[4] U.S. DEPARTMENT OF ENERGY (DOE), Record of Meeting. U.S. Department of Energy, Augusta, GA (September 1997).
[5] U.S. DEPARTMENT OF ENERGY (DOE), Tank Retrieval and Closure Demonstration Center Workshop. U.S. Department of Energy, Augusta, GA (January 2000).
[6] ENDERLIN, C. W., MULLEN, O. D., TERRONES, G., Performance Evaluation of the Quarter-Scale Russian Retrieval Equipment for the Removal of Hazardous Waste. PNNL-11740. Pacific Northwest National Laboratory, Richland, WA (1997).

ANNEX III
SLOVAKIA

III-1. SLUDGE WALKER AT THE NUCLEAR POWER PLANTS RESEARCH INSTITUTE, TRNAVA

1. STATEMENT OF PROBLEM

At Nuclear Power Plant A-1 at Jaslovské-Bohunice, Slovakia, sludges and slurries were generated in Tanks 2/1 and 2/2 in Building 44/10. The waste needed to be removed to make conditions suitable for the next decommissioning activities.

1.1. Waste type

Sludges and slurries were stored in the two tanks (theoretical volume of 390 m^3). The total gamma-beta activity waste is 2.10^{14} Bq; the alpha activity is approximately 10^{10} Bq. Radiation levels detected in and around the tanks have been up to 15 to 20 mGy/hr. The waste in the tanks separated into two distinct layers: sludge and supernate. Supernate is a slow alkaline (pH $\approx$ 8.5). The sludge layer consists of 4 to 5 cm of precipitants composed of ferrocyanide kalium, copper, caesium slurries, aluminiosilicate compounds, and a thicker layer in the middle of tanks that consists of 50 cm of contaminated sand and gravel. Principal radioactive components are fission products such as caesium and strontium, activation products such as cobalt, and actinides such as uranium, plutonium, and americium.

1.2. Storage arrangements

Both tanks have 390 m^3 capacities. They are constructed from the reinforced concrete vaults and their inside surfaces are constructed of stainless steel. The diameter of each tank is 11.6 m, and the height is 4.6 m. The tanks are underground. The middle of the tank bottom is settled space diameter of 2.5 m, and the depth is 0.5 m (that is, there is a sump or depression 2.5 m in diameter and 0.5 m deep in the centre of the tank to ease pumping). Pipelines with the main building NPP-A1 and evaporating unit at NPP-A1 connect the tanks.

1.3. Reasons for retrieval

This waste needs to be removed to decommission these tanks. According to valid Slovak legislative conditions, these tanks are not suitable for liquid radioactive waste storage. For this reason, the tanks will be decommissioned in the near future.

1.4. Objectives

The objectives for retrieving waste from the tanks were to 1) mix and remove waste in a cost-efficient manner, 2) reduce risks to environmental influence, and 3) minimise the generation of secondary waste.

2. RETRIEVAL STRATEGY

2.1. Sampling

Tanks 2/1 and 2/2 were sampled and characterised in 1999 and 2000. The waste was sampled to determine the appropriate retrieval strategy. Sampling was done by means of a manually operated specialty sampling device that was proposed and constructed in Vuje, Trnava.

2.2. Waste characterization

The waste was characterised using some methods from chemistry. The following analyses were performed:

- Particle size
- Cations
- Anions
- Solubility
- Settling tests
- Radiochemical compositions
- Oil content
- Content of combustible organic compounds

2.3. Infrastructure upgrade

A contaminated water layer, approximately 80 m^3, was repumped from Tank 2/2 into Tank 2/1 during year 2000 by the submersible pump, MNFU-SIGMA.

2.4. Downstream process

The liquid material from these tanks will be transferred[1] to technological tanks for conditioning in a cement matrix. The contaminated sand and gravel were transferred from tank 2/2 into 200-L steel drums that will be immobilized in the cement matrix directly in the drums.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

A sludge walker remote-controlled vehicle designed and fabricated by INMART-ATOM, Martin, Slovakia is a semi-robotic system operated by long-distance control system. It was used in the retrieval of sludge, sand, and gravel mixture from Tank 2/2 into the 200 dm^3 steel drums. Currently, 10 m^3 of the above mentioned waste mixture has been retrieved.

The sludge walker is a unique technical system because it can be deployed mechanically. A layer is formed from mixing materials, such as sludges, slurries, sand, gravel,

[1] In specially containers and after the transport is repumped.

and pieces of other solid parts. These materials are retrieved into the steel drums or other types of containers (for example, plastic containers).

By using the sludge walker it is possible to use some exchangeable tools, such as the following:

- Shovel for sand and gravel
- Floor cleaning system consisting of a rotating brush as a cleaning tool
- Sludge pump for the sludge removal (Maximum density of the sludge: 1.1 $kg.dm^{-3}$)
- Membrane pump for sludge re-pumping (Maximum density of the sludge: 1.3 $kg.dm^{-3}$. Maximum diameter of the solid particles: 3.2 mm).

The auxiliary technical system belongs to this technical system; it consists of the following:

- Small container: for the elevating of sludges and other materials from the tank (volume: 43 dm^3, measurement: height 420 mm x width 500 mm x length 380 mm, weight: 20 kg).
- Shovel: (measurement: upper part: 720 x 520 mm, under part 350 x 350 mm, height: 635 mm, weight: 46.3 kg, volume: 12 dm^3)
-

The sludge walker can be used for radioactive material retrieval of up to 10^9 $Bq.dm^{-3}$ activity (gamma, beta). It is movable on the sludge layer, sand, gravel, etc. Four specialized wheels that have independent movement supply the sludge walker movement.

The main technical parameters of the sludge walker are the following:

- Measurement: B 565 mm x H 550 mm x L 1303 mm
- Weight: 230.0 kg
- Velocity: 0-0.3 $m \cdot s^{-1}$
- Supplying of electroenergy: 3 x 380 V

3.2. Process

Outside the tank, the selected tools (shovel, rotating brush, etc.) are mounted on the sludge walker. The whole system is inserted through the tanks' shaft in a vertical position by using the auxiliary technical system (steel keeping and insert system) in the tank. The sludge walker is operated by means of a television camera system for process control. When an auxiliary container is full, its contents are replaced in the 200 dm^3 steel drum. The sludge walker has a decontamination unit as well.

3.3. Progress

From April to July 2001, 10 m^3 of the radioactive mixture (sludge, sand, gravel) was removed from Tank 2/2 in Building 44/10 at the NPP-A1 in Jaslovské-Bohunice.

3.4. Lessons learned

- The sludge walker was used in the W-tanks at NPP-A1 Jaslovské-Bohunice.
- Long-distance operation of the sludge walker minimises radiation exposure.

— The use of the exchangeable tools increases the universality of the sludge walker.
— The rapid installation process for the sludge walker can reduce costs.
— The use of sludge walker is suitable for tanks with a complicated geometric surface.
— The sludge walker is suitable for the contaminated sand and gravel retrieval as well.

BIBLIOGRAPHY

[1] PEKAR, A., JADLOVSKY, I. 2000. "Sludge Walker, Technical Parametres and the Assessment Active Experiments Concerning to Contaminated Sand and Gravel Retrieval." Presentation on the Workshop "Treatment of the RAW in Slovakia" November 2000, Zavažná Poruba, Slovakia.

[2] ZATKULAK, M., HOLICKA, Z. 2000. "Contaminated Sludges Treatment Results from the Laboratory Experimental Works." Presentation on the Workshop "Treatment of the RAW in Slovakia" November 2000, Zavažná Poruba, Slovakia.

[3] BREZA, M., ADÁMEK, A. 2000. "Systematical Approach to the RAW Treatment in Slovakia." Presentation on the Workshop "Treatment of the RAW in Slovakia" November 2000, Zavažná Poruba, Slovakia.

[4] MÍCHAL, V., KRAVÁRIK, K. 2001. "Technology Development for Decommissioning in Nuclear Power Plants Research Institute, Slovak Republic." The ANS 9th International Topical Meeting on Robotics and Remote Systems. Seattle, Washington. USA. March 2001.

[5] MÍCHAL,V., BAČA, M.,KRAVÁRIK, K., MENYHARDT, P. 2001. "Advanced Technologies for D&D of the A-1 NPP." Waste Management 2001, Tucson, Arizona. USA, March 2001.

[6] KRAVÁRIK, K., MÍCHAL,V., MENYHARDT, P. 2001. "Technologies Used for D&D of the A-1 NPP in Slovakia and their Comparison with Advanced Worldwide Approaches." Proceedings of the 8th International Conference ICEM 2001, October 2001, Brugges, Belgium.

[7] KOVER, M. 2001. "Waste Treatment Centre for Law and Intermediate Waste (BSC-RAO) and the Storage for Final Disposal of Conditioned Waste in Slovakia since March 2000 in the Active Test Phase." 8th International Conference ICEM 2001, Brugges, Belgium.

[8] Operationing Instructions No.T-057: Repumping of the Evaporator Concentrates in Bldb. No.809.

III-2. LONG REACH ARM MANIPULATOR AT THE NUCLEAR POWER PLANT A-1

1. STATEMENT OF PROBLEM

At Nuclear Power Plant (NPP)-A1 in Jaslovské-Bohunice, Slovakia, 10 tanks contain liquid waste with sludges and contaminated insoluble particles (sand, aluminosilicate compounds, etc.). The waste needs to be removed to make conditions suitable for the tanks' decommissioning.

1.1. Waste type

Approximately 240.0 m^3 of sludge is stored in the ten tanks at NPP-A1 Building 41. Radiation levels detected in and around the tanks are very low, within 1/10 mGy/hr. The tanks cannot be used for the sludge storage, and they are listed for the next decommissioning. The waste in the tanks separated into two distinct layers: sludge and supernate. During the year 2000, supernate from the eight tanks (No. 6/1, 6/2, 4/1, 4/2, 3/1, 3/2, 2, and 1) was removed using the submersible pump for the conditioning in the cement matrix. At present, in these tanks, the rest of the sludges are stored. Sludges are stored in Tanks 7/1 and 7/2. The sludge has a total volume of 230 to 235 m^3. The pH value of these sludges is alkaline (8 to 8.5). The major metal components in 7/1 and 7/2 are calcium, sodium, magnesium, calcium, iron, and chromium. The major anions are sulphates, carbonates, and nitrates. Besides this, there are some concentrations of oil and other organic compounds (burnable organic) and some aluminosilicates originated from the classic powder (from the cleaning rooms activities).

1.2. Storage arrangements

Two storage tanks, 7/1 and 7/2, have a capacity of 630 m^3 each. Two storage tanks, 6/1 and 6/2, have a capacity of 100 m^3 each. The storage tanks 4/1, 4/2, 3/1, 3/2, 2, and 1 have capacity 50 m^3/ per tank.

The tanks are held in underground concrete vaults that have the inside surface covered by PESL (polyester composition).

The bigger tanks are 7/1 and 7/2 that have a retrieval storage volume of 630 m^3 each. The diameter of the tank is 16.5 m and height is 7 m. The isolating inside layer (made from PESL) is damaged. The thickness of the walls is 30 cm. The tanks were connected to about 150 to 200 m of transfer pipelines to the NPP-A1.The tanks and pipelines have served for the collection of the contaminated water streams (low salinity) from NPP-A1 during its operation. In the last 10 years, it has been prohibited to use these storage tanks. Some connected pipelines were cut and closed.

The other storage tanks in Building 41 at NPP-A1 have the following main parameters: Tanks 6/1 and 6/2 are held in underground concrete vaults, and the inside surface is covered by PESL. The diameter of each tank is 6 m, height 3 m, and walls have a thickness of 30 cm. Tanks 4/1, 4/2, 3/1, 3/2, 2, and 1 have a similar construction as storage tanks 6/1 and 6/2, but in the middle, they are divided by a concrete wall. The above-mentioned storage tanks have an independent shaft for the sampling and control.

1.3. Reasons for retrieval

This waste together with the damaged isolation material (PESL) needs to be removed to prepare the tanks for the next decommissioning activities.

1.4. Objectives

The objectives for retrieving waste from storage tanks NPP-A1 Building 41 were to

— Mix and remove waste in a cost efficient manner
— Reduce the amount of time required to perform these activities
— Reduce risks, to workers, public and environment
— Minimise the generation of secondary waste
— Prepare the tanks for the decommissioning that should be done during the next 5 to 7 years.

2. RETRIEVAL STRATEGY

2.1. Sampling

Tanks 7/1, 7/2, 6/1, 4/1, 4/2, 3/1, 3/2, 2, and 1, in Building 41, were sampled and characterised from the year 2000 until June 2001. The waste was sampled by a special sampling device that was proposed, drawn, and constructed at VUJE.

Sampling was done by means of a normally operated small screw sample device, mounted on the auxiliary system. More information concerning for the sampling equipment are in documents.

2.2. Waste characterization

The waste was characterised using the approved methods by the Slovak Authorities for the nuclear energy.

The following analyses were performed:

— Particle size
— Cations
— Anions
— Radiochemical compounds
— Insoluble rest
— Oil contents
— Burnable organic compounds.

More information on the characterization of the waste can be found in the technical annual report.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The retrieval technical system, the Long Reach Arm Manipulator (LRAM) will be used for sludge retrieval. It is positioned on the covers of tanks, among the inside walls and pipelines, etc. It is useable for the sludge retrieval from the tanks. Because the tanks have a complicated geometric structure, LRAM will be used.

3.2. Infrastructure upgrade

Tanks 7/1, 7/2, 6/1, 6/2, 4/1, 4/2, 3/1, 3/2, 2, and 1 used existing penetration shafts. For the experimental purposes for the verification, VUJE proposed and constructed an experimental pilot stand and at present, verified the whole technical system.

The long-reach arm DENAR consist of the following:

— 1st arm pitch from - 90° lo + 30°
— 2nd arm pitch ± 90°
— 3rd arm pitch ± 90°

Three combinations of bailing arms

— 1st reach of manipulator 9.0 m
— 2nd reach of manipulator 6.15 m
— 3rd reach of manipulator bearing MT-80 6.15 m

The long-reach arm consists of three modules. On the long arm, it is possible to mount exchangeable tools such as a shovel, rotating saw, rotating brush, etc.

3.3. Process

The arm system is mounted on the auxiliary technical supporting system and is long-distance operated. It will be mounted directly in the upper part of the storage tank, beside the retrieval of the sludges from the storage tanks. The whole technical system is devoted for the decontamination activities as well. Fig. 1 is a view of the long-reach manipulator DENAR-41. Fig. 2 is a view of the basic technical parameters of the MT-80 manipulator. Fig. 3, 4, 5, and 6 are photos from the system verification during the inactive experiments at VUJE. Fig. 7 is a photo of MT-80 manipulator. Fig. 8 is the technical auxiliary trying system, and Fig. 9 is a photo of the long-reach arm.

3.4. Progress

As of January 2000, there was a prepared design and the completion of additional equipment for MT-80 manipulator. During the years 2000 and 2001, the software system for the MT-80 manipulator and for DENAR-41 was developed.

The long arm manipulator DENAR-41 was mounted at VUJE in October 2000 and during December 2000 to August 2001 and was tested in inactive conditions.

According to the time schedule, this manipulator will be tested for the active conditions during September to December 2001 for cleaning Tank 6/1.

3.5. Lessons learned

— In the storage Tanks 7/1, 7/2, 6/1, 6/2, 4/1, 4/2, 3/1, 3/2, and 2 at NPP-A1 Jaslovské-Bohunice, the long-reach arm will be used for the sludges retrieval and tank cleanings.
— In the present, the whole technical system is ready to use for the Tank 6/1 at NPP-A1.
— The use of the long-reach arm DENAR-41, together with manipulator MT-80, will minimise the generation of additional waste.
— The long-reach arm DENAR-41 together with manipulator MT-80 is suitable for tanks with the complicated geometric structures.
— The modular design, quick connect completion, and long operated system controlled by TV-cameras minimise radiation exposure.

ANNEX IV
UNITED KINGDOM

IV-1. B31 SLUDGE RETRIEVAL

1. STATEMENT OF PROBLEM

1.1. Waste type

First generation nuclear power stations in the United Kingdom used fuel clad in a magnesium alloy known as Magnox. Magnox fuel elements were stored under water in a pond to allow cooling and decay of short-lived radionuclides. Immediately before reprocessing, the cladding was removed in a process called decanning. Liquid effluents from the pond and decanning facility were passed through a settling facility (B31) to allow the solids to settle before the liquor was sent for further treatment. At the end of its life, the B31 facility contained significant quantities of Magnox sludge with traces of irradiated uranium metal.

1.2. Current storage arrangements

The settling tanks commenced operation in 1960 with a capacity of more than 200 m^3 [1] of Magnox sludge in two settling tanks, inlet chambers, and a sludge sump [2]. The settling tanks are open to the atmosphere, which gave rise to aerial discharges from the water surface [1].

1.3. Reasons for retrieval

The B31 settling tanks, although they were structurally sound, were not in a good radiological condition with up to 1 mSv/hr gamma radiation in the area around the tanks and chambers [1]. British Nuclear Fuels Limited Inc. has an intention to remove all mobile radioactive waste from obsolete plants, so it can be processed into a form suitable for long-term storage.

1.4. Objectives

At present, obsolete plants demand a high level of care and maintenance at a high financial and staffing cost. The objective is to achieve low surveillance and maintenance cost status as soon as possible [3], put the mobile radioactive waste into safe storage, and move to decommissioning the facility.

2. RETRIEVAL STRATEGY

2.1. Waste characterization

The sludge in the facility contained traces of irradiated uranium metal. The specific activity is such that the sludge is classified as intermediate-level waste [1].

2.2. Infrastructure upgrade

A new travelling bridge was installed along with a new pipeline to discharge the sludge to downstream intermediate settling facilities (B315). Maintenance areas at the east and west end of the facility were also constructed [2]. The operation was controlled from a new separate control cabin [1].

2.3. Downstream process

The sludge was sent to the new settling tank facility (B315), which was designed to take over from the original settling tanks [1]. The sludge was then sent to the Site Ion Exchange Plant (SIXEP) [4] for intermediate storage in modern stainless steel containment where it remains to date. Ultimately, the sludge will be recovered from the SIXEP storage vessels by the Sludge Export Facility and sent onto the Sellafield Drypac Plant [5]. After treatment, the product from the drypac plant will be sent to the Waste Encapsulation Plant [6] before being placed in the Encapsulated Product Store [7].

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Process

Sludge was removed from the B31 settling tanks using a pumping head mounted on a travelling bridge. It was then pumped along a pipeline to intermediate settling before transfer to SIXEP. The retrieval machine is comprised of two desludging heads, sized for the settling tanks and for the inlet chambers and sludge sump. These heads are suspended from the travelling bridge and crab unit, which allows access to the full area of sludge.

The equipment re-suspended the sludge in a controlled manner, converting it into a slurry, which could be pumped. The re-suspension and dilution processes were accomplished in a local containment system, thereby limiting the volume of re-suspension.

The desludging heads were maintained in contact with sludge layer as the sludge was removed. This ensured that any suspension of the sludge outside this mixing space was minimal. The re-suspension method used liquid jets, which impinged on the sludge causing re-suspension over a fixed and limited area within the containment. The re-suspended sludge was then diluted with water in the containment to a controlled slurry concentration. The bridge itself ran on rails fixed to the walls of the settling tanks and the operation was controlled remotely from a separate control cabin using positioning devices and a closed circuit television system [1].

3.2. Implementation

Because of the high radiation levels from the sludge, considerable design work and testing of the equipment to minimise dose uptake during installation, operation, maintenance, and decommissioning were carried out.

