

The Use of Transportable Processing Systems for the Treatment of Radioactive Nuclear Wastes

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ABSTRACT

EnergySolutions has developed two major types of radioactive processing plants based on its experience in the USA and UK, and its exclusive North American access to the intellectual property and know-how developed over 50 years at the Sellafield nuclear site in the UK. Passive Secure Cells are a type of hot cell used in place of the Canyons typically used in US-designed radioactive facilities. They are used in permanent, large scale plants suitable for long term processing of large amounts of radioactive material. The more recently developed Transportable Processing Systems, which are the subject of this paper, are used for nuclear waste processing and clean-up when processing is expected to be complete within shorter timescales and when it is advantageous to be able to move the processing equipment amongst a series of geographically spread-out waste treatment sites. Such transportable systems avoid the construction of a monolithic waste processing plant which itself would require extensive decommissioning and clean-up when its mission is complete.

This paper describes a range of transportable radioactive waste processing equipment that EnergySolutions and its partners have developed including: the portable MOSS drum-based waste grouting system, the skid mounted MILWPP large container waste grouting system, the IPAN skid-mounted waste fissile content non-destructive assay system, the Wiped Film Evaporator low liquid hold-up transportable evaporator system, the CCPU transportable solvent extraction cesium separation system, and the SEP mobile shielded cells for emptying radioactive debris from water-filled silos. Maximum use is made of proven, robust, and compact processing equipment such as centrifugal contactors, remote sampling systems, and cement grout feed and metering devices. Flexible, elastomer-based Hose-in-Hose assemblies and container-based transportable pump booster stations are used in conjunction with these transportable waste processing units for transferring radioactive waste from its source to the processing equipment.

INTRODUCTION

EnergySolutions has full and exclusive North American rights to use the intellectual property and know-how developed over 50 years by British Nuclear Fuels PLC, principally at the Sellafield nuclear site in the United Kingdom [1]. Two spent nuclear fuel recycling plants, three vitrification plants, three grouted waste encapsulation plants and a wide range of supporting nuclear waste treatment, cleanup and storage plants are currently operated at the Sellafield site. Some two billion curies (7.4×10^{10} GBq) of high level waste have been processed and over 70% of this waste has now been vitrified and is placed in engineered, passively-cooled stores at the site. In addition significant quantities of legacy waste, ranging from contact-handled TRU up to highly gamma-active residues, have been retrieved from storage drums and “silos”, encapsulated in cement grout and placed into interim storage in purpose-designed vaults.

The design and operation of these nuclear processing plants, together with EnergySolutions’ work on radioactive processing plants in the USA [1], has both required and facilitated the development and optimization of two types of radiation-shielded processing facilities: Passive Secure Cells and Transportable Processing Systems. The former have been described in a previously published paper [2] and are appropriate where there is a long-term need to process large amounts of radioactive material over an extended time period. The latter, which are the subject of this paper, are used for nuclear waste processing and clean-up when processing is expected to be complete within shorter timescales, when it is advantageous to be able to move the processing equipment within a facility or amongst a series of geographically spread-out waste treatment sites, and when it is desired not to produce a monolithic waste processing plant which itself would require extensive decommissioning and clean-up when its mission is complete.

This transportable processing equipment is typically constructed within standard steel ISO-containers, or similar sized spaceframes, and includes portable ventilation and off-gas equipment added as required. The ISO-containers are shielded and confined as necessary by the addition of steel shielding and confinements to the outside of the containers. Alternatively the ISO-containers are placed within separately constructed concrete enclosures that do not come into contact with any radioactive material and thus do not themselves require any radioactive decommissioning at mission end.

Within the shielded confinements maximum use is made of systems that greatly minimize the use of moving parts, substituting these with non-moving process equipment and instruments based on fluidics and compressed air. Additionally, use is made of “through-wall” drives where moving parts are located outside the shielded ISO-container, with only a shaft drive penetrating the shielding and connecting with the in-container processing equipment. These design provisions enable the placement of most mechanical items and instruments requiring maintenance outside the shielding and thus accessible, and ensure that there is no need for personnel to enter the shielded parts of the containers during the life of the system.