An inactive facility to commission the machine, its control room, and auxiliary equipment was installed to simulate operational requirements. An inactive trial assembly followed this. As much inactive commissioning as possible was carried out on the mock-up facility to minimise radiation exposure [2].

3.3. Progress and experience to date

The majority of the sludge has now been removed to stainless steel storage tanks [8]. Part of the remaining sludge has been compacted and may not be re-suspendable. The dose uptake during operations clearly shows the benefit of extensive inactive commissioning and training [1].

REFERENCES

[1] "Decommissioning a Liquid Effluent Treatment Facility - An Exercise in Dose Management". Radiation Dose Management. BNES. 1995 Manson British Nuclear Fuels plc, UK.

[2] "Sludge Problem is Settled". The BNFL Engineer, No 5, April 1993, Pages 3 & 4.

[3] WILLIAMSON, E.J., NORTON, D.H., HURLEY, A.F., and HOUGHTON, N.P., "Postoperational Cleanout Success at BNFL Sellafield, United Kingdom" Radwaste Magazine, July 1997, Pages 38 to 41.

[4] HOWDEN, M., "BNFL's Site Ion Exchange Effluent Plant". International Ion Exchange Conference. Cambridge. 1984.

[5] McCRACKEN, G., "Technical and Operational Risk Management Strategies for the Sellafield. Drypac Plant (SDP)", British Nuclear Fuels plc.

[6] "A System to Drum Up Waste Space". The BNFL Engineer, No 4, Spring 1992, Pages 4 & 5.

[7] WILSON, G.K., ELSDEN, A., "Monitored Retrievable Storage at Sellafield". Waste Management 90 Tucson, 1990.

[8] NORTON, D.H., WILLIAMSON, E.J., "Magnox Pond and Decanning Plant, Sellafield, Clean Up Strategy", Power, British Nuclear Fuels plc.

IV-2. REMOVAL OF BULK SLUDGE FROM D-BAY B30

1. STATEMENT OF PROBLEM

1.1. Waste type

The reprocessing of irradiated Magnox fuel involves storage underwater, removal of the can, dissolution in acid, and chemical separation. During 26 years of operation, residual and damaged fuel, sludge, and debris accumulated within the original Magnox fuel storage and decanning plant (B30) [1]. The sludges present in D-bay are a result of skip washing activities undertaken as part of the fuel export route. The sludge came from the rotary skip wash and was deposited in D-bay as a short-term measure. D-bay also contained redundant equipment, other miscellaneous beta gamma waste, and fuel residues.

1.2. Current storage arrangements

D-bay forms part of the B30 storage ponds system, which was commissioned in 1959-1960 for the receipt, storage, and decanning of irradiated Magnox fuel. D-bay was originally designed as an underwater fuel decanning facility; it was then utilised as a depository for small quantities of debris and subsequently was used as a sludge store. D-bay measures 5 m x10 m, and is 6 m deep. Although originally constructed as an open bay, it was covered some years ago.

1.3. Reasons for retrieval

Sludge retrieval is required from D-bay because of a rise to significant radiation levels, which in turn, limits the working time in some areas of the plants. It will also allow decommissioning of previously installed and currently inaccessible underwater decanning equipment in the bay [2].

1.4. Objectives

The aim of the project is to remove 230 m^3 of sludge from D-bay as part of the post-operational clean out, leaving only residual amounts.

2. RETRIEVAL STRATEGY

2.1. Sampling

A significant amount of work was undertaken to develop the solution for the desludging of D-bay, including sampling of the sludge to allow its characterization and the development of simulant.

2.2. Waste characterization

The sludge contained in D-bay is of the same origin as the sludge in B31 [2]. It is from the corrosion of Magnox fuel, with traces of irradiated uranium metal. The specific activity is such that the sludge is classified as intermediate-level waste [3]. D-bay also contains redundant equipment, a decanner machine, other miscellaneous beta gamma waste, and quantities of fuel.

2.3. Infrastructure upgrade

The B30 building has been upgraded and improved by installing new facilities that include the following: ventilation systems, extended radiation monitoring, fire alarms, control and access points, and building lighting [1].

2.4. Downstream process

The sludge will be hydraulically re-suspended to convert the sludge to a slurry. It will then be pumped via a coaxial pipeline into a shielded pipe bridge to intermediate settling tanks (B315). It will then be transferred to the Site Ion Exchange Plant (SIXEP) [4] for interim storage in stainless steel tanks. The current strategy shows that the sludge will eventually be transferred as one of the feeds to the Sellafield Drypac Plant [5] for conditioning and then transferred to the Waste Encapsulation Plant [6] for final encapsulation [2].

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Process

The retrieval design involved the deployment of four submersible pumps. Each pump was suspended from a gimbal system that allowed the pump to be raised and lowered, and rotated and tilted about the vertical axis. This allowed the sludge to be "jetted" to other locations in the bay. These pumps re-suspend the sludge and move it into the sphere of influence of an ejector, which transfers sludge from the bay to B315.

3.2. Implementation

A series of inactive trials were conducted both at the development stage and inactive commissioning stages where full-scale simulations were used. These steps brought significant advantages to the project [2]:

- Installation, operation, and maintenance personnel could be trained in an inactive environment.
- Significant amounts of initial testing could be carried out to review safety issues and to satisfy regulatory bodies.
- Optimisation of operating and maintenance procedures.

3.3. Progress and experience to date

The installation of equipment began in April 1995 and was commissioned in September 1995 [2]. During installation of the system on the plant, it was found that it was not possible to deploy all of the pumps and only two were installed due to previously unidentified obstructions. This restricted the effectiveness of the system. A sonar survey was carried out of the bay, which showed that in spite of the restricted system, some sludge has been transferred out of the bay. Work is ongoing to enable effective deployment of all four pumps.

REFERENCES

[1] WILLIAMSON, E.J., NORTON, D.H., HURLEY, A.F., HOUGHTON, N.P. "Post Operational Clean Out Success at BNFL Sellafield, United Kingdom", Radwaste Magazine, pp 38 to 41, July 1997.

[2] MILLER, J.W., WILLIAMSON, E.J., "Successful Progress in the Post Operational Clean Out of the Magnox Ponds and Silos at Sellafield", IMechE International Conference on Storage in Nuclear Fuel Cycle, 18–19 September 1996.

[3] MANSON, P., British Nuclear Fuels plc, UK, "Decommissioning a Liquid Effluent Treatment Facility — An Exercise in Dose Management", Radiation Dose Management. BNES, 1985.

[4] HOWDEN, M., "BNFL's Site Ion Exchange Plant", International Ion Exchange Conference. Cambridge, 1984.

[5] THE BNFL ENGINEER, "£400 million Drypac Project is the Biggest since THORP Flagship, No 9, "pp 12 to 14, 1997.

[6] NUCLEAR ENGINEERING INTERNATIONAL, "BNFL's First Encapsulation Plant Enters the Testing Phase on Programme".

ANNEX V
UNITED STATES OF AMERICA

V-1. WASTE MOBILIZATION AND REMOVAL FROM OAK RIDGE NATIONAL LABORATORY'S GUNITE AND ASSOCIATED TANKS

1. STATEMENT OF PROBLEM

This annex discusses the waste retrieval activities in the Gunite and Associated Tanks, specifically W-3, W-4, W-6, W-7, W-8, W-9, W-10, and TH-4.

1.1. Waste type

Approximately 85,000 gallons of sludge was stored in seven Gunite and Associated Tanks (W-3, W-4, W-6, W-7, W-8, W-9, and W-10) at the Oak Ridge National Laboratory in Tennessee. This waste varied from thick viscous waste to easily flowable liquid. In addition, the tanks contained dried waste that had the consistency of chalk. The sludge contained approximately 2333 TBq [1]. The radioactivity came from uranium, plutonium, thorium, and other long-lived isotopes, as well as high concentrations of cesium-137 and strontium-90, which have relatively short half-lives [2]. The tanks also contained organic materials in trace amounts and heavy metals.

Rainwater had leaked into the tanks, adding approximately 940 m^3 of wastewater. This water accumulated on top of the sludge layer. This supernate was radioactive, due to dissolved metal salts. The supernate and the tank walls contained an estimated 550 TBq.

A retrieval campaign 10 years earlier in some of the tanks used long range sluicing jets and conventional pumps. The campaign recovered 90% of the sludge, leaving hardened material in some of the tanks.

Tank TH-4, also part of the gunite tank group, was filled to capacity with supernate and approximately 1 m^3 of sludge [3].

1.2. Storage arrangements

The 16 Gunite and Associated Tanks Gunite and Associated Tanks have capacities ranging from 5 to 640 m^3. The gunite tanks were constructed using gunite. The associated tanks are located near the gunite tanks were constructed from stainless steel.

These gunite tanks involved in the waste retrieval effort were W-3, W-4, W-6, W-7, W-8, W-9, W-10, and TH-4. The tank walls were built in three layers. An outer wall approximately 15 cm thick was made of gunite, a mixture of cement, sand, and water sprayed through a nozzle over a steel reinforcing framework. The next layer was made of asphalt or bitumen embedded in the gunite provided the leak barrier. This layer was approximately 1.25 cm thick. The inner wall was composed of gunite, approximately 5 cm thick [4]. In tank W-5, remote inspections showed that the interior walls had deteriorated. Pieces of the gunite wall had fallen from the walls, exposing the metal mesh underneath [5].

The tanks were oriented vertically with domed tops. The top of the dome was located about 1.8 m below the ground surface. The tanks (except for TH-4) ranged in diameter from 7.5 to 15 feet, and had nominal capacities ranging from 160 to 640 m^3 [1]. Tank TH-4 is 6 m in diameter and 2.8 m tall with a nominal capacity of 52.5 m^3. These tanks were built to collect, neutralize, store, and transfer the liquid portion of radioactive and/or hazardous chemical waste [6].

1.3. Reasons for retrieval

The chemicals and radioactive materials in these tanks, which are located near buildings in the centre of the Oak Ridge National Laboratory complex, could have harmed the environment if they were released [7]. As the tanks aged, the possibility of the waste leaking to the surrounding soil and groundwater increased. The cumulative risk was too great to leave this waste in these tanks [8].

1.4. Objectives

The objectives of the retrieval activity were to remove the hazards associated with these tanks by (1) removing sludge and tank heel without adding large volumes of water or placing excessive stress on the deployment system or the tank, (2) cleaning gunite tank walls by removing dried waste and “shaving” off layers of contaminated concrete, and (3) rinsing waste off of residual hardware inside the tank.

2. RETRIEVAL STRATEGIES

2.1. Sampling

From May through August 1995, the waste in eight gunite tanks (W-3, W-4, W-5 through W-10) was sampled to determine the appropriate retrieval strategy. Analysis of the samples began immediately upon receipt, and data validation was completed in December 1995.

The characterization staff:

— Retrieved samples from almost any location within a tank using existing risers.
— Obtained sufficient samples to determine waste heterogeneity or homogeneity.
— Inspected tank walls, using an in-tank video system. They determined if the conditions of the walls presented retrieval limitations and determined the current state of the walls.
— Obtained tank wall samples to determine contamination in the surface and to a 1/4-inch wall depth.
— Estimated the sludge volume.

Waste samples were taken using pole samplers and the tank characterization system. This simple system uses a floating boom to retrieve samples. The boom was lowered into the tank via a riser, and floated on the water within the tank. The boom was used to deploy a clamshell grab sampler, video camera and lights, a wall chip sampler, a sonar depth finder, and a sonar transponder.

Several difficulties arose in obtaining the samples. The clamshell sampler was not heavy enough to sink into the denser sludge. The wall chip sampler was plugged by wet concrete dust, allowing only very small samples to be collected from the walls of tanks W-5 and W-8.

More information on tank waste sampling is available in *Results of 1995 Characterization of Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge,Tennessee*. ORNL/ER/Sub/87-99053/79. http://www.tanks.org/ttgdoc/DE96012206.pdf [9].

2.2. Waste characterization

The waste was characterized using Oak Ridge National Laboratory procedures or U.S. Environmental Protection Agency methods modified to incorporate radiological considerations. In some cases, changes to the procedures were required to incorporate additional safety measures or to handle unusual sample consistency.
The analyses performed included

— Metal analyses
— Mercury analyses
— Carbon analyses
— pH determination
— Volatile organic studies (gas chromatograph/mass spectrometer)
— Nonhalogenated volatile organic analyses
— Capillary column techniques
— Anion determination
— Microwave digestion
— Radioisotope determinations
— Densities.

More information on the characterization of the waste can be found in *Results of 1995 Characterization of Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee*. ORNL/ER/Sub/87-99053/79.
(http://www.tanks.org/ttgdoc/DE96012206.pdf. [9].)

2.3. Infrastructure upgrade

Very little of the support systems for the 50-year-old tank farms remained serviceable. While the tanks remained sound, generally, services were needed. All of the waste was transferred using new, temporary transfer lines. Several 76 cm risers were added to each tank for equipment access, although the Houdini was deployed through existing 61 cm risers. Utilities were brought into the area. A work platform (or bridge) was staged over each tank to support retrieval equipment.

2.4. Downstream process

The retrieved waste was moved to active storage tanks. This required a temporary connection to a 1.6 km-long transfer line. The requirements for slurry transfer through this line were 5–10 wt% solids. Controls needed to be established to achieve this. First, pulsed-air and propeller mixers were installed in the consolidation tank to float the lighter solids for transfer with the liquids to the receipt tanks. This continued during consolidation to make room in the consolidation tank and to take full advantage of availability of the site transfer system. Then, after the lighter sludge had been transferred and all other waste had been moved to the consolidation tank, the system was reconfigured to move heavier solids to a nearby active stainless steel process tank. From there, the site transfer system was used. It did not suspend high settling rate solids. Any remaining sludge could be size-reduced using nitric acid if needed for transfer. At the storage tanks, the waste is dried and packed for shipment to a repository. Therefore, no chemical interactions were considered, beyond safe storage.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The retrieval strategy for the Gunite and Associated Tanks involved the following technologies:

— Modified Light-Duty Utility Arm
— Houdini system
— Confined Sluicing End Effector
— Flygt mixer
— Pulsed-air mixer
— Russian pulsating mixer pump

Modified Light-Duty Utility Arm: Using a robotic arm capable of moving through 30 cm risers, this system deploys a variety of tools. The arm is capable of lifting 91 kg payloads and reaching 15 m horizontally and 4.5 m vertically [10]. By adding tools to the arm, such as a parallel-jaw gripper end-effector, the arm's reach can be extended slightly.

The system consists of a utility arm, skid-mounted deployment system, vertical positioning mast and housing, hydraulic power unit, control system, tank riser interface and containment system, and decontamination spray ring. The system is a slightly different design than the original arm developed for another waste site [11].

The Modified Light-Duty Utility Arm was developed by SPAR Aerospace, Ltd. with technical direction from the Tanks Focus Area and the Robotics Crosscutting Program [7, 12-14].

Houdini System: The Houdini vehicle positions retrieval and characterization tools inside confined radioactive spaces, such as underground tanks [15]. Because the system can be deployed through tank openings smaller than the vehicle itself, it was named after the magician Harry Houdini, who was renowned for getting into and out of tight spaces.

This system consists of a tethered track vehicle, Tether Management and Deployment System, and the Power Distribution and Control Unit. The stainless steel vehicle, which looks similar to a miniature bulldozer, is able to fold into an approximately 56 cm wide rectangle, allowing it to pass through 61 cm openings in tank roofs (called risers). Inside the tank, it unfolds to approximately 1.2 m wide and 1.5 m long [10, 16]. The vehicle moves via continuous tracks with rugged tread. It is teleoperated, which means it is controlled directly by an operator in a remote location. Onboard camera systems are used to provide the operator with an in-tank view [4]. The controls to the vehicle as well as power and hydraulics are passed through a 41 m tether. The 454 kg vehicle is also skid steered, meaning its speed and direction are controlled by the relative position of two joysticks, each of which corresponds to one tread's motion [7].

The vehicle is equipped with a squeegee-tipped plow blade and a six degree-of-freedom manipulator arm. The plow blade is used to manoeuvre sludge and to peel hardened waste off the floor. The arm, which has a 113 kg payload, is used to deploy tools, recover non-pumpable objects and clean the retrieval tools.

Researchers at Carnegie Mellon University's Robotics Institute first proposed the Houdini vehicle concept. Carnegie Mellon researchers worked with RedZone Robotics, Inc. during the early design stages. RedZone produced a prototype (Houdini I) and a second version (Houdini II) based on lessons learned at Oak Ridge for the Robotics Crosscutting Program. Houdini II is discussed here. The technology was tested and deployed under the auspices of the U.S. Department of Energy's Tanks Focus Area.

Confined Sluicing End Effector: The Confined Sluicing End Effector (CSEE) was developed and deployed to mobilize and remove residual radioactive waste. This system was used to mobilize and pump solids and accompanying liquids to a nearby receipt tank [12].

The CSEE, deployed on either a manipulator arm or remotely controlled vehicle, was equipped with three rotating jets mounted 120 degrees apart. As the jets rotated, a short-range stream of water was focused on and dislodged the solid waste. The rotating jets delivered water with a pressure of up to 700 bar. An electric motor rotated the jets at speeds from 0 to 500 rpm to cut hardened sludge [1].

The jets directed the dislodged material and water to an intake or suction port. The water jets were angled so they collided inside the inlet port that leads through a short hose to a water jet eductor pump. The pump is also powered by 700 bar water jets. This collision cancelled the energy of the jets and confined the water and dislodged materials at lower pressures. A screen over the port protected the pump and transfer line from potentially plugging objects, such as tools, plastic film, or wire, in the waste.

The retrieval system was operated from a control room in a trailer outside of the tank radiation zone. In-tank cameras were used to provide operators with an in-tank view. Waterjet Technology Inc., Pacific Northwest National Laboratory, the University of Missouri at Rolla, and the Westinghouse Hanford Company under the auspices of the U.S. Department of Energy's Tanks Focus Area developed the CSEE.

Flygt Mixer: The Flygt Mixer uses a propeller, similar in concept to an outboard motor on a boat, to mix tank waste. The propeller creates long-range currents capable of mixing over 20 000 gal/min of tank waste [17].

The following companies were involved in developing and deploying the mixer: Flygt, Oak Ridge National Laboratory, Westinghouse Savannah River Company, and Pacific Northwest National Laboratory.

Pulsed-air Mixer: This system uses an array of horizontal, circular plates, positioned a few inches from the tank floor. Pipes connected to the plates supply discrete pulses of air or inert gas to the underside of each plate. The air pulses rapidly create bubbles that quickly rise to the surface. This action prevents the settling of waste solids and mobilizes soft to moderately strong cohesive sludge, ranging in consistency from maple syrup to peanut butter [14, 18].

The following companies were involved in developing and deploying the system: PulsAir Systems, Inc., Pacific Northwest National Laboratory, and University of Washington.

Russian Pulsating Mixer Pump: The Russian Pulsating Mixer Pump (PMP) consists of a jet mixer powered by a reciprocating air supply. The primary function of the PMP is to mobilize and mix settled solids. The secondary function is to keep solids suspended while waste is being pumped from the tank. The PMP is comprised of a pump chamber, check valve, working gas pipe, discharge manifold, and four jet nozzles. The PMP uses two cycles, fill and discharge, to perform mixing.

Once in the tank, a vertical drive-screw system raises and lowers the selected pump to mix the waste at various levels in the tank. There are several benefits to using the PMP. First, the PMP is mechanically simple with few moving parts. Also, the mixing fluid does not leave the tank, which decreases the chance of secondary radiation. Finally, the PMP is a compact piece of equipment, with a relatively small cross section. It can be deployed through a 57 cm (22.5 in.) opening.

The following companies were involved in developing and deploying the system: Bechtel Jacobs, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, National Energy Technology Laboratory (formerly known as the Federal Energy Technology Center), and American Russian Environmental Services [9].

3.2. Process

The CSEE deployment system, either the Modified Light-Duty Utility Arm or the Houdini vehicle, was put into the tank. When the deployment system was ready, the Hose Management Arm deployed the CSEE through a tank riser. This arm holds the CSEE, conveyance hose, and jet pump. It tracks the movement of the CSEE and supports the load from the conveyance line and the high-pressure hose. Once the CSEE was in the tank, the Modified Light-Duty Utility Arm or the Houdini vehicle grasped the CSEE. Inserting the deployment system first ensured that the CSEE was grasped before it reached the tank waste. This prevented premature submersion of the CSEE that could cause plugging of the water jet nozzles with waste materials.

Video cameras able to function within the high radiation field were also deployed. These cameras provided the operators with an in-tank view, allowing them to operate the remote systems inside the tank.

With the CSEE and associated equipment placed in the tank, dewatering began. During this process, the CSEE jets were operated at ~10 bar to prevent nozzle plugging while the supernate was drawn off using the jet pump. Dewatering usually took 1 to 2 days.

When the sludge layer was revealed, pressure to the cutting jets was increased as necessary to break up and suspend the waste for sluicing. Typical cutting pressures ranged from 70 to 300 bar. Higher pressures were generally ineffective and caused the MLDUA to bounce around and set off position control alarms and faults. No positioning problems were encountered with the Houdini.

The system was most efficient at removing sludge when the waste was deep enough to partially submerge the CSEE, avoiding three-phase (solid, liquid, and gas) pumping. For the final 2/5 to 7.6 cm of waste, the Houdini plowed “waves” of waste to the end effector as it was held by the MLDUA. A coordinated effort with the MLDUA to position the CSEE and the Houdini to plow sludge to the CSEE along with an advanced sludge retrieval process resulted in successful waste removal.

The CSEE was used at pressures of 433 bar to scarify the gunite walls of tanks W-3 and W-4 [1]. Removing the dried sludge on the tank walls as well as a layer of gunite with the CSEE was done to reduce the in-tank radiation. Scarifying the walls reduced the radiation levels by 20%. However, problems did occur during scarifying. The CSEE only retrieved 50 to 70% of the 2.5 cm layer of gritty, hardened wall scale and gunite that accumulated in the bottom of the tank. Another end effector was designed and used to retrieve an additional 10 to 20% of the material [4]. The other walls were scarified with the Gunite Scarifying End Effector; this end effector is similar in design to the CSEE but can provide higher water pressures and a larger footprint for faster cleaning.

The Houdini vehicle is lowered through a riser near the tank wall, while the Modified Light-Duty Utility Arm was deployed in the centre. Once through the riser, the Houdini unfolds for work. In one tank, the system was used while suspended by the tether to cut and remove cables and steel pipes inside the tank. The manipulator arm is positioned so the elbow touches down first, allowing the vehicle to pivot on the elbow then the plough until the tracks touch, at which point they are driven forward slowly so the vehicle lands upright [13].

While the Houdini vehicle was designed to be completely submerged, to keep the cameras clean the operators create a shallow waste “landing spot” for the system, using retrieval tools held by the Modified Light-Duty Utility Arm. Different tools were deployed by the Houdini system depending on the retrieval work to be done:

— The Confined Sluicing End Effector was used to slurry and retrieve sludge. It was also used to wash tank walls and in-tank equipment.
— The plough blade was used to push the final 2.5 to 7.6 cm of waste to the Confined Sluicing End Effector for retrieval. The Modified Light-Duty Utility Arm deployed the CSEE.
— The robotic arm was used to pick up debris (such as tape, pipes, and hand tools) and move them to a consolidation basket for removal. It was also used to take waste samples and deploy the wall-coring tool. Further, it was used to hold the Confined Sluicing End Effector in the correct position for the Modified Light-Duty Utility Arm to grasp.
— The Gunite Scarifying End Effector and the Linear Scarifying End Effector were used to remove contaminated gunite from the tank walls. The Houdini did not have problems handling the reaction loads of the high-pressure water jet system, which did present problems to the Modified Light-Duty Utility Arm.

Using the Houdini system, Confined Sluicing End Effector, Waste Dislodging and Conveyance System, and a Flygt mixer, the waste was transferred from Tanks W-3, W-4, W-6, W-7, W-8, and W-10 to Tank W-9.

Because of the gunite pieces in the Tank W-5 waste, Flygt Mixers were used for mobilizing the waste. The gunite pieces in the waste could have damaged the Houdini system; thus, it was not used. The Flygt Mixer was deployed into the tank. The angled blades on the propeller mixed the waste into a transportable slurry that was pumped to Tank W-9 [5].

There, the waste was conditioned using the pulsed-air mixer. This effectively suspends the light waste fraction from the heavier particles, maintaining the lighter portion near the waste surface. This lighter waste can then be safely pumped through waste transfer pipelines to the six Melton Valley Storage Capacity Increase Tanks to await treatment. After pumping the waste to the capacity increase tanks, a dense layer of sludge was left at the bottom of W-9 [20]. With the Heavy Waste Retrieval System, the remaining sludge was mobilized and transferred out of W-9 [21].

In Tank TH-4, the Russian Pulsating Mixer Pump was operated in several 1-hour or more increments (up to 10 hours at a time in some instances) to mix sludge and supernate. Mixing was accomplished by lowering the pump and monitor into the tank. The system drew waste into a vertical cylindrical chamber near the tank floor. The waste was then expelled at the bottom of the tank, mobilizing and mixing the waste (as well as scouring the tank floor). Then, the waste was pumped out of TH-4 and into a holding tank [22].

An initial sludge depth ranging from 0.6 to 0.9 m deep at the beginning of pumping operations was reduced to an outer band ranging from 0.3 to 0.9 m wide and about 0.3 m deep at the end of pumping operations. The outer band of water sludge then "slumped" and spread across the tank floor. Sludge samples taken during transfer operations appear to have a high-water content [3].

3.3. Implementation

These new technologies and processes required the site safety and quality assurance staff to find ways to show that the intent of rules and safety requirements would be complied with during operations. A pilot operation “retrievability study” was used to demonstrate the technology and evaluate safety and regulatory concerns. This was less of a step than full-scale operations. Once the pilot-scale operations were shown to be acceptable, it was more manageable moving to full-scale operations.

3.4. Progress

In September 2000, 95% of the radiation sources and 99% of the sludge from seven tanks was removed [1, 5].

The Russian Pulsating Mixer Pump removed approximately 94 m^3 of waste from TH-4. U.S. Department of Energy and state regulators determined that additional sludge removal would not be necessary before the tank is closed [3].

3.5. Lessons learned

Deploying and retracting MLDUA: Operational efficiency and personnel radiation exposure levels were improved by leaving the arm inside the tank at the end of each shift [11].

— *Power systems and MLDUA*: To prevent the gripper tool from releasing (and thus dropping the tool it was holding), a separate hydraulic pump was added to maintain pressure to the gripper [11].
— *Operator Training on Houdini*: While the system does not require special qualifications, inexperienced operators can damage the system. Thus, sufficient lead time and a cold test facility are needed to train operators [7].
— *Ergonomics*: Designing systems to be easily operated is a critical issue. Several human interface occurred.
  - Reaching the Houdini vehicle in the containment system to perform maintenance is difficult because of limited glove port access and the extended distance between the glove ports.
  - Additional cameras could provide assist operators by providing more expansive views [11].
— *Separate Power Supplies*:
  - A separate power supply could make the Houdini Tether Management and Deployment System (TMADS) more versatile as current national safety regulations require power in the TMADS to be shut off during maintenance and repair.
  - The hoist inside the Houdini TMADS should have a separate power supply and all of the power supplies need to be accessible on the outside of the containment structure.
— *Sealing Bag-Out Port on Houdini System*: Water spray and splash from the decontamination spray ring made sealing the 51 cm bag-out port (located in the TMADS containment bezel) very difficult. Because of this poor seal, the port had to be cleaned before the polycarbonate material window could be placed in the port to provide additional light for workers [16].
— *Tank access for CSEE*: Ensure tank risers are large enough to deploy the CSEE, the deployment system, and in-tank video cameras.
— *In-tank components*: Risers, in-tank equipment, and debris in the tank can hinder deployment of the CSEE. Ensure that in-tank components are mapped and their interference with the CSEE system is understood.
— *Tank dome loading*: Ensure that the tank dome can support the weight of the system. A load-bearing platform may be needed.
— *Tank atmosphere*: Ensure that the tank atmosphere, especially a flammable environment, is evaluated and impacts on the CSEE are understood.
— *Vehicle deployment*: Consider the value of providing a temporary holster or resting place for the CSEE when the vehicle arm is needed for short-term tasks.
— *CSEE seals*: Determine the impact of the nature of the waste on CSEE seals. The abrasive nature of the waste caused excessive seal wear. As the seal wore, the vacuum at the CSEE inlet was reduced and pumping efficiency dropped.
— *Water additions*: Coordinate activities and emphasize water conversation in waste retrieval.
— *Inlet screen and CSEE*: The inlet screen was easily plugged by waste and debris. Backflushing was not as efficient as operators hoped. In addition, it added significant water volume to the system.
— *Shock waves in pulsed-air mixer*: When a relatively high gas pressure is used, a considerable shock wave can be produced within the waste. This shock wave could damage mechanical and structural elements of the tank. Before pulsed-air mixing is

used, the tank must be studied to ensure that the shock wave will not damage the tank [14].

— *Aerosol generation and pulsed-air mixer*: A fine mist of waste slurry is generated when the pulsed-air mixer is used. This mist could require higher capacity tank ventilation systems, although unlikely [14].
— *Stiff, cohesive sludge and pulsed-air mixer*: The pulsed-air mixer is not the correct choice for mobilizing stiff, cohesive sludge in large diameter, flat-bottomed tanks [14].
— *Russian Pulsating Mixer Pump (PMP)*: The deployment schedule was extremely tight, which did not allow time for system fine tuning. It is believed that more solids could have been removed from the tank with additional mixing and pump-out cycles [23].
— *Operating pressure for the PMP*: The maximum operating pressure for the PMP was de-rated from 16 to 6 bar. A higher pressure would have increased the effective cleaning radius of the jets and lowered the levels of residual sludge [23].

REFERENCES

[1] LLOYD, P.D., FITZGERALD, C.L., TOY, H., RANDOLPH, J.D., DEPEW, R.E., FALTER, D.D. BLANK, J.A. 2001. Performance Assessment of the Waste Dislodging and Conveyance System During the Gunite and Associated Tanks Remediation Project. American Nuclear Society (2001).

[2] OAK RIDGE RESERVATION (ORR), Oak Ridge Reservation Annual Site Environmental Report, Oak Ridge National Laboratory, Oak Ridge, TN (1998).

[3] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights: January 2001, Richland, WA (1 June 2001).

[4] BLANK, J.A., BURKS, B.L., GLOVER, W.H., GLASSELL, R.L., RANDOLPH, J.D., LLOYD, P.D., RULE, V., Performance Assessment for Operation of the Modified Light-Duty Utility Arm and Confined Sluicing End Effector in Oak Ridge National Laboratory Tank W-3: Gunite and Associated Tanks Project. ORNL/TM-13646. Oak Ridge National Laboratory, Oak Ridge, Tennessee (1998.

[5] ROEDER-SMITH, LYNNE, "Gunite tanks cleaned out at Oak Ridge Reservation." Initiatives Online. Volume 8, http://www.wpi.org/initiatives/init/spring01/gaat.htm, (2001).

[6] GUNITE AND ASSOCIATED TANKS (GAAT), GAAT Tank Design, http://gaat.stepenv.com/tankdes.com (25 January 2001).

[7] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: Houdini I and II Remotely Operated Vehicle. U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (1998).

[8] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Confined Sluicing End Effector, Richland, WA (15 February 2001).

[9] OAK RIDGE RESERVATION (ORR), Results of 1995 Characterization of Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee. ORNL/ER/Sub-87-99053/79, Oak Ridge Reservation, Oak Ridge, TN (1996.).

[10] WASTE POLICY INSTITUTE (WPI), "OST Dovetails Technologies for Remote Tank Cleanup." Initiatives Online, Volume 4, http://www.wpi.org/Initiatives/init/apr97/dove.htm (1997).

[11] Unknown. Heel Technology Guide, http://www.tanks.org/ttgdoc/heel/modified_light_duty_utility_arm.htm (9 May 2001).

[12] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: Confined Sluicing End Effector, U.S. Department of Energy, Office of Environmental Management. Office of Science and Technology, Washington, D.C. (1998).

[13] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: Houdini II Remotely Operated Vehicle System. U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (December 1999).
[14] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: Pulsed-Air Mixer. U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (August 1999).
[15] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Manipulator Arm on Houdini Vehicle, Richland, WA (7 May 2001).
[16] VESCO, D. P., BURKS, B. L., VAN HOESEN, S. D., KINGTON, D. J., Lessons Learned and Final Report for Houdini Vehicle Remote Operations at Oak Ridge National Laboratory. ANS Topical Meeting on Robotics and Remote Systems, American Nuclear Society (2001).
[17] TECHNOLOGY MANAGEMENT SYSTEM (TMS), Axial Flow Mixer Pump, U.S. Department of Energy, Office of Science and Technology Washington, D.C. (7 June 2001).
[18] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), FOCUS ON: Closing the Gunite Tanks Oak Ridge Reservation Takes Big Steps Forward in Closing Gunite Tanks, Richland, WA (1 June 2001).
[19] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Key Products to be Delivered in FY00, Richland, WA (24 May 2001).
[20] WASTE POLICY INSTITUTE (WPI), "Spotlight on Tanks Focus Area." Initiatives Online, Waste Policy Institute, Blacksburg, VA (1 June 2001).
[21] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights: September 30, 2000, Richland, WA (1 June 2001).
[22] U.S.-RUSSIAN JOINT COORDINATING COMMITTEE FOR ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT (JCCEM), Russian Pneumatic Pulsating Pump, http://www.jccem.fsu.edu/success_pump.cfm (2001).
[23] HATCHELL, B., LEWIS, B., RANDOLPH, J., AND JOHNSON, M., Russian Pulsating Mixer Pump Deployment in the Gunite and Associated Tanks at ORNL. PNNL-SA-34056. Pacific Northwest National Laboratory, Richland, WA (2001).

V-2. FLUIDIC PULSE JET MIXER AT THE BETHEL VALLEY EVAPORATED WASTE TANKS

1. STATEMENT OF PROBLEM

At the Oak Ridge National Laboratory in Tennessee (USA), evaporator-generated waste in the Bethel Valley Evaporator Service Tanks (BVESTs) needed to be removed to make room for newly generated waste.

1.1. Waste type

Approximately 490 of liquid low-level waste were stored in the BVESTs. The five BVESTs (W-21, W-22, W-23, C-1, and C-2) held waste that contained approximately 800 TBq [1]. Radiation levels detected in and around the tanks have been up to 0.27 Gy/hr [2].

The waste in the tanks separated into two distinct layers: sludge and supernate. Because the supernate was acidic, sodium hydroxide was added periodically to neutralize it. The 8 to 13 cm sludge layer was primarily composed of metal nitrate, carbonate, and hydroxide precipitants [2][1]. The major metal components in W-21, W-22, and W-23 were calcium, sodium, magnesium, and potassium [3]. There were several metal components in Tanks C-1 and C-2 including chromium, lead, and mercury [4]. The sludge was considered remote handled because of high gamma radioactivity; it has also been classified as transuranic (TRU). Principal radioactive components are fission products such as caesium and strontium; activation products such as cobalt; and actinides such as thorium, uranium, and plutonium [3].

1.2. Storage arrangements

All five tanks have 190 m^3 capacities. The stainless steel tanks are held in underground concrete vaults located in the centre of the Oak Ridge National Laboratory campus. The vaults have double containment and measure 3.6 m in diameter and 18.7 m in length [2]. The concrete vault walls vary in thickness from 0.6 to 0.9 m. The roof is between 0.9 and 1.05 m thick. The tanks are connected by about 1 mi of transfer pipelines to the Melton Valley Storage Tanks. There is limited access into the W-21, W-22, and W-23 tanks. These tanks have one 48 cm access hole located 5 m from the north end. The tanks contain many obstructions located along their centrelines [3].

1.3. Reasons for retrieval

This waste needs to be removed to free space in the tanks. The space is needed for the newly generated waste being produced by the Oak Ridge National Laboratory [5].

[1] Sludge in Tanks C-1 and C-2 was described as light and dark tan and yellowish-green with a "mud-like" consistency. The C-1 tank had black particulates dispersed throughout the sludge [4]. A detailed physical description of the waste in Tanks W-21, W-22, and W-23 was not found.

1.4. Objectives

The objectives for retrieving waste from the BVESTs were to (1) mix and remove waste in a cost-efficient manner, (2) reduce the amount of time required to perform these activities, (3) reduce risks, and (4) minimize the generation of secondary waste [6].

2. RETRIEVAL STRATEGIES

2.1. Sampling

Tanks W-21, W-22, and W-23 were sampled and characterised in the late summer and fall of 1996; Tanks C-1 and C-2, in 1997. The waste was sampled to determine the appropriate retrieval strategy [4, 7]. Sampling was done by means of manually operated grab samplers mounted on a long rod.

2.2. Waste characterization

The waste was characterised using the U.S. Environmental Protection Agency methods. Some modifications were made to handle chemical matrix problems, high radiation levels, and waste content. The following analyses were performed [4, 7]:

- Particle size
- Metal
- Anion
- Radiochemical
- Nonhalogenated volatile organic
- Volatile organic
- Semivolatile organic
- Polychlorinated biphenyls
- Settling tests
- Hydroxylamine.

More information on the characterization of the waste can be found in [4, 7].

2.3. Infrastructure upgrade

Tanks W-21, W-22, and W-23 used existing tank penetrations and piping. The pulse jet mixer was fitted and plumbed into an existing service pit. To receive the jet mixer apparatus, Tanks C-1 and C-2 required two additional 1.8 m risers to be installed near each end of the tank. The risers were installed during the summer of 1997. The access holes are located on the east and west ends of the tanks. Before the installation of these risers, there was no way to access these tanks [4].

2.4. Downstream process

The material from these tanks was transferred to active storage tanks. The waste is planned for later retrieval, and the waste will be immobilized for disposal.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

A fluidic pulse jet mixer, designed and fabricated by AEA Technology [8], was used in the retrieval process for the BVEST. The fluidic pulse jet mixer is a unique technology because it has no moving parts except for solenoid valves that are easily replaceable [3].

The pulse jet system is connected to six existing tank nozzles; each nozzle is 7.6 cm in diameter. The nozzles have a 90° bend towards the end and extend to approximately 20 cm above the tank bottom [6]. They hang throughout the length of the tank in opposing pairs. Each nozzle is connected to a charge vessel. The jet pump is attached to the charge vessels to apply the necessary vacuum or pressure to the waste. The pressure, frequency, and sequence of pulsing are adjusted to achieve the best possible mixing action [3].

The pulse jet system is composed of seven modules: two charge vessel skids, a jet pump skid, valve skid, off-gas skid, pipe bridge skid, and control cubicle. The valve skid, jet pump skid, and charge vessel skids are constructed out of 304L stainless steel. The stainless steel prevents corrosion and is compatible with acidic cleaning solutions.

3.2. Process

The existing nozzles of the pulse jet mixer were vertically mounted in the tank [3]. Nozzles were immersed in fluid to mix settled sludge with existing supernate in the tank.