This paper describes the principles underpinning the design of transportable radioactive waste processing systems and transportable radioactive waste piping systems, and illustrates the application of these principles to transportable systems designed for use at the Hanford and Savannah River nuclear site tank farms, the Hanford K-Basins, and at Sellafield in the UK.

MOBILE DRUM GROUTING SYSTEMS

General Principles

EnergySolutions have successfully grouted over 468,000 ft³ (13,000 m³) of liquid, sludge and solid radioactive waste streams at more than 45 nuclear sites in over 30 years of designing, owning and operating radioactive waste grouting systems in the US, Europe and Asia. These wastes have ranged from Low Level Waste to Remote Handled Transuranic Waste (RH-TRU).

In the process of supporting these facilities, EnergySolutions has developed a world class Process Control Program (PCP) to ensure that optimum cementation chemistry is utilized for each type of waste, and that suitable tests and calculations are performed to satisfy waste acceptance criteria and other client requirements, at the highest practical waste loading.

EnergySolutions PCP and solidification processes have been approved by a variety of regulators for wastes requiring long term disposal including those at the Barnwell Waste Facility managed by EnergySolutions. Other applications have been developed to provide wastes suitable for certification by the Waste Isolation Pilot Plant (WIPP) in New Mexico.

EnergySolutions has developed Mobile Solidification Units (MSU) specifically to allow in-container solidification of various radioactive wastes. MSUs generally consist of a number of assemblies either fitted with wheels, or mounted on trailers or skids or on other readily mobilized platforms. MSUs typically employ quick-disconnection fittings on process lines and utilities allowing rapid deployment and redeployment of these systems between or within facilities. The wastes typically processed by these systems include evaporator bottoms, resin beads, POWDEX®, filter sludges, filter precoat backwash, resin regeneration chemical wastes (sodium sulfate), decontamination solutions, oil sludges, oil, uranium and americium and other troublesome legacy nuclear chemical components. These systems are designed and operated in accordance with all applicable industrial and nuclear regulatory requirements, as well as EnergySolutions' own design criteria.

Immobilization of the waste is accomplished using readily available cementitious dry chemicals in conjunction with proprietary process additives. All conditioning and solidification of the waste occurs in a disposable liner or drum. Depending on waste characteristics, some of the required conditioning chemicals may be pre-loaded into the disposable liner/drum prior to waste loading. Pre-installed mixer blades permit continuous agitation until a thick cement paste has formed that will set to a hard, homogenous, water-free matrix, and these blades are then left within the waste form (the “lost paddle” system). The end product is a true cement structure formed in accordance with established principles of concrete technology.

Hanford Mobile Solidification System (MOSS)

A recent example of an EnergySolutions MSU is the Hanford K-Basins Mobile Solidification System (MOSS) which successfully passed factory acceptance testing in Spring 2007.

For the Hanford site, EnergySolutions has developed a system for the transfer, conditioning and solidification of uranium-based sludges [3] for ultimate disposal at WIPP in New Mexico. Equipment was designed, tested and supplied to remotely retrieve, transfer via Hose in Hose (see later section), and treat high dose spent fuel sludge that had accumulated in the Hanford K Basins over many decades. Retrieving and stabilizing the sludge is the final

stage in removing fuel and sludge from the basins to allow them to be decontaminated and decommissioned, thus removing the threat of contamination to the nearby Columbia River.



Fig.1. The MOSS waste solidification system used to cement encapsulate spent fuel sludges

The EnergySolutions treatment facility (Fig.1.) is modular in design in order to be housed in an existing K-Area building. After receipt of the sludge at this facility the reactive uranium metal within the sludge is planned to be corroded to avoid hydrogen generation during future transport to WIPP. The uranium corrosion process, which will also be performed in a large skid mounted unit, is a robust, tempered process very suitable for dealing with a range of differing sludge compositions and uranium particle sizes.