In Tanks C-1 and C-2, the charge vessels were installed through two existing risers at opposite ends of the tank [9]. A small amount of water was added when needed [6]. The pump then created a partial vacuum and drew liquid from the storage tank into the six charge vessels. Once the charge vessels were full, they were then pressurized, which forced the liquid back into the sludge. The waste and fluid were then mixed [2]. When the liquid waste contained 10% solids, it was pumped to the other tanks [5]. Finally, the system was vented to depressurise the charge vessels. After emptying one tank, the charge vessels were taken out and bagged, then moved to the next tank needing to be mixed. The system was easily moved between tanks, and the process was repeated until no additional sludge could be suspended [2].

Before the first waste transfer to the Melton Valley Service Tanks, the slurry in the tank was tested. Suspended solids in the slurry could plug the transfer line. Testing determined the amount of suspended solids to guard against. After completing the waste transfer, the skids, excluding the charge vessels, were moved to the new capacity increase tanks installed at the site[1]. The capacity increase tanks are stainless steel tanks 4.9 m in diameter and 24.3 m long with a capacity of more than 380 m^3. One of the tanks, expected to contain transuranic sludge, was built with a fluidic pulse jet mixer permanently installed. The system is much like the system installed in Tanks C-1 and C-2, two of the Bethel Valley Evaporator Service Tanks. Although two new larger air pistons were built and installed for the capacity increase tanks, many of the skids were used from the C tank system.

3.3. Progress

As of August 1999, 163 m^3 or 96.9% of the waste had been removed from the five tanks [6].

3.4. Lessons learned

— In the W-Tanks, the pulse jet mixer could mix sludge in multiple tanks when cross-connection nozzles existed [6].
— The modular design, quick connect couplings, and low maintenance requirements minimize radiation exposure [8].
— The use of existing or recycled liquid waste minimized the generation of additional waste.
— Continuous monitoring of the slurry for solids (which could plug transfer lines) could shorten mixing times, reduce operating costs, and provide better assurance of sufficient mixing.
— The rapid installation process for the pulse jet mixer can reduce costs.
— The amount of waste removed was limited by the physical characteristics of the sludge and the configuration of the tank [6].
— The pulse jet mixer is suitable for tanks with interior structures.
— The pulse jet mixer is suitable for use in tanks with flammable gasses [10].

REFERENCES

[1] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Oak Ridge Reservation: Bethel Valley Evaporator Service Tanks, Richland, WA (30 May 2001).

[2] U.S. DEPARTMENT OF ENERGY (DOE), Bethel Valley Evaporator Service Tanks: Fact Sheet EM, U.S. Department of Energy, Environmental Management Program, Washington, D.C. (6 June 2001).

[3] KENT, T.E., TAYLOR, S.A., MOORE, J.W., STELLERN, J.L., BILLINGSLEY, K.M., Demonstration of Fluidic Pulse Jet Mixing for a Horizontal Waste Storage Tank. ORNL/TM-13578. Oak Ridge National Laboratory, Oak Ridge, TN (1998).

[4] KELLER, J.M., GIAQUINTO, J.M., Characterization of the C1 & C2 Waste Tanks Located in the BVEST System at ORNL. ORNL/TM-13546. Oak Ridge National Laboratory, Oak Ridge, TN (January 1998).

[5] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Focus On: Applying International Technology to Solve U.S. Problems, Richland, WA (31 May 2001).

[6] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: AEA Fluidic Pulse Jet Mixer. U.S. Department of Energy, Office of Environmental Management. Office of Science and Technology, Washington, D.C. (August 1999).

[7] KELLER, J.M., GIAQUINTO, J.M., MEEKS, A.M., Characterization of the BVEST Waste Tanks Located at ORNL. ORNL/TM-13358. Oak Ridge National Laboratory, Oak Ridge, TN (January 1997).

[8] KENT, T.E., TAYLOR, S.A., MOORE, J.W., Deployment of a Fluidic Pulse Jet Mixing System for Horizontal Waste Storage Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee. BJC/OR-82. Bechtel Jacobs Company LLC, Oak Ridge, TN (August 1998).

[9] MURRAY, P., 2002 personal correspondence. AEA Technology, United Kingdom

[10] U.S. DEPARTMENT OF ENERGY (DOE), Tank Retrieval Technologies, U.S. Department of Energy, Office of Environmental Management. Office of Science and Technology, Washington, D.C. (1999).

V-3. SMALL TANKS AND WASTE RETRIEVAL AT OAK RIDGE NATIONAL LABORATORY

1. STATEMENT OF PROBLEM

Waste retrieval is complicated by the various sizes and configurations of the tanks, especially small (less than 190 m^3) vessels. The technologies that are capable of retrieving waste in one configuration are not necessarily adaptable to another. The Oak Ridge National Laboratory, in Tennessee (USA), has small horizontal and small vertical tanks with different access configurations. A pulse jet mixer was successfully used in larger tanks, and Oak Ridge wanted to adapt it to smaller tanks because of the potential for portability and low requirements for water addition (secondary waste). This annex describes the application of a small, mobile pulse jet system to Oak Ridge's Tank 3003-A, a small tank built in the early 1940s.

1.1. Waste type

The waste in Tank 3003-A was previously pumped, leaving less than 0.3 m of sludge and approximately 1.7 m of supernate [1]. Estimates regarding the actual volume of waste in gallons vary. During retrieval, the tank was found to contain a significant quantity of long pine needles placed in the tanks because of suspected contamination.

In the supernate, the following metals were detected: arsenic, barium, cadmium, calcium, nickel, and thorium. The following radionuclides were also detected: caesium, plutonium, and uranium. No volatile or semivolatile organic compounds were detected. The density, which is considered a suspicious measurement, was between 0.9575 and 0.9608 g/mL. The pH was 8.

The sludge contained the following metals: lead, chromium, iron, calcium, zinc, magnesium, sodium, and cadmium. In addition, it contained the following radionuclides: caesium, plutonium, and uranium. No volatile organic compounds, pesticides, or polychlorinated biphenyls were detected. However, semivolatile organic compounds were detected, including 2-methylnaphthalene.

1.2. Storage arrangements

Tank 3003-A is a 61-m^3-capacity concrete tank located partly aboveground. It is about 2.1 m in diameter and 4.2 m in height, and does not have secondary containment or level detection [2]. The tank contains a 0.9 m diameter access port. Built in 1943, it received liquid radioactive waste from three cells and a stack in Building 3003, which was the air-handling facility for the Oak Ridge graphite reactor.

1.3. Reasons for retrieval

There are two reasons for retrieving the waste from Tank 3003-A. First, according to the terms of the Federal Facility Agreement, the U.S. Department of Energy must remediate all of the tanks removed from service, such as Tank 3003-A [3] Second, the tank does not have secondary containment and as the tank ages the possibility of waste leaking increases.

1.4. Objectives

The objective of the retrieval activity was to remove enough sludge and supernate to allow stabilization of the tank in place with grout. This was evaluated after retrieval using visual and sample data. There were no pre-determined cleanliness criteria.

2. RETRIEVAL STRATEGY

2.1. Sampling

Most of the liquid samples were collected using suction from a small vacuum pump to minimize radiation exposure to workers. This technology may have volatilised the lighter organic compounds in the liquid. The samples were collected into 250-mL glass sample jars with Teflon™-lined caps. Sludge was collected using an open-ended sample collection tube. After the sludge enters the tube, a flat, neoprene-coated pate is rotated over the opening to close it.

Access to the tanks was limited because of the tank design and worker safety issues. This limited access restricted the number and heterogeneity of the samples taken. This sampling method did not show the large amount of pine needles in the tank.

For more information on waste sampling, see [1].

2.2. Waste characterization

Liquid and sludge samples were characterised using U.S. Environmental Protection Agency or Contract Laboratory Program methods that were modified to incorporate radiological considerations. In some cases, changes to the procedures were required to incorporate additional safety measures. The analyses performed included the following:

- Metal analyses
- pH determination
- Volatile organic studies
- Semivolatile organic studies
- Pesticides and polychlorinated biphenyls
- Anion determination
- Radioisotope determinations
- Densities [2].

For more information on waste characterization, see [1].

2.3. Infrastructure upgrade

The access to this tank was sufficient for retrieval and access to the transport truck. No tank-top modifications were required.

2.4. Downstream process

Following loading of the transport truck, the waste was moved to a Bethel Valley Evaporator Service Tank. From there, the material was pumped via existing pipeline to the

Melton Valley Storage Tanks for treatment and packaging for disposal (at the Nevada Test Site as solid waste).

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technology involved

The Mobile Retrieval System was used to remove supernate and sludge from Tank 3003-A. The MRS consists of (1) a charge vessel skid housing the operating pressure vessel, the jet pumps that control vacuum and pressure in the charge vessel, control sensors and valves, and piping directing the pressurized liquid either into the tanks to mobilize the waste or to a discharge path; and (2) a control skid containing a control computer and switchgear, trace heating controls, and compressed air valves that operate the jet pump. Both skids can be transported to the desired waste tank [4]. A nozzle individually manufactured to suit the tank conditions is installed through the tank riser. The nozzle pipe work is connected to the charge vessel/air piston by a flexible double-contained hose shielded by lead blankets as required. In addition to mixing and retrieving waste, the system can be designed to sample homogenized waste, transfer waste, and introduce grout into the tank and mix the heel with the grout to give a stable final waste form.

The system is considered mobile. The charge vessel skid is 2 m high, by 1.8 m wide, and 2.4 m long; and weighs 18 kN. The control skid is approximately 2.1 m high, 1.8 m wide, and 2.4 m long; and weighs 9 kN.

3.2. Operating principle of fluidic system

The pulse jet pump system mixes the sludge and supernate via a three-phase mixing process:

— A suction phase. During the suction phase, the jet pump is used to create a partial vacuum in the charge vessel, which draws liquid up from the storage tank into the vessel
— A drive phase. Once the charge vessel has been filled with the liquor, the jet pump pressurizes the charge vessel, which drives the liquor back into the storage tank, agitating the contents of the tank and re-suspending settled solid particulates into the supernate.
— A vent phase. When the liquor levels have reached the bottom of the charge vessel, the drive phase is terminated and the charge vessel is depressurised through the jet pump in the vent phase.

The cycle is repeated until the sludge and the supernate have been mixed. AEA Technology, Oak Ridge National Laboratory, and Bechtel Jacobs worked together to develop and deploy the technology [5].

3.3. Process

The Mobile Retrieval System nozzle is specifically designed for deployment through the tank riser. The nozzle is deployed inside the tank through standing liquid until it contacts the sludge layer of the waste.

Liquid is pulled in through the nozzle to the charge vessel using the jet pump to create a partial vacuum. Once the charge vessel is filled, the jet pump pressurizes the charge vessel, forcing the waste back into the storage tank, agitating the contents of the tank and re-suspending settled particulates into a slurry. The process gradually entrained more sludge into the liquid; the mixing cycle continued until the required suspended solid composition was reached. At this point, the mobilized sludge and entrained liquid slurry are drawn into the charge vessel and directed to the receiving vessel on the transfer truck [6].

After two days of operation, approximately 2625 L of sludge and liquid were removed from Tank 3003-A. On the third day, the system's nozzle became plugged with pine needles that resided on the bottom of the tank. The suction lines were not flushed after operations concluded on day 2; this might have exacerbated the situation. The pulse tube was disconnected and left in the tank [7]. Had the presence of the pine needles been known, the nozzle could have easily been design to accommodate their bulk.

3.4. Progress

The Oak Ridge staff determined that enough material was removed from the tank to allow closure. The Oak Ridge staff have cancelled plans to use the Mobile Retrieval System in other tanks, citing concerns that the nozzle could become blocked above ground with waste that has a high plutonium content [7].

3.5. Lessons learned

— Ensure the system is flushed every day to prevent the build-up of solid material.
— Sample the tank in a way that assures a representative sample.
— A generic, mobile system can empty a series of tanks without expensive infrastructure upgrades.
— The mixing nozzle design can be adapted for a specific tank geometry.
— The system design allows the skids to be quickly and efficiently decontaminated.
— The system is easily transported between tank locations and can be set up quickly without extensive training and requirements.

REFERENCES

[1] BECHTEL NATIONAL, Inc./CH2M Hill, Waste Characterization Data Manual for the Inactive Liquid Low-Level Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee. DOE/OR/01-1159&D1. Oak Ridge National Laboratory, Oak Ridge, TN (1993).

[2] KUHAIDA, JR., A. J., PARKER, A. F., Site Descriptions of Environmental Restoration Units at Oak Ridge National Laboratory, Oak Ridge, Tennessee. ORNL/ER-391. Lockheed Martin Energy Systems, Inc., Oak Ridge TN (1997).

[3] U.S. ENVIRONMENTAL PROTECTION AGENCY (REGION IV) (EPA), U.S. DEPARTMENT OF ENERGY (DOE), AND TENNESSEE DEPARTMENT OF HEALTH AND ENVIRONMENT, Federal Facility Agreement for the Oak Ridge Reservation (19 June 2001).

[4] AEA TECHNOLOGY, General Document On Mobile Fluidic Pulse Jet Mixing System. AEA Technology Engineering Services, Inc., Mooresville, North Carolina (2000).

[5] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), TFA Key Products FY00, Richland, WA (15 June 2001).
[6] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights Period Ending January 31, 2000, Richland, WA (15 June 2001).
[7] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights Period Ending March 31, 2000, Richland, WA (15 June 2001).

V-4. LONG-SHAFT MIXER (SLURRY) PUMP RETRIEVAL AT THE SAVANNAH RIVER SITE

1. STATEMENT OF PROBLEM

Tank 8, at the Savannah River Site in South Carolina (USA), contains radioactive sludge and supernate. While the tank is considered sound, it is approaching the end of its design life (approximately 50 years). The bulk of the tank waste needs to be removed to meet the site's schedule for waste vitrification.

1.1. Waste type

The waste in Tank 8 contained dried solid material. Water was added to the tank to re-hydrate this waste. The dried materials dissolved into the water and segregated into a heavier sludge layer and a supernate layer. The sludge layer is approximately 43 in. in depth. The supernate is approximately 32 in. in depth [1]. The waste in this tank was not characterised before retrieval.

1.2. Storage arrangements

Tank 8 (a Type I tank) has a carbon steel primary tank, a secondary pan, and a concrete support structure. The primary tank has a 2840 m^3 capacity, is 22.9 m in diameter, and is approximately 7.4 m high. The pan is 1.5 m deep and 1.5 m larger in diameter than the primary tank. The tank and pan are set on a 76 cm-thick base concrete slab. A cylindrical 56 cm-thick reinforced concrete wall and a flat concrete roof enclose the tank space. Twelve 0.6 m diameter concrete columns support the roof; each column is encased in steel plate. The roof is covered with approximately 2.7 m of earth. Access to the tank is provided through eight risers, averaging 0.6 m in diameter [2].

1.3. Reasons for retrieval

The waste in Tank 8 needs to be removed before structural problems develop that allow the waste to leak into the soil and groundwater. In addition, the sludge must be removed to meet the site's schedule for waste vitrification.

1.4. Objectives

The sludge in Tank 8 was needed to provide feed to the Defense Waste Processing Facility glassification plant. A second objective was to remove as much waste as practical for eventual closure of the tank. A follow-on retrieval campaign (to be defined later) will take the tank to closure conditions.

2. RETRIEVAL STRATEGY

2.1. Waste characterization

Recent characterization efforts were not done before the waste was retrieved. However, several characterization efforts were completed after the waste was retrieved [3].

2.2. Sampling

Recent sampling efforts were not done before the waste was retrieved. However, several efforts were completed after the waste was retrieved, including sampling in September 2000 [3, 4].

2.3. Infrastructure upgrade

Significant infrastructure upgrades, including bearing water, electrical systems, and load support structures, were required to use the long-shaft mixers at Tank 8 [5].

2.4. Downstream process

At the Savannah River Site, the tank waste is not homogenized during retrieval to meet the vitrification requirements. Instead, the waste is mixed with inhibited water (0.01 M sodium hydroxide) to maintain the flow rate in the slurry line [1, 3, 6]. Homogenizing and other activities to prepare the material for vitrification are conducted in the receipt tank, in this case, Tank 40.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technology involved

To remove the bulk of the sludge from the tank, four long-shaft vertical mixers and a telescoping transfer pump were deployed into the tank. These 110 kW mixers use a dual jet and pump system to mix the waste. The pump, located at the centre of the shaft, pulls waste in. The waste is then forced out through two jets, located on opposite sides of the pump. This system rotates inside the tank, mixing solid waste with supernate. The pump, which can be lowered in increments, removed the mixed waste.

3.2. Process

The bulk of the supernate in Tank 8 evaporated. To retrieve the waste, water was added to the tank. This water combined with the dry solid materials to form a layer of supernate and a layer of hydrated sludge. Four standard long-shaft mixers were positioned above the sludge level. The four mixers were used along with the telescoping transfer pump to cover the 23 m diameter of the tank. The mixers and pump were located on the periphery of the tank. The mixers drew in supernate and forced it back out into the tank through two nozzles located on opposing sides of a vertical pump. The mixers were operated until a 12 wt% solids level was reached in the waste. This is the maximum solids concentration that can be transferred. The mixed waste was pumped out using a telescoping transfer pump.

Sludge soundings were taken after 7 days of full-speed running to estimate the effective cleaning radius of the mixers. When the mixers had effectively removed the waste in a circle approximately 8.5 m in diameter, the mixers and the telescoping pump were lowered 25 cm and resumed mixing. This generated another batch of mixed sludge and supernate that was pumped out of the tank. This process was repeated one more time [1]. After this last batch was completed, operations were halted.

3.3. Progress

Approximately 0.3 m of waste is left in the tank. Plans call for this waste to be removed using other technologies before the tank is closed.

3.4. Lessons learned

- *Expense*: Because of the infrastructure upgrades required for long-shaft mixers, using this technology is expensive, with a cost ranging from $6 million to $11 million.
- *Efficiency*: This technology can be inefficient, depending on both the tank design and the operations plan. In some cases, it can leave as much as 150 m^3 of waste in the tank.
- *Time*: This technology requires time-intensive upgrades to the tank infrastructure [5].
- Long-shaft (18 m) mixers are prone to shaft vibration and bearing/seal failure.

REFERENCES

[1] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), *Tanks Focus Area, Technical Highlights Period Ending March 31, 2000*, Richland, WA (29 June 2001).

[2] McNATT, F. G., *Annual Radioactive Waste Tank Inspection Program - 1998*. WSRC-TR-99-00069, Westinghouse Savannah River Company, Aiken, SC (1999).

[3] CONWAY, J. T., Letter to Carolyn Huntoon, Assistant Secretary for Environmental Management, U.S. Department of Energy (29 June 2000).

[4] SWINGLE, R. F., BIBLER, N. E., and FELLINGER, T. L., *Tank 8F Sludge Slurry Analysis Results*. WSRC-RP-2000-00962. Westinghouse Savannah River Company, Aiken, SC (2000).

[5] SAVANNAH RIVER SITE, *Develop Advanced Mixing* Technology. ID:SR00-2041, Savannah River Site Technology Coordination Group, Aiken, SC (2 July 2001).

[6] WILMARTH, W. R., MILLS, J. T., DUKES, V. H., CADLE, R. L., COLEMAN, C. J., HART, J. C., *Silicon Analysis of Tank 8F and Tank 40H Turbidity Samples*. WSRC-TR-2001-00065. Westinghouse Savannah River Company, Aiken, SC (2001).