The final process steps include assay to determine the fissile content of each batch of sludge so that the fissile content of each drum can be controlled to achieve the waste acceptance criteria, and the MOSS drum grouting (cementation) system.

The MOSS system comprises the following stations:

- Drum fill plug (to close the filling aperture in the drum lid) removal/replacement station
- Wet dosing station where sludge is metered in accordance with waste acceptance criteria
- Dry dosing station where cementitious materials are added to the drum and the in-drum lost paddle is driven to homogeneously blend the waste and the cementitious materials.

MOSS can be adapted to suit the size of drum preferred by the customer. For K-Basins this was a DOT-7A, 55 gallon drum. The plug removal and replacement station can be tailored to suit the application. Variants utilizing central screw lids (as K-Basins), crimped lids (Barsebäck in Sweden) and bolted flanged lids (other European customers) have been utilized.

Addition of sludge to MOSS at K-Basins will be strictly controlled according to algorithms, which utilize outputs from the upstream assay system and solids and coriolis flow meters, to ensure that the drum does not exceed: Fissile Gram Equivalent (FGE), Radiation Dose, total Curie, weight or radiolytic hydrogen generation limits imposed by storage criteria.

Similarly, addition of cementitious materials is controlled by algorithms which ensure that appropriate water to cement ratios are achieved to ensure that radiolytic hydrogen generation and WIPP residual liquid (<1%) requirements are satisfied.

The MOSS unit allows all stages of the drum handling to be carried out remotely, so it is particularly suitable for this high gamma radioactivity sludge.

Key features of the MOSS include:

- Fills standard 55-gallon drums.
- Production capacity typically five to eight drums per day (440 gallons, 1.7 m³).
- Modular design fits in a standard 20 foot ISO-container.
- System is designed and built to NQA-1 standards
- System can be shielded and radiation-hardened depending on radioactivity of material being processed
- Can be operated hands-on or controlled remotely from a separate control station
- Provides full QA process records. Fully compliant with customers' waste acceptance criteria.
- Utilizes lost paddle in-drum mixing.

EnergySolutions has worked closely with its customer at Hanford to optimize the treatment processes and to make maximum use of existing buildings and facilities on site. A key tool in this process was Operational Research Modeling, using the WITNESS software suite which was used to analyze all unit operations to ensure maximum efficiency and throughput for each sub-system.

Sellafield Skid Mounted Large Container Grouting System

The Mobile Intermediate Level Waste Packaging Plant (MILWPP) (Fig.2.) is a simple, robust and flexible solution for cement encapsulation of a range of radioactive wastes, combining features from the proven MOSS systems, and from the Mobile Solidification Units used by the EnergySolutions' subsidiary Duratek, to solidify radioactive liquids, sludges and solids in large High Integrity Containers (HIC).

MILWPP is capable of encapsulating various types of radioactive liquid, including:

- Powdered Ion Exchange Resin
- Bead Ion Exchange Resin
- Evaporator Bottoms
- Sludge and Laundry Waste
- Filter Aids
- Sand

EnergySolutions is supplying a MILWPP encapsulation plant for immobilization of the intermediate-level sludges from the Building 30 (B30) spent nuclear fuel storage pond at the Sellafield nuclear processing site in the United Kingdom. The 48,000 ft³ (1350 m³) of sludge will be retrieved from the pond by others and EnergySolutions is designing, supplying and utilizing the MILWPP equipment to encapsulate the sludge in cementitious grout within UK NIREX-compliant 3 cubic meter (106 ft³) containers for intermediate storage at the Sellafield Site, prior to transport to a national geological repository. The MILWPP will be capable of producing 10 containers per week with an estimated total of 750 containers produced over the plant's lifetime.

Key Features of MILWPP include:

- Modular and transportable, enabling extensive pre-assembly together with functional and performance testing at the fabrication facility, thus minimizing site setup and commissioning time.
- Process is housed in a stainless steel containment complete with containment wash down, drum decontamination capability, and monitoring of collected wash-down liquids prior to disposal
- The fill head seals to the container and this feature, combined with an inner lid, reduces any potential for airborne activity post curing of the cement
- The drum uses the "lost-paddle" feature to homogenize the waste and grout thus providing an effective encapsulation technique, further minimizing contamination potential due to drips from a removed stirrer and thus removing the need for decontamination of the outside of the product container
- Operations are remotely controlled, and locally applied shielding protects operators to maintain ALARA principles
- Equipment within the containment is simple and robust. Prime movers such as motors and gearboxes are located outside the containment with through-wall drives, thus significantly reducing the need for manned intervention for maintenance of equipment within the shielded area.
- Maximum use is made of standard commercially available equipment.

- The MILWPP Fill Head is based on the proven Mobile Solidification Units and seals to the 55 gallon drum-sized lid of the High Integrity Container (HIC) [Fig.2.]
- The design avoids the use of “over-automation”. This is done by combining simple automation of certain tasks with the flexibility that operators provide for combinations of tasks. Experience has shown us that this provides more reliable and consistent operation than a fully automated, but less flexible, plant.