V-5. WASTE RETRIEVAL FOR TANK 19 AT THE SAVANNAH RIVER SITE

1. STATEMENT OF PROBLEM

At the Savannah River Site (South Carolina, USA) high-level waste in Tank 19 needed to be removed to allow tank closure.

1.1. Waste type

Approximately 1070 m^3 of supernate, salt, zeolite, and sludge were in Tank 19 [1]. The waste was produced by separating uranium and plutonium from irradiated fuel [2]. Zeolite, an ion-exchange column resin, was used to remove caesium during nuclear processing. When the zeolite was spent, it was placed in Tank 19 where it settled to the bottom of the tank [3], forming a mound. Zeolites are crystalline aluminosilicates of the group I (alkali) and group II (alkaline earth) elements [4] that physically resemble coarse sand. Other insoluble chemical constituents include aluminium oxide (33 wt%), iron oxide (30 wt%), silicon oxide (6 wt%), and sodium nitrate/nitrite salts (6 wt%) [5].

The major elements found in the solid mound in the tank were sodium, aluminium, silicon, and iron. Assuming all of the silicon in the sample is due to zeolite, the sample contains approximately 30% zeolite by weight. This implies that the majority of the sample could be sodium aluminate that was never dissolved and removed from the tank in the early 1980s [6].

The tanks at the Savannah River Site hold highly radioactive waste, containing approximately 2,000,000 TBq. The primary radioactive constituents are caesium-137 and strontium-90 [7]. The supernate in the Savannah River Site tanks is a highly concentrated solution of salt compounds in water [2]. Soluble chemical constituents are primarily sodium salts such as sodium nitrate (49 wt%), sodium nitrite (12 wt%), sodium hydroxide (13 wt%), sodium-aluminium tetrahydroxide (11 wt%), sodium sulphate (6 wt%), and sodium carbonate (5 wt%) [5].

1.2. Storage arrangements

Tank 19, a Type IV tank, has a 4900 m^3 capacity. It is a carbon steel tank built with a single layer steel wall and no active cooling system [8]. The tank was designed for waste storage that did not require auxiliary cooling. It was built in a concrete vault and the tank measures 25.9 m in diameter and 10 m height [9]. Access to the interior of the tank is achieved through risers located at the top of the tank. These round openings are less than 0.6 m in diameter and approximately 1.8 m long [7].

The equipment being used to close the tank was installed in many different areas and occupied many of the different riser locations, while other risers contained monitoring equipment. This equipment occupied riser space and created obstructions along the tank interior and along the floor. Other miscellaneous obstacles occupied the tank floor as well [7].

Tank 19 has cracks in the tank walls (well above current waste levels), which are believed to have been caused by groundwater corrosion. A small amount of water has leaked into the tank, but there is no evidence of waste leaking out of the tank [8].

1.3. Reasons for retrieval

This waste needed to be removed to begin the tank closure processes. Currently, the Savannah River Site is on a mission to stabilize material, restore the environment, manage waste, and decontaminate facilities no longer needed. The tank closure will comply with the U.S. Department of Energy's responsibilities and the South Carolina closure requirements [8].

1.4. Objectives

The objectives of the waste retrieval process were to (1) leave no more than 3750 L of waste in the tank [7], and (2) stabilize contamination [10].

2. RETRIEVAL STRATEGIES

2.1. Sampling

Tank 19 was sampled and characterised during the summer of 1996. The waste was sampled to determine the best possible retrieval method. Two cups were dropped into the tank to obtain samples. The samples were taken from the top few inches of the mound that is in contact with a large volume of supernate. About 50 g of solid material was retrieved in one cup (the other did not acquire a sample) [6].

How representative the sample is of the entire mound of residual solids is uncertain. The sample contained moist, dark brown solids that were easily broken apart with light pressure from a spatula. It was more granular than typical sludge samples. A very small amount of liquid was drained from the sample.

More information on the sampling of the waste can be found in [6].

2.3. Waste characterization

The analyses performed included

- Weight solids
- Aluminium
- Metallic
- Mercury
- Actinide
- Strontium
- Gamma-emitting fission product tests
- Technetium (WSRC 1997).

2.4. Infrastructure upgrade

Tank 19 required upgraded services to operate the retrieval equipment. Existing mixers and transfer pumps had to be rearranged to provide access for the new equipment. The transfer line to the destination tank (Tank 18) required installation of a diverter in Tank 18 to allow the same existing pipe to carry slurry from Tank 19 to 18 and decanted liquid back to Tank 19.

2.5. Downstream process

At the Savannah River Site, the tank waste is not homogenized during retrieval. Instead, the waste is mixed with inhibited water (0.01 M sodium hydroxide) and supernate from Tank 18 to maintain the flow rate in the slurry line [11, 12, 13].

Tank 18 will be retrieved in the 2003 time frame. The waste will be sent for processing in the Defense Waste Processing Facility, a vitrification facility at the site [11, 12].

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The three technologies involved in retrieving waste out of Tank 19 were

— Three 50-hp Flygt mixers

— Submersible transfer pump (BIBO)

— Air-operated-type scavenging pump (Pitbull ™)

Flygt mixer: The Flygt mixer is used to suspend solids in the tank waste. The Flygt mixer’s open propeller is configured to create long-range currents at a rate of 76 m^3/min [14]. The Flygt mixer’s propeller is approximately 56 cm in diameter and runs at 860 rpm [15]. Flygt and Westinghouse Savannah River Company developed the Flygt mixer. Pacific Northwest National Laboratory conducted the testing.

Submersible transfer pump (BIBO): Similar to a large pump used to empty swimming pools, the BIBO pump is a centrifugal pump designed to transfer 700 L/min at 38 m of total head [7]. The lightweight pump is designed for use in difficult abrasive situations. The pump housing is made of deformation-resistant, durable, cast aluminium. The inspection screws in the main housing and oil housing are always accessible from the outside of the tank. The impeller is made of high-alloyed steel, wear-resistant material. Bolt connections are made of corrosion-proof material and designed for repeated use as well as to the size of the pump [16]. The BIBO pump is a product of Flygt.

Air-operated scavenging pump (Pitbull ™): The submersible transfer pump (Pitbull ™) is an alternative to diaphragm pumps for retrieving residual tank waste. The pump is comprised of airlines, a pump chamber, and a control panel [17]. The chamber is cylindrical to facilitate insertion of the pump through a tank riser. It is 35 cm in diameter and 1.25 m tall. The inlet to the pump is through a 13 cm check valve located on the bottom of the pump. The check valve is horizontally orientated to prevent solids from settling inside the valve. A 5 cm discharge valve is located above the chamber [18]. The pump is designed to sit on the bottom of the tank and vacuum sludge through a 2.5 cm gap between the tank bottom and the inlet. The Chicago Industry Pump Company and the Savannah River Site developed the Pitbull™. The scavenging pump was deployed into the tank; however, it was not used.

3.2. Process

Three Flygt mixers were installed in August 2000 and retrieval processes began in September 2000. First, 2.2 m of water were added. Then, to mobilize the settled solids, the mixers were operated in racetrack mode, then oscillated across the tank centre. Racetrack mode allows waste to be pushed to the centre of the tank; centre mode then pushes the material to the periphery. During the mixing cycle, the tank was pumped to the 1.2 m level as the waste was transferred to Tank 18. The 2.2 m liquid level was reached again when the decanted liquid was returned to Tank 19. The process was repeated. Periodic full pump-downs to gauge progress were performed [19]. In December 2001, the mixer in the southwest riser failed. Operations personnel began limiting long-term use for the two remaining mixers to prevent premature failure [20].

The BIBO pump was also installed and deployed in August 2000 [21]. It rested 76 cm from the tank floor on a zeolite mound. In November 2000, it eventually broke the mound and was lowered to within 25 cm of the floor through a hole in the zeolite crust [3, 22]. After breaking the zeolite mound, the pump was basically encased in the resulting hole, limiting its ability to pump liquid lower than 18 in. deep.

3.3. Progress

The Westinghouse Savannah River Company moved waste to Tank 18. Operation of the Flygt mixers alone removed all but 26 m^3 of waste. Further retrieval, if required will use clean waste sluicing to concentrate the waste at the transfer pump. The tank is scheduled for complete closure in 2003 [1].

3.4. Lessons learned

Flygt mixers

— Using an increased number of mixers in the tank decreased the required mixer power needed to suspend the solids.

— Decreasing the size of the zeolite, from 0.7 mm to 0.3 mm, decreased the required mixer power needed to suspend the particles [15].

— Mechanical abnormalities as a result of extended use, age of hoists, and the lack of an internal maintenance/inspection program resulted in a hoist failure. Review of maintenance and inspection processes for these type hoists are recommended [23].

Pitbull ™

— Improvements on the check valve should be made to improve the ability to pump slurries containing hard solids.

— The original stainless steel exhaust valve (model EXVS75) should be replaced with a larger aluminium valve (EXV200) to reduce the likelihood of icing.

— Gaskets should be added between the valve body and mating flanges.

— The pump is likely to inject air into the discharge line when operated without surveillance for long time periods. This could result in water hammer defects. To prevent this and increase reliability, a low-level bubbler could be added to the pump.

— The vendor recommends aluminium-sealing surfaces for pumping slurries containing harder materials. Nitrile was used specifically for Savannah River Site.

— To reduce solid accumulation in the pump chamber, the gap should be reduced between the discharge pipe and chamber bottom. The current gap is 6.35 cm. Air nozzles could be incorporated into the chamber to suspend solids [18].

REFERENCES

[1] KEILERS, C.H. and DAVIS, R.T., SRS Report for Week Ending August 4, 2000, http://www.dnfsb.gov/weekly/sr/2000/sr080400.pdf. (12 June 2001).

[2] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Savannah River Site, Richland ,WA (12 June 2001).

[3] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights – Period Ending January 31, 2001, Richland, WA (18 June 2001).

[4] McFARLANE, H.F., GOFF, K.M., FELICIONE, F.S., DWIGHT, C.C., and BARBER, D.B., Hot Demonstrations of Nuclear-Waste Processing Technologies, Argonne National Laboratory – West, Idaho Falls, ID (18 June 2001).

[5] WESTINGHOUSE SAVANNAH RIVER COMPANY (WSRC), FY-96 High-level Waste Management Technology Program Plan, HLW-TEC-950027, Westinghouse Savannah River Company, Aiken, SC (December 1995).

[6] WESTINGHOUSE SAVANNAH RIVER COMPANY (WSRC), Characterization of Tank 19F Samples in Support of Tank Closure, WSRC-RP-97-074, Westinghouse Savannah River Company, Aiken, SC (6 March 1997).

[7] WESTINGHOUSE SAVANNAH RIVER COMPANY (WSRC), Tank 19F Folding Crawler Final Evaluation, Rev. 0., WSRC-TR-2000-00301, Westinghouse Savannah River Company, Aiken, SC (September 2000).

[8] U.S. DEPARTMENT OF ENERGY (DOE), High-Level Waste Tank Closure Draft Environmental Impact Statement: Summary, U.S. Department of Energy, Washington, D.C. (November 2000).

[9] SAVANNAH RIVER SITE (SRS), SRS Information & Insight: High Level Waste Tank Farms, Aiken, SC (May 2001).

[10] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: SRS Tank Closure, U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (August 1999).

[11] CONWAY, J. T., Letter to Carolyn Huntoon, Assistant Secretary for Environmental Management, U.S. Department of Energy (29 June 2000).

[12] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights – Period Ending March 31, 2000, Richland, WA (29 June 2001).

[13] WILMARTH, W. R., MILLS, J. T., DUKES, V. H., CADLE, R. L., COLEMAN, C. J., HART, J. C., Silicon Analysis of Tank 8F and Tank 40H Turbidity Samples, WSRC-TR-2001-00065, Westinghouse Savannah River Company, Aiken, SC (2001).

[14] U.S. DEPARTMENT OF ENERGY (DOE), Technology Summary Sheet Preview: Axial Flow Mixer Pump, U.S. Department of Energy, Washington, D.C. (7 June 2001).
[15] POIRIER, M.R., POWELL, M.R., GLADKI, H., Suspending Insoluble Solids in Waste Tanks with Shrouded Axial Impeller Mixers, Westinghouse Savannah River Company, Aiken, SC (November 1998).
[16] ITT FLYGT CORPORATION, Nothing Compares to a BIBO Pump, ITT Flygt Corporation, Trumbull, CT (28 June 2001).
[17] U.S. DEPARTMENT OF ENERGY (DOE), Pit Bull Pump, Office of Science and Technology, Washington, D.C. (7 June 2001).
[18] HATCHELL, B.K., POWELL, M.R., COMBS, W.H., RINKER, M.W., HYMAS, C.R., WHITE, M., Performance Evaluation of the PITBULL Pump for the Removal of Hazardous Waste, PNNL-11968, Pacific Northwest National Laboratory, Richland, WA (September 1998).
[19] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights – Period Ending October 31, 2001, Richland, WA (2 July 2001).
[20] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights – Period Ending March 31, 2001, Richland, WA (18 June 2001).
[21] SAVANNAH RIVER SITE (SRS), BIBO Pump, Savannah River Site, Aiken, SC (March 2001).
[22] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights – Period Ending December 31, 2001, Richland, WA (2 July 2001).
[23] U.S. DEPARTMENT OF ENERGY (DOE), Lessons Learned Database: Rigging Failure on FLYGT Mixer, U.S. Department of Energy, Washington, D.C. (31 March 1999).

V-6. WASTE RETRIEVAL FOR TANK 17 AT THE SAVANNAH RIVER SITE

1. STATEMENT OF PROBLEM

Tank 17 was the second high-level waste (HLW) tank closed at the Savannah River Site (SRS), near Aiken, South Carolina (USA). Retrieval of the waste in the tank was needed to allow tank closure.

1.1. Waste type

Tank 17 had approximately 10 m3 of sludge and 1135 m^3 of tritiated water, that is, supernate [1]. The primary chemical constituents in Tank 17 included aluminium, iron, manganese, nitrate, and uranium. The major radionuclides included tritium and plutonium [2]. High levels of technetium were observed in the sludge heel. The sludge contains 1.9×10^4 Bq/g ^{99}Tc/mL, nearly 1,000 times more than the supernate's specific activity, 2.5×10^4 Bq/g [3]. The waste in the tanks at the SRS was produced by separating uranium and plutonium from irradiated fuel [4].

1.2. Storage arrangements

Tank 17 is a carbon steel tank with a single layer steel wall and no active cooling system. The tank was designed for waste storage that did not require auxiliary cooling. It was built in a concrete vault, and the tank measures 25.9 m in diameter and 10 m in height, with a 4900 m^3 capacity [5, 6]. The tank is located slightly above the water table. Tank 17 did not contain much internal equipment, which made it an ideal candidate for closure. There are small cracks in the walls of Tank 17, but there is no evidence of leaks [7, 8].

1.3. Reasons for retrieval

Tank 17 had exceeded its design life and was scheduled for closure. The waste needed to be removed to allow closure. Currently, SRS is on a mission to stabilize material, restore the environment, manage waste, and decontaminate facilities no longer needed [6, 9]. Closure will reduce the potential for environmental problems in the future [7, 8].

1.4. Objectives

The objectives of the waste retrieval process for Tank 17 were to 1) remove the bulk of the waste and stabilize residual contamination and 2) provide answers to many of the technical and institutional questions relating to HLW tank closure and to help baseline the tank closure process [6].

2. RETRIEVAL STRATEGIES

2.1. Sampling

Sampling was accomplished by attaching a float to an electric sample pump and allowing the sample pump to float on the liquid surface. One end of a flexible hose was connected to the sample pump and the other end hung from the floating pump and rested on the bottom of the tank using a weight as a ballast. A filter and sample vial were attached to the sample pump discharge. A small air hose was attached to the float to act as a propulsion device. This allowed the float and sample pump assembly to collect samples from various areas in the tank. The suction hose was dragged across the floor. Two samples were taken. Once the samples were retrieved from the tank, they were shipped to Savannah River Technology Centre for analysis. More information on sampling activities can be found in [2].

2.2. Waste characterization

The Savannah River Technology Centre used characterization methods previously developed by the centre for HLW. The following analyses were performed:

- Tritium
- Metals
- Mercury
- Silver
- Alpha-emitting radionuclides
- Gross beta
- Gamma-emitting radionuclides
- Radionuclides
- Specific ions
- Specific gravity.

More information on the characterization of the waste can be found in [2].

2.3. Infrastructure upgrades

The transfer path for the waste to move to Tank 18 had to be modified, tested, and certified. Electrical and air services were provided. Several new access ports were added to the top of the tank for the addition of closure grout. A grout plant and grout service/distribution were set up to fill the tank.

2.4. Downstream process

The air-operated diaphragm pump transported the waste through an existing transfer line to Tank 18. From there, the waste will be transferred to vitrification staging tanks for eventual vitrification at the Defense Waste Processing Facility.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The technologies involved were

- Pan-and-tilt sluicer using clean water at 7 bar, 600 L/min
- Air-operated double-diaphragm scavenging transfer pump
- Water mouse waste spreader/leveller

Pan-and-tilt sluicer: A commercial pan-and-tilt sluicer was used for spray water washing using inhibited water (0.1 M sodium hydroxide) for corrosion control. The sluicer was a commercial fire-fighting unit, inverted and inserted into the tank through a riser access port.

Air-operated double-diaphragm scavenging transfer pump: The pump was a simple, air-operated pump with a 12 m head at 450 L/min [3]. Although it has relatively slow pump rates, it can lift waste more than 18 m. It is rugged and reliable but susceptible to fouling from heavy solids (sand and gravel).

Water mouse: An adaptation of an off-the-shelf, commercial technology designed for pipe cleaning, the water mouse consists of a rectangular, hollow steel cleaning head measuring 30 cm wide, 33 cm long, and 15 cm tall. It weighs about 22.5 N. It has 10 rear-facing thruster jets to propel it up a pipe, and two forward-facing jets to clean or cut [10, 11]. For this application, the mouse was mounted on a small base plate with light steel cables on either side that run to a central mast and up through the tank top. Pulling one or the other cable turns the plate and causes the main jets to slew the mouse to one side. Water is supplied to the unit at approximately 240 L/ min and 140 bar from an external source. The water mouse was used to redistribute sand-like solids from drifts resulting from sluicing to a level, thin layer, more conducive to grout entrainment [14].

3.2. Process

Due to limited space for water additions, an air-operated double-diaphragm scavenging transfer pump was used. The pump was installed in the northeast riser. A pan-and-tilt sluicer was installed through tank risers. The sluicer used inhibited water to move the waste towards the pump [2]. After washing with the sluicing stream, video cameras were used to survey the tank and identify areas that needed further cleaning. The sluicer was used to sweep heavy solids towards the diaphragm pump. Collector arms with their vertex at the pump suction concentrated the solids there. Small water jets on the arms helped move the solids to the pump suction [12].

The water mouse was deployed in the last stage before proceeding with tank closure. The system was deployed through a 56 cm riser. It was then manoeuvred through the tank to spread out the solid drifts to make the solids more accessible for grout entrainment. The water mouse was left in the tank rather than removed and decontaminated [14].

To finish the tank closure process, sludge-entraining reducing grout, which inhibits the spread of soluble radionuclides, was added before the risers and other pipes were sealed [13].

3.3. Progress

Tank 17 was officially closed on December 15, 1997, three months after the process began [6]. Approximately 8 m^3 to 12 m^3 of waste were left in the tank.

3.4. Lessons learned

- Sluicing or spray washing was effective on lighter residual material; however, the remaining rapid settling, heavier solids were more difficult to remove [14].
- Proper isolation of the tank following closure safely relaxes long-term administrative burden of tank monitoring.
- Ventilation requirements need to be considered carefully [6].