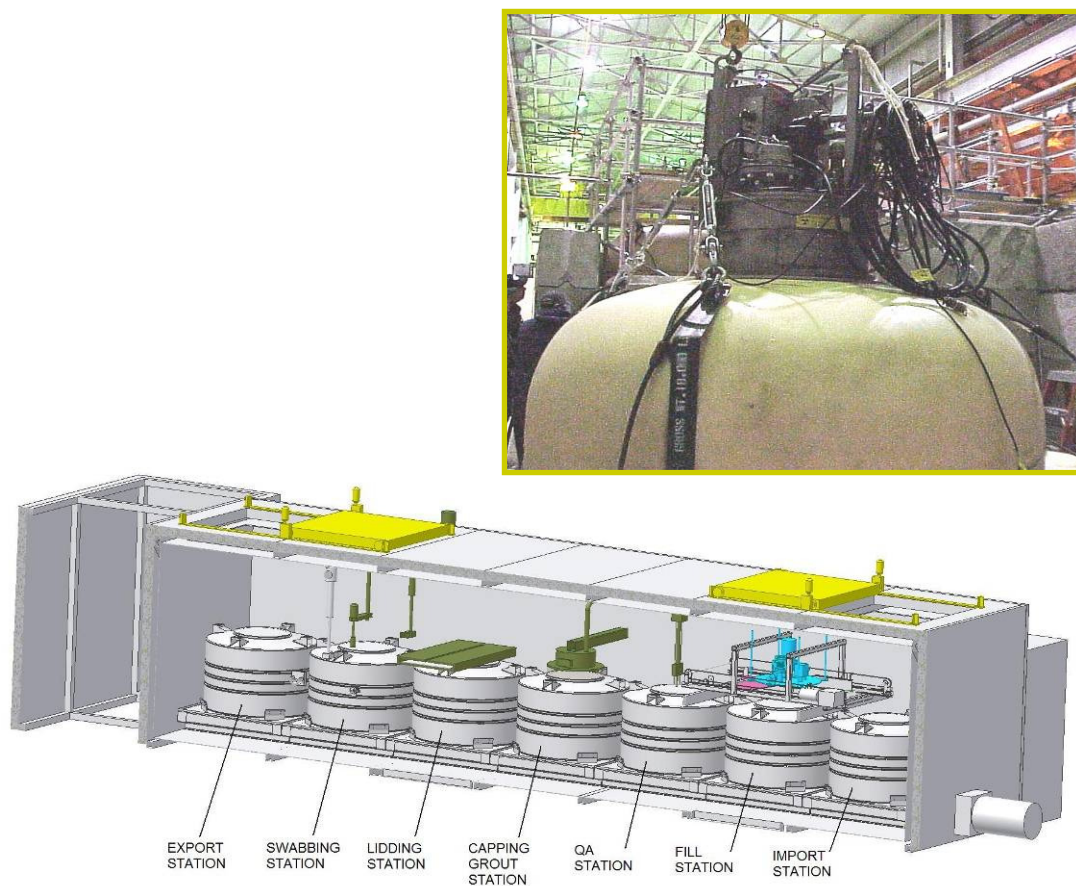


Fig. 2. Schematic of the MILWPP Waste Encapsulation System showing the Fill Head in place on a 3 m³ Container

The Sellafield Sludge Packaging and Export Facility MILWPP is being designed to the very stringent waste acceptance requirements that NIREX (now part of the UK Nuclear Decommissioning Authority) has specified for the UK National Geological Repository.

The MILWPP product must also meet stringent hydrogen generation, dose rate, radionuclide inventory, residual water limits and monolithic criteria. In early 2008 the project will conduct hydrogen gas modeling and small-scale grout formulation testing to confirm the initial formulations. MILWPP incorporates all equipment features such as level and mass measurement, emergency emptying and weep water removal and physical testing of grout strength which are necessary to provide operational data which, combined with this test data and with sludge characterization data, will demonstrate compliance with the waste acceptance criteria.

SKID MOUNTED IPAN FISSILE CONTENT ASSAY SYSTEM

Operating Principles and Technology

EnergySolutions has worked closely with Parajito Scientific Corporation (formerly BIL Solutions Inc.) to incorporate its Imaging Passive Active Neutron (IPAN) Technology in an in-process manner within the Hanford K-Basins sludge treatment system, rather than in the product confirmation approach that IPAN is usually utilized. The combined MOSS and Assay system designed for K-Basins is shown in Fig.3. The Assay System provides a non-destructive assay to measure the fissile content and gross gamma output of the waste sludge that is introduced into it. Suitable Total Measurement Uncertainties (TMU) are factored into these readings by statistically combining the known accuracy of all instrumentation within, and upstream of, IPAN. IPAN also takes account of Acceptable Knowledge (AK) which utilizes customer data on the characteristics of the sludge to be processed based on historical physical sampling of the sludge. Algorithms within a separate Data Management System combine these data with other process measurements to determine the quantity of sludge that can be pumped to MOSS for encapsulation into each drum.

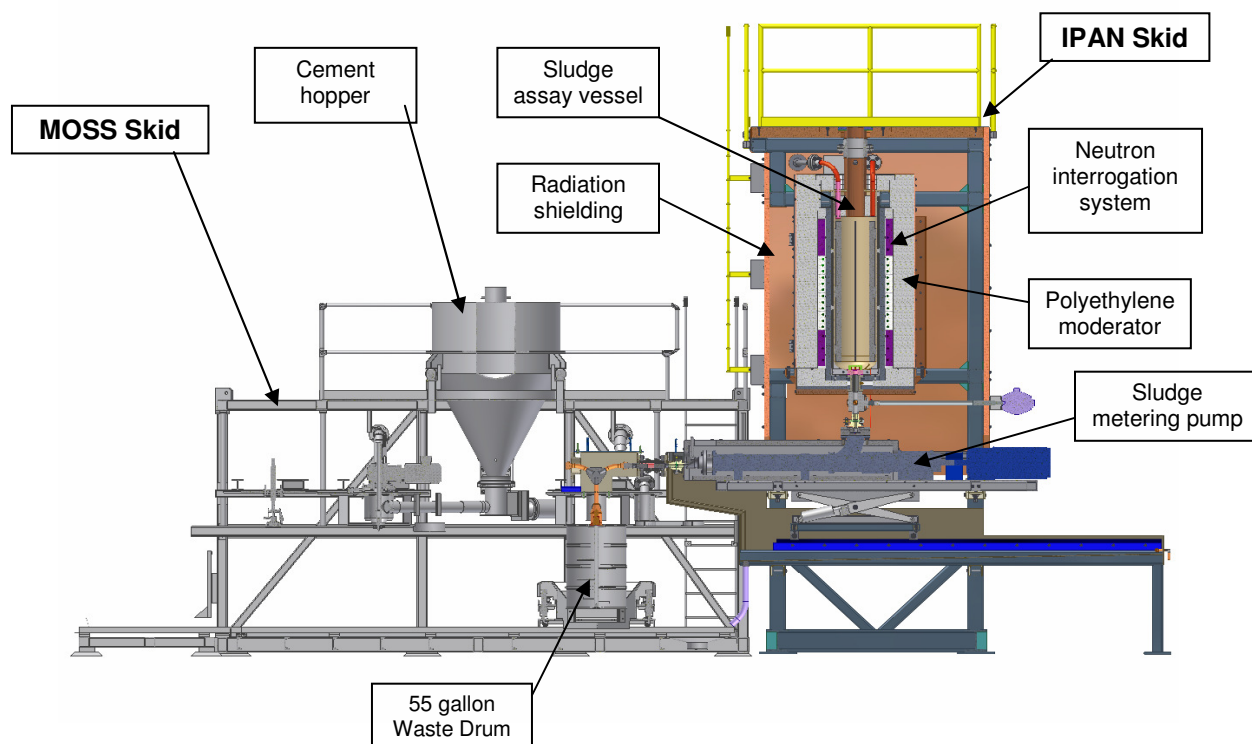


Fig. 3. Combined MOSS and IPAN Skids for processing Hanford K Basins sludge (shielding removed)

IPAN performs both an active neutron interrogation and passive neutron coincidence counting over a period of 30 minutes. During the passive mode assay the detector packages will detect neutrons produced by spontaneous fission and (α , n) interactions in the sludge. Differentiation between the fission neutrons and (α , n) neutrons is accomplished by coincidence counting. Upon completion of the count, the calculated coincidence neutron signal is combined with calibration information and an efficiency measurement derived from a passive source imaging analysis, to determine the Pu-240 effective mass within the sludge. The imaging analysis uses total neutron count data that is acquired at the same time as the coincidence counting, and determines the distribution of passive neutron sources within the assay vessel, thereby providing correction for any heterogeneity in the distribution of fissile material within the sludge.

During the active mode assay, the detector packages are used to detect neutrons arising from induced fission reactions resulting from thermal neutron interrogation. The interrogation neutron source is a Zetatron 14 MeV neutron generator, which is located within a polyethylene moderating assembly on one side of the assay chamber.

During the active mode assay, the Zetatron will produce short, intense fast neutron pulses, which are moderated from high-energy to thermal energies by the polyethylene moderator in the sides of the assay system and by moderating materials within the sludge itself. The neutrons arising from the induced fission reactions are measured by the detectors in a gated time interval after the neutron pulse from the generator, and the number of neutrons released during the fission events is proportional to the mass of fissile material. An imaging analysis is then applied to determine the distribution of fissile material within the sludge vessel, and corrected for source heterogeneity effects in the same way as for the passive measurements. The imaged fissile mass distribution is then summed up to determine the Pu-239 effective mass within the sludge.

Dependent on the user-definable mode selected within the IPAN software, the final calculation of Fissile Gram Equivalent (FGE) and associated TMU is based on the Pu-239 effective mass or Pu-240 effective mass using conversion parameters derived from AK isotopic fractions that are stored in user-definable parameter files.

Validation of the data provided by the IPAN system to the process control system is accomplished via an independent technical review of the data and the following Quality Control (QC) features:

- Built-in instrument performance checks; collectively referred to as the “Standardization Check”, which periodically are used to confirm that the active neutron, passive neutron and gross gamma elements of the IPAN system are functioning correctly.
- A background radiation check, referred to as the “Environmental Background Check”, which periodically is used to confirm that the levels of neutron and gamma background radiation are acceptable.
- Automated data review quality checks, performed by the IPAN software, which ensure data quality for individual assays and provide data quality flags to assist the independent technical reviewer in identifying invalid IPAN data.