— Running a caustic liquid through an aluminium sluicer degrades the sluicer over time and reduces spray acuity. This is a cost trade. For Tank 17, the sluicer life was adequate.
— Improvements to directional control on the water mouse should be made.
— Wide high-pressure spray from the water mouse was effective at mobilizing material and has the potential for many tank and vessel floor-cleaning applications.

REFERENCES

[1] FORTENBERRY, J.K. and SANDERS, J., Defense Nuclear Facilities Safety Board Memorandum: SRS Activity Report for Week Ending January 31, 1997, Aiken, South Carolina (31 January 1997).

[2] U.S. DEPARTMENT OF ENERGY (DOE), Industrial Wastewater Closure Module for High-Level Waste Tank 17 System -Revision 2, U.S. Department of Energy, Washington, D.C. (26 August 1997).

[3] U.S. DEPARTMENT OF ENERGY AND RUSSIAN ACADEMY OF SCIENCES (DOE and RAS), Collaboratory Agreement (Contract) Between the U.S. Department of Energy and the Institute of Physical Chemistry of the Russian Academy of Sciences. U.S. Department of Energy, Washington, D.C (1 August 1999).

[4] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA). 2001a. Savannah River Site, Richland, WA (12 June 2001).

[5] SAVANNAH RIVER SITE (SRS), SRS Information & Insight: High-Level Waste Tank Farms, Aiken, SC (May 2001).

[6] U.S. DEPARTMENT OF ENERGY (DOE), Innovative Technology Summary Report: SRS Tank Closure, U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology, Washington, D.C. (August 1999).

[7] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA). 1999a. Press Release: SRS Completes Second High-Level Radioactive Waste Tank Closure This Year, Richland, WA (2 December 1999).

[8] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA). 1999b. Reference Abstract: Industrial Wastewater Closure Module for High-Level Waste Tank 17 System, Richland, WA (6 December 1999).

[9] WESTINGHOUSE SAVANNAH RIVER COMPANY (WSRC), Tank 19F Folding Crawler Final Evaluation, Rev. 0. WSRC-TR-2000-00301, Westinghouse Savannah River Company, Aiken, SC (September 2000).

[10] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA). 2001b. Technology Abstract: Water Mouse, Richland, WA (6 July 2001).

[11] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Technology Guide (TTG). 2001. Water Mouse, Richland, WA (5 July 2001).

[12] U.S. DEPARTMENT OF ENERGY (DOE), High-Level Waste Tank Closure Draft Environmental Impact Statement: Summary, U.S. Department of Energy, Washington, D.C. (November 2000).

[13] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA). 1997. Technical Highlights – Period Ending October 15, 1997, Richland, WA (5 July 2001).

[14] SAVANNAH RIVER SITE (SRS), Tank Heel Removal/Closure Technology, Aiken, SC (October 2000).

V-7. RETRIEVAL AT IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

1. STATEMENT OF PROBLEM

A sludge heel and deposits adhering to tank walls were discovered in Idaho National Engineering and Environmental Laboratory (INEEL) tanks (USA). Previously, no solids were assumed to exist in the highly acidic waste in these tanks. A spray ball sluicer, steerable sluicing jets, and a steam jet removal/transfer pump are being tested to remove waste heels from tanks with cooling coils on the walls and floor space and to clean the tank walls.

1.1. Waste type

Plans call for the system to be used initially in Tanks WM-182 and WM-183. These tanks contain stronium-90 and caesium-137. The primary chemicals in the waste are nitrates, sodium, aluminium, zirconium, and fluorides. The high-level waste is acidic, with a pH of less than 1 [1]. The solid residuals are stable at this low pH.

1.2. Storage arrangements

Tanks WM-182 and WM-183 are located in concrete vaults of pillar and panel construction. These stainless steel tanks are free standing in those vaults. The 1135 m^3 capacity tanks have a 15.2 m diameter with walls 6.4 m high. The tanks contain cooling coils on the walls and floor [1]. The cooling coils inhibit remote equipment that could move the sludge across the tank floor to the retrieval pump. The highly adherent residue on the tank walls also presents waste removal challenges.

1.3. Reasons for retrieval

Previously, researchers believed the acidity of the tank waste prevented solids from forming. However, inspection and sampling in three of INEEL’s tanks discovered a layer on the bottom of the tanks and dry deposits adhering to the cooling coils and the tank walls. This waste needs to be removed to meet regulatory requirements and agreements [2].

1.4. Objectives

The objective of this retrieval activity is to remove enough radioactive sludge from the tank floor and deposits from the walls to safely close the tanks [3].

2. RETRIEVAL STRATEGY

The rotating spray ball will agitate the heel sludge in the residual 15 to 30 cm of liquid in the tank into slurry and wash the tank walls. A steam jet removal/transfer pump will be added that has its suction at 1.25 cm from the tank floor (versus 15 to 30 cm of original pumps). The pump should remove most of the heel and cleaned wall deposits. The directional sluicer will target stubborn wall deposits and push material on the floor of the tank towards the jet transfer pump for removal. When this process is complete, concrete grout will be added in a pattern that will force more of the residual slurry to the transfer pump and entomb the remainder.

2.1. Sampling

Heel samples were taken from Tanks WM-182 and WM-183 with the Light-Duty Utility Arm along with video footage.

2.2. Waste characterization

Waste samples were taken from Tanks WM-182 and WM-183. Analyses performed included the following:

— Settling rate
— Particle size distribution
— Yield stress [3].
— Radioactive and chemical analysis for closure calculations.

2.3. Infrastructure upgrades

The spray ball and sluicers require very few infrastructure changes above the tank. A pad has been installed for water and air supplies and a control room. Existing transfer lines will be used. The major infrastructure expense lies in removal of existing in-tank equipment to make room in the access riser for the new pump, spray ball, and sluicers.

2.4. Downstream processes

The downstream processing of this waste would include additional water. The retrieved waste will be transferred to another waste tank for consolidation of solids. The wastewater will be removed and sent an evaporator. The disposition of these solids will have to be developed, but it is not required to get waste out of these tanks.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The waste retrieval system for the tanks at INEEL included the following [3]:

— Video camera system
— Spray ball system
— Controlled directional nozzles
— Steam jet pump.

Video camera: Video cameras provide the operators with information on the tank waste retrieval process. Video camera systems are positioned above the spray ball and located directly on the directional sluicer nozzles.

The camera will include the following features:

— Pan and tilt movement
— Manual and automatic focus
— Lighting
— Water-tight integrity

— Lens protection
— Lens cleaning system (water spray).

Spray ball system: This is a stainless steel rotating two-nozzle washing system. A clockwork driven by an internal water wheel rotates the two nozzles to cover the entire tank interior. The system is lowered into the tank through a central tank riser. This type of system is used commercially in the shipping and petroleum industries to clean storage tanks.

Directional nozzles: These are custom stainless steel (for acid resistance) nozzles with piggyback cameras mounted directly on the nozzle that can be pointed directly at "trouble areas" to remove accumulated waste solids.

Steam jet pump: The commercially available steam jet pump, similar to the two already in INEEL Tanks WM-182 and WM-183, was used. The steam jet eductor's high specific drive energy results in minimum net water addition during pumping. A steam jet eductor requires a separation tank to vent off gasses.

3.2. Process

On September 13 and 14, 2000, testing was conducted using a test bed with a tank mock-up (approximately 15 m in diameter and 4.8 m in height—actual diameter of the tank, but half the circumference of an actual INEEL pillar and panel tank). Solid simulant and water were placed in the test bed to a depth of 28 cm, with 20 cm of settled solids. The solids at INEEL have a slow settling rate and will stay in suspension several minutes after agitation [3].

The rotating spray ball was placed in a shroud that caught the jets as they pointed away from the mock-up (Gibbons 2000). The spray ball washed solids from the cooling coils and walls. However, it did not move the solids on the floor well, except near the steam pump. A "wave action" from the spray ball caused larger and heavier solids to move towards the tank perimeter. The system was not effective at accessing or mobilizing this waste; however, overall, the spray ball sluicer removed 90 to 95% of the solid material, leaving an approximately 1.8 cm-deep slurry layer [2, 3].

Because using the spray ball to remove this waste would have added significant volumes of water, two directional spray nozzles were deployed near the tank walls to remove the remaining waste. The nozzles directed a liquid stream at the waste near the tank walls. The nozzles easily moved the waste towards the pump, where it was drawn out of the tank [2, 3].

3.3. Implementation

The retrieval strategy described is scheduled for implementation in 2001 and 2002.

3.4. Progress

The system proved reliable and effective, removing 99.2% of the solid waste. A 1.6 mm-thick layer was left on the tank floor. A hot demonstration is planned for 2001 [2, 3].

3.5. Lessons learned

— *Video camera system effectiveness*: Recording capability, that is, the clarity under full magnification using the digital and optical zoom, was acceptable.
— *Video camera operation*: The operators should complete training and practice exercises with the camera, video recording, and lighting system before actual deployment.
— *Video camera positioning*: The location of the camera relative to the spray ball should be optimised to reduce liquid spray.
— *Spray ball system effectiveness*: After approximately 8 hours of washing with the spray ball and pumping with the steam jet, 85% of the solid material was removed.
— *Spray ball nozzle size*: The 10-millimeter nozzle is recommended with water supplied at a pressure of 5.3 to 7 bar. The smaller nozzles were not as effective for washing. The larger nozzles added excessive amounts of water and were no more effective than the 10-millimeter nozzle.
— *Spray ball configuration*: The two-nozzle configuration for the spray ball is recommended. The four-nozzle configuration adds additional liquid and poses deployment problems because of the larger size.
— *Wave movement*: The spray ball system created waves of waste on the floor of the tank and underneath the cooling coils. The waves pushed waste towards the tank walls, away from the pump. The cooling coils on the floor prevented the water and solids from moving or settling back towards the centre of the tank. This left waste in a 2.54 cm layer near the tank walls.
— *Water use*: To minimize the amount of water added, the usage of the spray ball and the directional nozzles should be optimised.
— *Steam jet pump*: Being able to adjust the height of the pump proved effective in waste removal. The primary concern is in lowering the pump too close to the tank floor and cutting off the flow to the pump. This occurred if the pump was located less than 1/4 in. from the tank bottom. However, this may be due to the jet support system and may not cause problems in an actual tank.
— *Steam jet effectiveness*: The steam jet is not capable of removing water as fast at it is added by the spray ball; thus, the spray ball must be stopped on occasion to allow the steam jet to “catch up.” This allows the solids to settle quickly. However, the spray ball does not effectively contact the solids with the excess liquid in the tank, so the liquid must be removed.
— *Transfers*: The steam jet and piping system can transfer surrogate slurries as high as 165 g/L.
— *Use of vendor facility*: The mock-up tank was located at a private vendor facility. This allowed for rapid construction and testing (that is, 4 to 6 weeks for construction, equipment setup, and initiation of the first test) [3].

REFERENCES

[1] PACIFIC NORTHWEST NATIONAL LABORATORY, Tanks Focus Area (TFA), Idaho National Engineering and Environmental Laboratory, Richland, WA (2001).
[2] GIBBONS, P. W., “Overview of the Tanks Focus Area HLW Tank Retrieval Activities (Remote Operations).” In Proceedings of the American Nuclear Society 9th International Topical Meeting on Robotics and Remote Systems [CD-ROM]. March 4-8, 2001. American Nuclear Society, Richland, WA (2000).

[3] IDAHO NATIONAL ENGINEERING AND ENVIRONEMENTAL LABORATY (INEEL), INTEC Tank Farm Facility Closure Mockup Test Report Project File No. 015722. INEEL/EXT-2001-00299. Bechtel BWXT Idaho, LLC, Idaho Falls, ID (2001).

V-8. WASTE RETRIEVAL SLUICING AT THE HANFORD SITE

1. STATEMENT OF PROBLEM

Tank C-106[1] at the Hanford Site (USA) contained 185,000 TBq of strontium-90; this strontium produced high levels of heat, capable of damaging the tank's structure [1]. The temperature inside the tank reached a high of approximately 113°C [2]. To dissipate the heat by evaporation at the waste surface, about 23 m^3 of water were added to the tank every month [1, 3].

1.1. Waste type

The waste volume was estimated at 870 m^3 (or 1.8 m), including 725 m^3 of sludge [1, 2, 4, 5, 6].

The supernate included the following metals: phosphorous, silver, sodium, sulphur, and uranium. It also included the following anions: nitrate, nitrite, oxalate, phosphate, and sulphate. The supernate included the following radionuclides: caesium, plutonium, uranium, and strontium. Finally, it included organic and inorganic carbon [6].

The sludge included the following metals: aluminium, calcium, chromium, iron, phosphorous, silicon, silver, sodium, and sulphur. It also included the following anions: nitrate, nitrite, oxalate, phosphate, and sulphate. The sludge included the following radionuclides: caesium, plutonium, uranium, and strontium. Finally, it included organic and inorganic carbon [6].

1.2. Storage arrangements

The underground tank, built in the early 1940s, was constructed of a single layer of mild steel (ASTM A283 Grade C) within a concrete vault and dome. The tank is 22.7 m in diameter, with a dish-shaped bottom [6, 7]. It has a 2000 m^3 capacity [8]. The top of the tank dome is located approximately 2 m underground [6]. For access, the tank has 10 risers (cylindrical ports connecting openings between the tank to the surface) ranging in diameter from 10 to 90 cm.

1.3. Reasons for retrieval

Regulatory and other agencies were concerned about this tank because sufficiently high temperatures could cause a structural failure, which could result in highly toxic and highly radioactive waste leaking to the environment [1, 9]. If the tank leaked, the water additions would have to be continued or the resulting high temperatures could lead to a dome collapse [10]. Thus, the waste needed to be removed from this tank to prevent possible damage to the environment.

---

[1] The complete identifier for the tank is 241-C-106. For convenience, the abbreviated form is used.

1.4. Objectives

The waste retrieval sluicing system for Tank C-106 has three goals: (1) remove enough sludge from the tank to eliminate the need to add water to the tank, (2) demonstrate that waste can be removed safely, and 3) provide high-level waste feed for vitrification [1].

2. RETRIEVAL STRATEGIES

2.1. Sampling

Grab sampling was performed during February and March 1996. Vapour samples were collected in February 1994 and March 1996. Because the tank was deactivated in 1979 and no further waste was added, the sampling results are considered valid and current [6].

During the 1996 grab sampling event, samples of the supernate and upper 60% of the sludge were taken from two locations. The lower 40% of the sludge was not sampled, and this may have biased the characterization data.

All of the grab samples were collected in glass bottles and were a nominal 125 mL in volume. The samples were taken at various depths within the supernate and upper 60% of the sludge. Duplicate samples were taken.

2.2. Waste characterization

The samples were analysed according to the safety screening data quality objectives.

The analyses performed included [6]:

- Energetics
- Specific gravity
- Water content
- Total alpha activity
- pH determination
- Particle size
- Viscosity
- Anions
- Metals
- Total organic and inorganic carbon
- Radionuclides
- Semivolatile organic compounds
- Normal paraffin hydrocarbons and tributyl phosphate
- Flammability of the vapours inside the tank but above the waste level (tank headspace)

In addition, studies were performed on the compatibility of the waste in Tank C-106 with the waste in Tank AY-102, the receiving tank.

2.3. Infrastructure upgrade

The upgrades required for waste removal included installation of dual 4-in. transfer lines. One carried supernate from the receipt tank to the sluicing nozzle. The other carried waste to the receipt tank. This required modifications to the highly radioactive sluicing and pump pits, located on top of the tank. It cost $4 million to modify these pits because of the high levels of radiation. These pits collected any waste leaked from jumper connections and drained it back into Tank C-106. The ventilation system was upgraded. A backup, portable heating, ventilation, and air conditioning system was maintained in readiness to replace this C-006 system within the allowed recovery time frame should it fail to operate. The cooling system in the receipt tank was upgraded to handle the high-heat waste. Power was brought in to run the equipment. An old transfer pump was removed. A crew facility and change room was installed with a remote control capability for the retrieval equipment. Extensive operating procedures and safety evaluations were prepared and defended. All this contributed to the more than $100 million cost of retrieving the waste in Tank C-106.

2.4. Downstream process

The waste was transferred to cooled, double-shell Tank AY-102, which has a 3785 m^3 capacity. The temperature, flammable gas levels, solids settling rates, and density profile were monitored in this tank [11]. Chemical compatibility with future vitrification of the Tank AY-102 contents was assessed.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technology involved

The waste retrieval sluicing system consists of a sluicer, a submersible transfer pump in Tank C-106, a booster pump in the pit above Tank C-106, two double-encased underground pipelines running between the tanks, an in-tank camera system, and extensive instrumentation to measure and monitor temperature, flammable gas generation, and leak detection [1]. The waste retrieval system is a departure from past-practice sluicing, which uses sluicing jets on opposite sides of the tank and a pump in the centre [12].

3.2. Process

The sluicer, approximately 29.2 cm in diameter, was installed in a 30 cm-diameter riser in Tank C-106 at one edge of the tank, approximately 1.5 m from the internal wall [12]. The sluicer system has a 2.5 cm-diameter nozzle with two degrees of motion control (rotation 194°) and nozzle elevation. The nozzle moves at a fixed elevation in the tank and can be aimed with a dedicated hydraulic system. It can be operated at pressures up to 20 bar [3].

An adjustable height submersible pump was installed at the other end of the tank, approximately 19.7 m from the sluicing nozzle [3, 12, 13, 14]. The pump is a centrifugal, direct-drive, end suction, 29 kW pump with a 6 mm mesh intake screen.

Supernate was pumped from Tank AY-102 to a booster pump at Tank C-106 that then pumped the waste to the sluicer nozzle in the tank. The supernate, which contained less than 10% solids loading, greatly reduced the amount of additional water needed for sluicing [3]. The sluicer was operated in a specific circular pattern pushing the waste to the slurry pump. The submersible pump moved the waste from the tank to the transfer line where the waste was forced along the 10 cm-diameter double-encased underground pipe to Tank AY-102. Each pipe was approximately 545 m long [12]. The pipe terminated into a pump pit, where it was instrumented to monitor for percentage of solids and other characteristics. Then, the waste was pumped into Tank AY-102. Water was provided for flushing and other activities to ensure that the transfer lines and pumps did not become clogged [3].

3.3. Implementation

After several years of preparation, sluicing was accomplished in 1999 [13. The system worked as designed, removing 9% to 97% of the sludge [14, 15]. Hardpan sludge remained; it broke up and formed a bank of sludge and rubble located across the tank from the sluicer jet. The lack of a heel pump at the bottom of the dish (in the tank centre) prevented complete removal of water from the tank. Addition of a centrally located heel pump, a second sluicing nozzle, and/or an effective in-tank viewing system at the end of the sluicing operations would have removed more waste. Demonstration of a crawler-based system was proposed to complete retrieval, but it was diverted to a tank containing more waste.

3.4. Progress

Approximately 705 m^3 of an estimated total of 727 m^3 of radioactive sludge was removed from the tank and transferred to a double-shell tank better equipped to handle the high heat levels [2, 5, 14, 15]. However, approximately 208 m^3 of liquid waste was left in the tank. This waste will evaporate in the next 1.5 to 2 years. These transfers occurred in 21 batches. The temperature in Tank C-106 was reduced from approximately 93°C to less than 56°C, ending the safety concern about the tank [16].

3.5. Lessons learned

— *Improve hose management:* In lowering the pump into Tank C-106, the pump hose often became twisted or kinked. This caused difficulties in placing and using the pump. Reducing the length of the hose, using stiffer material for hose construction, or using a spiral wound wire spring may resolve this issue [14, 15, 16].
— *Operate continuously:* Because of safety concerns, sluicing was done in batches, removing 30 cm of sludge at a time. Continuous sluicing would significantly reduce costs. Even if facility or system modification is required to implement continuous operation, a cost-benefit analysis should be conducted [16].
— *Maintaining continuity of key personnel:* Retaining key project personnel from the design through the operational phase helped to ensure that critical in-depth systems knowledge was not lost [14, 15].
— *Provide additional sluicing efficiency:* The single sluicer lacked sufficient power to mobilize the sludge mounds next to the in-tank slurry pump, which was on the other side of the tank [16]. This forced sluicing to cope with excess supernate covering sludge in areas of the tank. A second sluicer added adjacent to the pump is one option; however, it would result in increased complexity and costs. Another option is to add a sluicing feature to the pump, which would be less complex and costly [14, 15].
— *Reduce dispersion from sluicer nozzle*: A new sluicer straightening vein tube design should be substituted for the current design to reduce the dispersion of the sluicing stream. This would enhance the ability of the sluicing stream to mobilize waste at greater distances.
— *Cooling needed for hydraulic system:* The hydraulic system for the sluicer overheated during the hot summer months (the tanks are located in a desert-like region of the USA). A cooling system should be considered.

— *Shorten and decrease flexibility in slurry pump hose:* The slurry pump discharge hose was more flexible than anticipated and longer than needed. In addition, the mechanical rotary piping joints were more resistant to rotation than planned. These factors resulted in the formation of a loop in the hose reaching below the level of the pump inlet screen. After water flushing the transfer line and pump/winch assembly, the hose never completely drained. When the pump was lowered back into the waste, the looped hose configuration produced a liquid seal in the discharge hose. The seal prevented air trapped in the pump impeller casing from moving up the transfer line, preventing pump priming. This problem was solved at the site by blowing air through the line for several hours after the transfer line flush. This significantly extended the time required for sluicing. Adding a small vent hole at the high point of the pipe elbows on the submersible pump discharge line, immediately before the first rotary joint, would be an alternative that would not require extensive waiting periods.

— *Reduce gas from boost pump seals:* The gas seals for the sluice and slurry booster pumps were selected to avoid adding water or organic materials to the tank. Instead, the seals added volumes of gas into the process stream. This interfered with the mass flow meter, causing erroneous estimates for the mass of solids transferred to Tank AY-102. These seals required continual adjustments during the early phases of the project. These seals or the control system should be modified to reduce this problem.

— *Add heel pump:* A heel pump, located in the centre riser of the tank, could reduce any potential for leakage from the tank by reducing the hydrostatic head over a potential leak site. In addition, it would simplify the evaluation of sluicing progress by allowing more waste to be pumped from the tank, increasing the visibility, and thus volume estimates, of the sludge.

— *Resolve booster pump intake issues:* When the sluicing stream was directed towards the intake of the operating slurry pump, inadequate booster pump intake pressure problems were encountered. The reduced pump intake caused the booster pump to shut down. A solution was not discovered for this problem; it should be studied before continued sluicing operations are conducted.

— *Simplify flushing capabilities:* Supernate should be used to flush the slurry transfer lines where possible. In designing the transfer line, heavy equipment, placement issues, such as the use of cranes or heavy equipment that can increase costs, should be considered.

— *Simplify maintenance for in-tank imaging:* The image from the in-tank video camera slowly degraded during sluicing; this, in part, was the result of the inability to wash the camera and lights. One alternative is to wash the camera lens and lights independently. Another is to use an infrared imaging system that does not require lights. Finally, portable systems could be used to provide additional views of the tank interior [14, 15].

REFERENCES

[1] U.S. DEPARTMENT OF ENERGY (DOE), "Hanford's Tank C-106 Waste Removal System in Place", In: Hanford Press Releases [Web Site], Available: http://www.hanford.gov/press/1998/98-044.htm. (20 June 2001).

[2] U.S. DEPARTMENT OF ENERGY (DOE), "Radioactive Waste Removed from High-Heat Storage Tank", In: Hanford Press Releases [Web Site], Available: http://www.hanford.gov/press/1999/orp/100599.orp.html. (20 June 2001).

[3] BAMBERGER, J.A., An Assessment of Technologies to Provide Extended Sludge Retrieval from Underground Storage Tanks at the Hanford Site, PNNL-13048, Pacific Northwest National Laboratory, Richland, WA (2000).

[4] HANLON, B.M., Waste Tank Summary Report for Month Ending August 31, 1998, WHC-EP-0182-125, Fluor Daniel Hanford, Inc., Richland, WA (1998).
[5] SANDERS, G.H., Completion of Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Interim Milestone M-45-03B, Complete Sluicing Retrieval of Tank 241-C-106 Sludge, Due December 31, 1999, 00-ORL-010 [Online Database]. Available from Tri-Party Agreement Administrative Record and Public Information Repository, Richland, WA. (29 June 2001).
[6] SCHREIBER, R.D., DOUGLAS, J.G., CROMAR, R.D., WELSH, T.L., SIMPSON, B.C., FERGESTROM, L.J., OZANICH, R.M., Tank Characterization Report for Single-Shell Tank 241-C-106, WHC-SD-WM-ER-615, Revision 0., Westinghouse Hanford Company, Richland, WA (1996).
[7] U.S. DEPARTMENT OF ENERGY (DOE), "DOE's Hanford Site Begins Tank C-106 Waste Removal", In: Hanford Press Releases [Web Site], Available: http://www.hanford.gov/press/1998/99-005.html. (20 June 2001).
[8] HANFORD TANKS INITIATIVE (HTI), "Current and Completed Activities", In: Hanford Tanks Initiative [Web Site], Available: http://www.hanford.gov/tanks/hti/cca.htm. (20 June 2001).
[9] U.S. DEPARTMENT OF ENERGY (DOE), "Why Must Hanford's Tanks Waste Be Cleaned Up Now?" In: Office of River Protection [Web Site], Available: http://www.hanford.gov/orp/what_pg1.html. (20 June 2001).
[10] SCHREIBER, R. D., BABAD, H., CASH, R. J., "Resolution of Tank C-106 Organic Fuel-Related Concerns in Support of Retrieval and Resolution of the High-Heat Safety Issue at the Hanford Site", In: Waste Management 97 Proceedings [Web Site], Available: http://www.wmsym.org/wm97proceedings/sess32/32-03.htm. (20 June 2001).
[11] SANDERS, G.H., Third Bi-Monthly Report on Status of Tank C-106 Waste Retrieval Sluicing System and Submittal of Signed Change Request M-45-99-01, 99-OPD-046 [Online Database], Available from Tri-Party Agreement Administrative Record and Public Information Repository, Richland, WA. (29 June 2001).
[12] ERIAN, F.F., MAHONEY, L.A., TERRONES, G., Descriptive Models for Single-Jet Sluicing of Sludge Waste, PNNL-11703, Pacific Northwest National Laboratory, Richland, WA (1997).
[13] BAILEY, J.W., HNF-2427, Project W-320, 241-C-106 Sluicing Supporting Documentation Bibliography, Rev. 3, Numatec Hanford Corporation, Richland, WA (April 19, 1999).
[14] BAILEY, J.W., Waste Retrieval Sluicing System and Project W-320, Tank C-106 Sluicing, Lessons Learned, RPP-5687, Rev. 0., Office of River Protection, Richland, WA (2000).
[15] BAILEY, J.W., ECN 657913, Modifies the above document adding references created during and immediately after the C-106 sluicing operations. (February 2000).
[16] SANDERS, G.H., Fourth Bi-Monthly Report on Status of Tank C-106 Waste Retrieval Sluicing System and Submittal of Signed Change Request M-45-99-01, 99-EAP-496 [Online Database], Available from Tri-Party Agreement Administrative Record and Public Information Repository, Richland, WA (29 June 2001).

V-9. WASTE TRANSFER ISSUES

In the USA, radioactive waste retrieved from underground tanks is transferred to other storage tanks or to processing facilities. The transfers can be done in a single pass, that is, moving the waste from the tank to the destination or an intermediate destination can be used to decrease the distance the waste must be pumped in a single pass. This annex describes research to understand the chemistry of precipitation/solids formation plugs and to develop better methods to remove both precipitated and settled plugs when they occur. In addition, this annex describes a new technology used at the Savannah River Site to ensure that waste is easily retrieved from the intermediate destination.

1. STATEMENT OF PROBLEM

With pipelines up to 11.5 km long and the dilution factors currently planned for waste removal, millions of gallons of waste will be pumped through pipelines [1]. Typically, these pipelines are 5 to 7.5 cm in diameter and are buried or mostly buried underground [2]. When radioactive waste is transferred, solids can settle during an inadvertent pump shutdown to form blockages in the pipeline, or saturated salt precipitation and other chemical reactions can occur that cause solids to form. Water pressure flushing was used to remove pipeline plugs in most cases; however, this method is not always effective. Several lines have been abandoned as a result of plugging.

Plugged pipelines present severe financial and scheduling problems for the radioactive waste site [3, 4]. In addition, because of the high radiation levels in the buried pipes and insufficient knowledge about the location or nature of the plug, it is often not possible to cut into the pipeline and remove the plug. When it is possible to remove the plug, for example, at the evaporator transfer line at the Savannah River Site (USA), the cost is extremely high [5]. Often, waste plugs require the project to find another way to transfer the waste, increasing the time required to complete the project and the associated costs.

The problem is slightly different in using pump or holding tanks. The waste transferred into the tank settles and separates into layers. These layers (for example, liquids, precipitated solids, and sludge) can make remobilizing and retrieving the waste difficult, allowing a sludge layer to accumulate in the tank and interfering with retrieval and possibly complicating the retrieval chemistry.

1.1. Chemistry of precipitated waste plugs

The radioactive tank waste in the USA varies in complexity. The Hanford Site (USA) contains very complex waste because of the different nuclear processing methods used. As a result, operators are concerned about the possibility of plugs developing when the waste is transferred. Five of seven long waste transfer lines at the site have plugged [1]. Waste transfer criteria are based on physical properties, such as viscosity, specific gravity, and percent solids, and the chemistry of the waste solutions. Studies performed on waste plugging and saltcake dissolution [5] are helping form the basis for future transfers.

Background: Waste plugs develop from one of two sources: (1) precipitation or a chemical reaction or (2) solids settling. Likely scenarios for precipitation of solids in a transfer line include reaction of chemicals used in the waste retrieval process (water, dilute sodium hydroxide, or other liquid) with the tank waste to form additional solids and precipitation of solids in a saturated liquid as the retrieved waste cools in the transfer lines. The lines are underground, thus cooler than the tanks, which have a degree of radiation heating. A sufficient volume of solid material can precipitate to block the line. For example, a Hanford pipeline was plugged when the pipe temperature decreased and small sodium-fluoride-phosphate crystals formed. In Russia, pipeline plugs are often the result of salt formation/crystallization [6]. Other chemical reactions can also occur. For example, the waste may contain chemicals that react and form gelatinous mixtures. At the Hanford Site, a 8.7 cm-diameter transfer line was plugged because of a chemical reaction between aluminium and phosphate in the waste. The combination of these elements resulted in a blockage described as "green gunk" [1]. In addition, solids settling during sludge transfer can occur when the motive force is slow enough to allow particles trapped in the motive liquid to settle onto the bottom of the pipeline. When enough of these solids settle, a plug can form, especially if a dip or low spot occurs in the pipe [7].

New information: While the general causes of waste plugs are known — chemical formation of solids during transfer and settling — detailed information on the specific chemical components and physical properties is needed. Starting in the late 1990s, tests were conducted on Hanford Site waste. These studies included (1) prediction of solids formation from ionic waste solutions, (2) measurement and prediction of the viscosity of waste solutions and slurries, (3) measurement of the kinetics of precipitation and measurement of precipitate properties, (4) pilot-scale tests of slurry transfers, (5) development of slurry transport models, (6) measurement of the properties of settling sludge suspensions, and (7) laboratory dissolution testing with actual saltcake. Sources of additional information on these studies include [5, 8].

1.2. Technologies for unplugging blocked pipelines

The configuration of the U.S. tanks makes accessing plugged pipelines difficult. Because of the radioactivity of the materials, the pipelines were built underground with few access ports. This makes accessing, not to mention locating, the plug difficult. The high radiation levels require remote technologies [7, 9].

Four technologies for removing pipeline plugs were tested at the Hemispheric Center for Environmental Technology at Florida International University. These technologies were tested to determine performance basis. The radioactivity of the waste will be considered in final technology selection. The technologies were

(1) Ridgid snake® by Roto-Rooter®[1]
(2) High-pressure water jets on a flexible hose by A-to-Z Environmental Services, Inc. [10]
(3) Hydrokinetics™ sonic resonance technology by the Atlantic Group[2]
(4) Fluidic wave action technology by AEA Technology.

Ridgid snake®: This technology is a long, slightly flexible cable that is used similar to an auger to drill through and push out plugs. It is a type of pipe snake used to remove materials from residential sewer lines in the USA. This technology removed simulated clay-like waste but was limited to 2 to 300 ft insertion length including three to five elbows

[1] Ridgid Snake is a registered trademark of Roto-Rooter, Inc.
[2] Hydrokinetics is a trademark of the Atlantic Group.

[11, 12]. Of the technologies evaluated in this annex, this is one of the least costly systems to buy, but it would be very costly to implement in a remote application.

High-pressure water jets: A high-pressure water jet was tested. A hose was propelled by water into the line under 130 to 200 bar pressure. The pipeline was cleaned by powerful forward and reverse jets of water, which washed waste and other materials back to the insertion point [11, 13]. This technology was effective against the clay-like waste, but it is limited to 112 m insertion including three to five elbows [11, 12]. Of the technologies evaluated in this annex, this is one of the least expensive to purchase. Development of remote application configuration appears feasible.

Hydrokinetics™ sonic resonance technology: The Atlantic Group is the distributor for AIMM Technologies, Inc. Hydrokinetics™ technology for cleaning fouled and even completely blocked pipes, heat exchanger tubes, and furnaces [14]. This technology is based on creating sonic resonance with the liquid-filled pipe. The sonic resonance travels through the liquid between the plug and the transfer source. The resonance vibrates both the pipe and the plug. Because the pipe wall and the plug are made of different materials, they vibrate at different frequencies. These different frequencies break the cohesive bond between the plug and the pipe, allowing the plug to be expelled, usually in large pieces [14, 15]. The pipe is exposed to the sonic wave for only a fraction of the process time, well below the number of cycles required to cause metal fatigue, even in soft metals. The surrounding structures as well as the pipe will have to be analysed for the loads and fatigue potential of this type of system. The Hydrokinetics™ technology can be used with "pigs," small torpedo-shaped devices that can be inserted into the pipeline. The pig is forced through the pipeline where it dislodges material.

The technology requires the pipe to be full of liquid up to the point of application. As most waste transfer lines are sloped, this technology can be applied above the location of the blockage. Distance to the blockage and number of elbows in line was not a limitation (tested up to 512 m). This technology has a potentially short mobilization, demobilization, and unplugging times. For more information, see [6, 16]

Fluidic wave action technology: This technology is designed on the suction/drive concepts used on AEA Technology's pulsed mixers (see Annex US(2)). The system is connected to the end of the blocked pipe that is at a lower elevation than the blockage and, therefore, is empty of liquid below the blockage. A vacuum is drawn on the pipe. The pipe is then back-filled with water or other solvent to about 95% capacity. The charge vessel is pressurized to 1.3 to 7 bar, generating a wave at the air-water interface. The wave washes under the bubble at the end of the clear pipe area and breaks against the blockage. Waves are continually generated; this erodes and/or dissolves the plug until it loosens and can be flushed from the pipe. The continued waves erode the blockage much as waves erode jetties in the ocean [15]. This is the only technology available that can work on a blocked pipe from the dry end and the only technology that can deliver a solvent of choice to the blockage area. Tests to date have been effective at 512 m, the extent of the existing test pipeline.

1.3. Pump tank mixers for removing waste from small tanks

At the Savannah River Site in South Carolina, pump tanks are 3.6 m in diameter and 2.6 m tall. They are located 6.1 m underground in concrete pits. Mixing the contents of these tanks is necessary to blend the process liquids with the sludge, making the waste easier to pump [17]. The mixing prevents sludge accumulation at the bottom of the tank. AEA Technology developed the pump tank mixer to ensure homogenous consistency of the waste before it was pumped. The mixer was installed in Pump Tank 1 at the Savannah River Site in August 1999 [18][1]. The mixer, adapted from AEA's pulsed jet mixing technology (described in detail in US(2)), uses a 360-degree fan jet nozzle to sweep the bottom of the tank. The pump tank mixer was so successful in removing the sludge that it had to be turned off to allow some to settle again. This was done to ensure that the waste would meet specifications. After adding water, additional runs completely cleaned out the tank, with work completed in September 2000 [17].

1.4. Lessons learned

— *Hydrokinetics*™: A powerful and available technology that can work from the upper/flooded end of a pipeline and is not greatly affected by pipe length or number of elbows. This technology should be coupled with a flushing source.
— *AEAT pulse system*: This technology is a combination of solvent application, wave action erosion, and cyclical pressure and vacuum acting to form a bypass or leak in the blockage. Once the leak is formed, the surging liquid quickly opens the blockage restoring flow. This technology can only be applied at an elevation below the blockage.
— *Transfer lines*: At the Savannah River Site (USA), 7.5 cm transfer lines typically have short radius elbows for ease of seismic and thermal stress calculations. These add difficulty to any mechanical intrusion system. It is commonly assumed that sweep elbows would have been used for ease of cleanout. This may not be the case and needs to be verified on a case-by-case basis.
— *Considerations*: A remote system for adapting unplugging technology to a pipeline has to consider confinement, shielding, and the path to a destination for residual liquid in the pipe after the blockage is removed.
— *Pump tank mixer:* Safety issues arose related to potential aerosol generation and premature system shutdown. An investigation showed an error in calibrating the computer that timed the mixer's suction and drive phases [17].

REFERENCES

[1] GEPHART, R.E., LUNDGREN, R.E., Hanford Tank Cleanup: A Guide to Understanding the Technical Issues. Battelle Press, Columbus, OH (1998).

[2] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Tanks Focus Area - Technical Highlights Ending April 30, 2001, Richland, WA (16 July 2001).

[3] HUNT, R. D., LINDNER, J.S., MATTUS, A.J., SCHRYVER, J.C., WEBER, C.F., Waste Preparation and Transport Chemistry: Results of the FY 2001 Studies. ORNL/TM-2001/289, Oak Ridge National Laboratory, Oak Ridge, TN (2002).

[4] HUNT, R.D., MCGINNIS, C.P., WEBER, C.F., WELCH, T.D., JEWETT, J.R., FY 2000 Saltcake Dissolution and Feed Stability Workshop. ORNL/TM-2000/202. Oak Ridge National Laboratory, Oak Ridge, TN (2000).

[5] HUNT, R.D., BEAHM, E.C., CHASE, C.W., COLLINS, J.L., DILLOW, T.A., WEBER, C.F., Prevention of Solids Formation: Results of the FY 1999 Studies. ORNL/TM-1999/263. Lockheed Martin Energy Research Corporation, Oak Ridge National Laboratory, Oak Ridge, TN (1999).

[1] Murray, Paul. 2002 personal correspondence. AEA Technology, United Kingdom.

[6] HEMISPHERIC CENTER FOR ENVIRONMENTAL TECHNOLOGY (HCET), Plugging Prevention & Unplugging of Waste Transfer Pipelines, Hemispheric Center for Environmental Technology, Miami, FL (13 July 2001).
[7] TECHNOLOGY MANAGEMENT SYSTEM (TMS), Pipe Unplugging, U.S. Department of Energy, Office of Science and Technology Washington, D.C. (7 June 2001).
[8] HERTING, D.L., EDMONSON, D.W., SMITH, J.R., HILL, T.A., DELEGARD, C.H., Saltcake Dissolution FY 1999 Status Report. HNF-5193, Revision 0. Fluor Daniel Hanford, Inc., Westinghouse Hanford Company, Richland, WA (1999).
[9] WELCH, T.D., Tank Waste Transport, Pipeline Plugging, and the Prospects for Reducing the Risk of Waste Transfers, ORNL/TM-2001/157, Oak Ridge National Laboratory, Oak Ridge, TN (2001).
[10] HEMISPHERIC CENTER FOR ENVIRONMENTAL TECHNOLOGY (HCET), Equipment Test on Large-Scale Test Beds: A-to-Z Environmental Services, Hemispheric Center for Environmental Technology, Miami, FL (13 July 2001).
[11] HEMISPHERIC CENTER FOR ENVIRONMENTAL TECHNOLOGY (HCET), Equipment Test on Large-Scale Test Beds: Roto-Rooter, Hemispheric Center for Environmental Technology, Miami, FL (13 July 2001).
[12] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Tanks Focus Area - Technical Highlights Ending April 30, 2000, Richland, WA (16 July 2001).
[13] ROTO-ROOTER, Business Services: Water Jetting, Roto-Rooter, Cincinnati, OH (16 July 2001).
[14] HEMISPHERIC CENTER FOR ENVIRONMENTAL TECHNOLOGY (HCET), Equipment Test on Large-Scale Test Beds: Atlantic Group, Hemispheric Center for Environmental Technology, Miami, FL (13 July 2001).
[15] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Tanks Focus Area - Technical Highlights Ending October 31, 2000, Richland, WA (16 July 2001).
[16] EBADIAN, M.A., LIN, C.X., SKUDARNOV, P.V., SUKEGAWA, Y., KANG, H.J., ALLEN, M., COUPET, K., Fiscal Year 2001 Semi-Annual Technical Progress Report for the November 2000 to April 2001 Period: Plugging Prevention and Unplugging of Waste Transfer Pipelines. Hemispheric Center for Environmental Technology, Miami, FL (2001).
[17] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Tanks Focus Area - Technical Highlights Ending September 30, 2000, Richland, WA (12 April 2002).
[18] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Tanks Focus Area - Technical Highlights Ending October 31, 2000, Richland, WA (12 April 2002).

V-10. CHEMICAL RETRIEVAL TESTING FOR SAVANNAH RIVER SITE

1. STATEMENT OF PROBLEM

The mechanical retrieval systems (long-shaft centrifugal, dual-jet slurry mixers with transfer pumps) used on underground tanks at the Savannah River Site (SRS) (South Carolina, USA) can leave up to 150 m^3 of radioactive waste in a tank that contains support columns and cooling coils [1]. This waste contains contaminants that, if they leached to the groundwater, could harm the environment, workers, and nearby residents. To remove the residual waste, chemical cleaning methods that break down solids until they can be pumped out are being studied.

1.1. Waste type:

The plutonium-uranium extraction sludge in the SRS tanks, which is the primary component of residual waste, contains aluminium, iron, manganese hydroxide precipitates, mercury, and sodium nitrate/nitrite/hydroxide salts. Organic constituents may be present in low to trace concentrations. The primary radioactive constituents are strontium-90; caesium-137; plutonium-238, -239; and lesser amounts of other transuranic elements. The fissile isotopes are neutron poisoned by iron and manganese from fission products [2, 3].

1.2. Storage arrangements

Type I and II tanks at SRS contain support columns that obstruct mechanical retrieval technologies. The Type I tanks each contain 12 concrete columns to support the flat concrete roof. Cooling coils are both vertical on 1.2 m centres and horizontal across the tank floor. The columns are 0.6 m in diameter and encased in carbon-steel plate. The tanks are 22.9 m in diameter and 7.5 m in height; they each have a capacity of 2840 m^3. The 3900 m^3-capacity Type II tanks each have a single central roof-supported column. The tanks have a diameter of 25.9 m and a height of 7.2 m. In both cases, the walls are composed of carbon steel. A secondary carbon-steel pan provides additional containment [2].

1.3. Reasons for retrieval

Mechanical radioactive waste retrieval methods at SRS can leave as much as 151 m^3 of waste in an obstructed tank [1]. This waste can contain technetium-99 and other contaminants of concern that are radioactive and highly mobile in groundwater [4]. If the tank is "closed" with the waste inside the tank, a possibility exists that the contaminants could leach to the soil and groundwater. Thus, retrieving the residual waste, and reducing the volume of technetium, would reduce the risk the tanks pose to the environment.

1.4. Objectives

The objectives are to find a chemical cleaning process that effectively mobilizes hard-to-retrieve sludge. The process must maintain criticality safety, prevent disintegration of tank walls and floors, and minimize impacts on downstream treatment processes [5].

2. RETRIEVAL STRATEGY

Following normal retrieval operations, when it is determined that residual waste needs to be removed to meet radioactive source-term limits, acid reduction of sludge will be considered. The SRS baseline for this is oxalic acid. This was used to remove waste from Tank 16 in the 1980s. It has been determined that oxalic acid alone tends to concentrate plutonium relative to iron and manganese. This negated a key assumption of the site criticality safety basis. Alternate chemistry is being sought that will work on compounds containing these three elements at an equal rate.

2.1. Sampling

Waste samples will be obtained from SRS tanks.

2.2. Waste characterization

When chemical cleaning is performed on actual tank waste, the waste will be characterised before and after the cleaning.

2.3. Infrastructure upgrade

Depending on the chemical cleaning process used, infrastructure upgrades, such as chemical tanks, delivery systems, and offgas recovery and processing systems could be required at the tank site.

2.4. Downstream process

Downstream processing issues will include metal concentrations, chemical concentrations, and waste volume and their impact on caesium separation and immobilization in glass.

3. DEVELOPMENT OF CHEMICAL CLEANING RETRIEVAL PROCESS

3.1. Process

Research on simulated SRS tank waste showed that oxalic acid effectively dissolved the majority of the components in waste, except for manganese dioxide and mercury oxide. However, regulatory agencies are concerned because pure oxalic acid does not dissolve plutonium and the neutron poisons at the same rate and this could lead to a criticality incident (that is, enough nuclear material could be in the right configuration to cause an energetic nuclear chain reaction). This concern forced researchers to look at other chemical cleaning agents.

A mixture of oxalic acid (0.06 M) and citric acid (0.026 M), neutralized by sodium hydroxide to a pH of 4 to 4.2, effectively dissolved the sludge, except for aluminium. The presence of aluminium considerably decreased the dissolution rate of the sludge.

Thus, the following process was created to remove the aluminium and dissolve the remaining waste:

— Leach the aluminium from the sludge using 2M sodium hydroxide solution heated to 60°C. The sludge is leached seven times.
— Rinse the sludge with water to remove excess sodium hydroxide.
— Treat the sludge with 5 g/L oxalic acid and 5 g/L citric acid heated to 60°C. The sludge to solution volume ratio is 1:2.

This process effectively dissolved the sludge. The solution from this process did not pose a criticality issue, because the concentration of plutonium was exceedingly low (1/10 g/L). The solid phase could be a criticality issue, because of the higher concentration of plutonium and the lower levels of neutron poisons; however, extremely uneven distribution of plutonium would be required to produce a criticality event. Because of the possibility of a criticality, experiments were conducted on adding a neutron poison to the sludge. Crystalline boron carbide was selected for the following reasons: (1) it will readily settle out of the sludge, (2) at concentrations up to 10% by mass, it does not impact the dissolution rate or the completeness of dissolution, and 3) it is not cost prohibitive. However, intensive stirring is required. The pH of the oxalic and citric acid combination and the temperature increase (to 60°C) lead to a small increase in the corrosion rate of the carbon steel. The corrosion rate of the combined acids in simulated sludge did not exceed 0.09 mm/yr. In conclusion, the oxalic acid and citric acid combination effectively dissolved simulated SRS waste [6].

3.2. Implementation

Following a positive recommendation, the site authorization basis will be updated, and candidate tanks will be evaluated for field demonstration.

3.3. Progress

Simulated waste tests were conducted. Actual waste tests will be conducted before further consideration is given to using the process [6].

3.4. Lessons learned

— *Simulated waste vs. real waste*: Experiments with simulated waste in controlled laboratory conditions are not identical to actual plutonium-uranium extraction waste containing fission products. Further testing, with actual waste, is needed before final consideration can be given to a process.
— *Plutonium*: Use of oxalic acid to partially dissolve plutonium-uranium extraction sludge can preferentially dissolve iron and manganese compounds removing plutonium neutron poisons.

REFERENCES

[1] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), TFA — Key Products FY00, Richland, WA (18 July 2001).
[2] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Savannah River Site, Richland, WA (18 July 2001).

[3] U.S. DEPARTMENT OF ENERGY (DOE) AND V.G. KHLOPIN RADIUM INSTITUTE (KRI), Collaboration Agreement (Contract) Between the U.S. Department of Energy and the V.G. Khlopin Radium Institute, St. Petersburg, Russia. U.S. Department of Energy, Washington, D.C. (2000).

[4] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), "FY00 Multiyear Technical Response#: A9363," Multiyear Technical Responses FY2001 – FY2003, Richland, WA (18 July 2001).

[5] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area (TFA), Technical Highlights - Period Ending October 31, 2000, Richland, WA (17 July 2001).

[6] POPIK, V., "Development of Chemical Methods of Dissolution of Sludges Accumulated in HLW Tanks on Savannah-River Site." Notes from Tank Retrieval and Closure Demonstration Center Workshop. U.S. Department of Energy, Washington, D.C. (25 and 26 January 2001).

V-11. WASTE RETRIEVAL AT THE WEST VALLEY DEMONSTRATION PROJECT

1. STATEMENT OF PROBLEM

High-level waste in Tanks 8D-1 and 8D-2 at the West Valley Demonstration Project near West Valley, New York (USA), needed to be removed and transferred to the vitrification facility. Removal was necessary to allow the high-level waste to undergo vitrification [1].

1.1. Waste type

Tank 8D-1 was considered a “spare” tank at the site. It stored 144,000 lb (65,300 kg) of spent zeolite under an alkaline liquid. Zeolites are crystalline aluminosilicates of the group I (alkali) and group II (alkaline earth) elements used in ion-exchange processes [2]. Ion-exchange columns located in the top of the tank were used to strip caesium and strontium from liquid wastes before evaporation or grouting. When the columns were saturated, the zeolite was dumped into Tank 8D-1. In addition, Tank 8D-1 contained 137,000 gal (520,000 L) of excess liquid from pretreatment and zeolite transfer operations. The liquid had a pH of approximately 10.5 [1].

Tank 8D-2 contained a mixture of washed plutonium-uranium extraction sludge solids, zeolite, and supernate. The sludge included the following chemical constituents: iron oxide (35.5 wt%), silicon dioxide (20.8 wt%), sodium oxide (14.4 wt%), thorium oxide (10.4 wt%), and aluminium oxide (7.1 wt%). The sludge was estimated at 220,500 lb (100,000 kg), with a specific gravity of 3.35. The primary radionuclides in the sludge were strontium-90 and thorium and uranium isotopes. The strontium-90 activity was estimated at 215,000 TBq. Approximately 57,000 kg of zeolite contained approximately 204,000 TBq of caesium-137 [1].

1.2. Storage arrangements

Tank 8D-1 and 8D-2 are 2.8 ML carbon-steel tanks contained in separate underground concrete vaults with secondary containment pans. The tanks measure 21.3 m in diameter and 8.2 m in height. The tank bottoms are reinforced by complex internal grid work structures, which support the tank roof and floor. The tanks contain four inactive air circulators, thermowells, a heat exchanger, and level/density probes. The internal grid work and structures make the waste retrieval process difficult by blocking sluicing jets and limiting physical equipment access [1, 3].

1.3. Reasons for retrieval

The West Valley site is required to remove the waste by federal law, that is, the West Valley Demonstration Project Act of October 1, 1980. This act mandated the U.S. Department of Energy remove and solidify the high-level waste into a form suitable for transportation to the federal repository for final disposal.

1.4. Objectives

The objectives of the waste retrieval process are to remove waste from the tanks to prepare the tanks and the removed waste for final disposition and storage.

2. RETRIEVAL STRATEGIES

2.1. Sampling

Tank 8D-2 was sampled and characterised extensively. Supernate sampling was done through the only available riser using a Penberthy air jet eductor. The device is lowered into the tank using a winch. Supernate samples were taken at 0.3 and 1.5 m below the vapour/solution interface at one depth setting, and at 4.6 and 5.8 m below the interface at a second setting. As waste was removed from Tank 8D-2, it was directed to a vitrification-staging tank where it was well mixed and assayed. This provided an accurate assessment of the waste removed and sent to vitrification. More information on the sampling of the waste can be found in [4]. Tank 8D-1 was sampled in the vitrification staging tank.

2.2. Waste characterization

Tank 8D-2 waste was extensively characterised. Tests performed included the following:

- Chemical analyses
- Radiological analyses
- Specific gravity
- Density
- Leachability
- Temperature

More information on the characterization of the waste can be found in [4]. Caesium-laden zeolite and other waste in Tank 8D-1 was characterised after retrieval.

2.3. Downstream process

After retrieval, liquid waste was polished through a zeolite ion-exchange column and then grouted into rectangular metal containers with the form factor of a standard 55-gal drum. Solid waste, including the loaded zeolite resin, was transferred to the vitrification facility for immobilization in borosilicate glass, sealed into stainless steel containers.

3. DISTRIBUTION OF RETRIEVAL PROCESS

3.1. Technologies involved

The technologies used in the waste retrieval process were as follows:

- Mast-mounted tool delivery system with various tools
- Transfer pump
- Long-shaft vertical mixer pumps

Mast-mounted tool delivery system: The mast-mounted tool delivery system is a remotely operated mast with tools mounted on carriages that can be raised and lowered along the mast. Tools include an arm-mounted sluicer, arm-mounted wall sampler, lights, and cameras. The system is comprised of a 14.9 m steel beam, deployed through a 65 cm riser, that extends to within 30 cm of the tank bottom. The top of the beam extends out of the riser and is mounted to a rotary bearing connected to an electric gear motor. A series of eight hydraulic winches and actuators are mounted to the mast, above the rotary bearing. Each winch can lift a maximum of 2200 kg [5].

Transfer pump: The transfer pump is a 13-stage, 12-m slurry transfer pump. It has a radial inlet suction that extends approximately 7 to 9 cm above the tank bottom. Two concentric strainers prevent large debris from entering the pump. It has a 14.9 kW motor located in a concrete-shielded pump pit directly over the pump column. The pump has the capacity to pump 380 L/min with a 60-m head [1].

Long-shaft vertical mixer pumps: The 15.3 m long centrifugal pump powered by a 110 kW motor has one impeller that draws material into the pump suction. The pump suction is fitted with a strainer to prevent large debris from entering the pump. The suction is positioned 2.5 to 10 cm above the bottom of the tank. Two tangential, 3.8 cm diameter nozzles discharge the pumped waste about 18 to 25 cm above the bottom of the tank. Each nozzle distributes 2 270 L/min at the 100%-rated pump speed of 1 800 rpm [1].

3.2. Process

Six transfer pumps were used to mix the bulk of the solid-based waste that settled on the tank bottom. A long-shaft vertical mixer pump transferred the mixed waste out of the tanks. Sluicers were attached to the mast-mounted tool, which was deployed after the bulk of the waste was removed. The sluicers were used to remove waste from the tank walls and loosen stubborn floor deposits. This residual waste was pumped out of the tanks using the long-shaft pump. Between June 1996 and September 1998, West Valley Demonstration Project performed 102 waste transfers from the tanks to the vitrification facility.

3.3. Implementation

Eight additional risers were remotely installed on the top of the tank to provide for pump installations (and, subsequently, other retrieval equipment), and three trusses were constructed over the tank to support the pumps and distribute the weight [1].

3.4. Progress

Most of the waste was removed from the two tanks. In Tank 8D-1, approximately 96% of the caesium-137, strontium-90, and sludge were removed [1]. In Tank 8D-2, greater than 99% of the long-lived radioactivity was removed, only a few small areas of settled caesium-137-laden zeolite remain [6, 7].

3.5. Lessons learned

— A mobilization pump trial failed. The impeller key sheared. Pump designs were then modified so that the easily accessible motor coupling key would fail before the inaccessible coupling key was sheared.
— Mobilization pump suctions lowered from 10 cm above the tank bottom to 4 cm provided additional clearance between the jet centrelines and the tank structural grid work. This improved the effective solids mobilization radius, and it allowed for the pumps to be operated at lower tank levels.
— Installing transfer pump motors, a pump tachometer, and valve position switches inside the pump pits proved easy and cost-effective.
— Positioning equipment outside the pump pit (so it can be easily serviced) eliminated the need for personnel to enter a highly contaminated area, and it kept the equipment cleaner.

REFERENCES

[1] HAMEL, W. F. JR., MEESS, D. C., "High-Level Waste Mobilization and Removal at the West Valley Demonstration Project," WM '99 Conference, February 28 – March 4, 1999, http://www.wmsym.org/wm99/pqrsta/10/10-10.pdf (1999).
[2] MCFARLANE, H.F., GOFF, K.M., FELICIONE, F.S., DWIGHT, C.C., BARBER, D.B., Hot Demonstrations of Nuclear-Waste Processing Technologies, Argonne National Laboratory – West, Idaho Falls, ID (18 June 2001).
[3] HAMEL, W. F. JR., MCMAHON, C. L., MEESS, D. C., Waste Removal from the West Valley Demonstration Project High-Level Radioactive Waste Storage Tanks, WM2K #390 (18 January 2000).
[4] U.S. DEPARTMENT OF ENERGY (DOE), High-Level Waste Characterization at West Valley: Progress Report for the Period 1982-1985. DOE/NE/44139-14. West Valley Nuclear Services Company, Inc., West Valley, NY (2 June 1986).
[5] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Technology Guide (TTG), Mast Tool Delivery System (MTDS), Richland, WA (16 July 2001).
[6] PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL), Tanks Focus Area, Key Highlights, Richland, WA (30 July 2001).
[7] U.S. DEPARTMENT OF ENERGY, Ohio Field Office (DOE, OFO), High-Level Waste (HLW) Tank Closure, US Department of Energy, Ohio Field Office (30 July 2001).

CONTRIBUTORS TO DRAFTING AND REVIEW

Addison, B.	British Nuclear Fuels (BNFL), United Kingdom
Allan, D.	British Nuclear Fuels (BNFL), United Kingdom
Breza, M.	SE-VYZ, Slovakia
Burcl, R.	International Atomic Energy Agency
Cleland, G.	Ontario Power Generation, Canada
De Lamartinie, L.	SGN, France
Delrieu, J-C.	SGN, France
Gibbons, P.W.	Numatec Hanford Corp., United States of America
Kansra, V.P.	Bhabha Atomic Research Centre (BARC), India
Khubetsov, S.	All-Russian Research Institute for Nuclear Power Plants, Russian Federation
Meeus, A.	Belgoprocess, Belgium
Nechaev, A.	St. Petersburg Institute of Technology, Russian Federation
Pekár, A.	VUJE, Slovakia
Gonzalez, J.L.	International Atomic Energy Agency

Consultants Meetings
Vienna, Austria: 9–13 October 2000, 6–10 May 2002; 16 January 2006

Technical Meeting
Vienna, Austria: 3–7 September 2001