Examples of applications of the IPAN Assay System

IPAN technology is mature and has been successfully demonstrated on Non-Destructive Assay systems used at a number of DOE Sites:

- Hanford Waste Removal & Packaging (WRAP) facility. This is a WIPP-certified system that assays 55-gallon drums containing Contact Handled TRU (CH-TRU)
- Rocky Flats Environmental Technology Site (RFETS) Passive/Active Drum Counter. WIPP-certified system used to assay 55-gallon drums containing CH-TRU.
- Rocky Flats Multi-Purpose Crate Counter. This is a WIPP-certified system used to assay crated CH-TRU.
- Savannah River Mobile IPAN. This is a WIPP-certified system used to assay 55-gallon drums containing CH-TRU.
- Idaho Advanced Mixed Waste Treatment Plant (AMWTP) Retrieval Box Assay System. This is a process instrument used to characterize crated CH-TRU, in order to confirm that each crate meets the Waste Acceptance Criteria for the AMWTP box processing facility.
- Hanford K Basins Closure, Stabilization and Packaging (KBCSP) sludge assay system. Verifies that waste packages can meet WIPP Waste Acceptance Criteria

The application of the IPAN technology for KBCSP sludge streams is novel because the sludge streams are Remote-Handled TRU (RH-TRU) and the sludge is contained in an agitated vessel with relatively thick ($\frac{1}{4}$ inch) stainless steel walls while it is being assayed, rather than being containerized in a thin-walled drum. Development testing of the system demonstrated its effectiveness with $\frac{1}{4}$ inch wall thickness vessels.

However, RH-TRU presents particular problems for IPAN measurements because of potential interference of gamma radiation from Cs-137 with the performance of the neutron detectors. It was found [4] that these problems can be eliminated by applying suitable lead shielding to the detectors and by hardening them to the effects of gamma radiation using materials (aluminum walled, CO₂ quench gas), which have been demonstrated to produce excellent performance in high gamma radiation fields of up to 20 R/hr.

TRANSPORTABLE EVAPORATOR SYSTEM WITH LOW LIQUID HOLD-UP

Wiped Film Evaporator System

Most evaporators for radioactive material use have hitherto been of standard “kettle” or similar design, with a relatively large holdup of the radioactive liquid within them. This requires them to be fixed installations, enclosed in heavy shielding. Design and pilot-scale studies for radioactive liquid evaporation conducted by EnergySolutions’

partner, Columbia Energy & Environmental Systems, Inc. (Columbia Energy) showed that a Wiped Film Evaporator (WFE) could be adapted for radioactive use.

WFE systems have been used for more than 50 years for evaporation of petrochemicals and specialty chemicals, and for the recovery of oil, waxes, resins, pharmaceutical compounds, food products and waste solutions. Over the last two years, Columbia Energy has completed testing and design work required to deploy this technology in a nuclear environment. Pilot-scale testing successfully demonstrated the concentration of simulants of the Hanford high-level tank wastes with high pH and high salt content. The technology produced evaporator condensate equal to or less than U.S. Environmental Protection Agency drinking water standards while concentrating waste streams from a specific gravity of 1.1 to greater than 1.5, without system fouling or the need for excessive flushing.

Typical vertical and horizontal WFEs are shown inset in Fig.4. The motor turns a shaft (3) with its attached wipers that contact the evaporator vessel walls. These are heated by a heating fluid that enters and leaves a jacket at points (5). The feed liquid enters the evaporator vessel at point (4) and is immediately spread into a thin film on the vessel walls by the wipers. Evaporation is thus quick and efficient and the concentrated liquid leaves the vessel at point (6). Overheads leave the vessel at point (1).

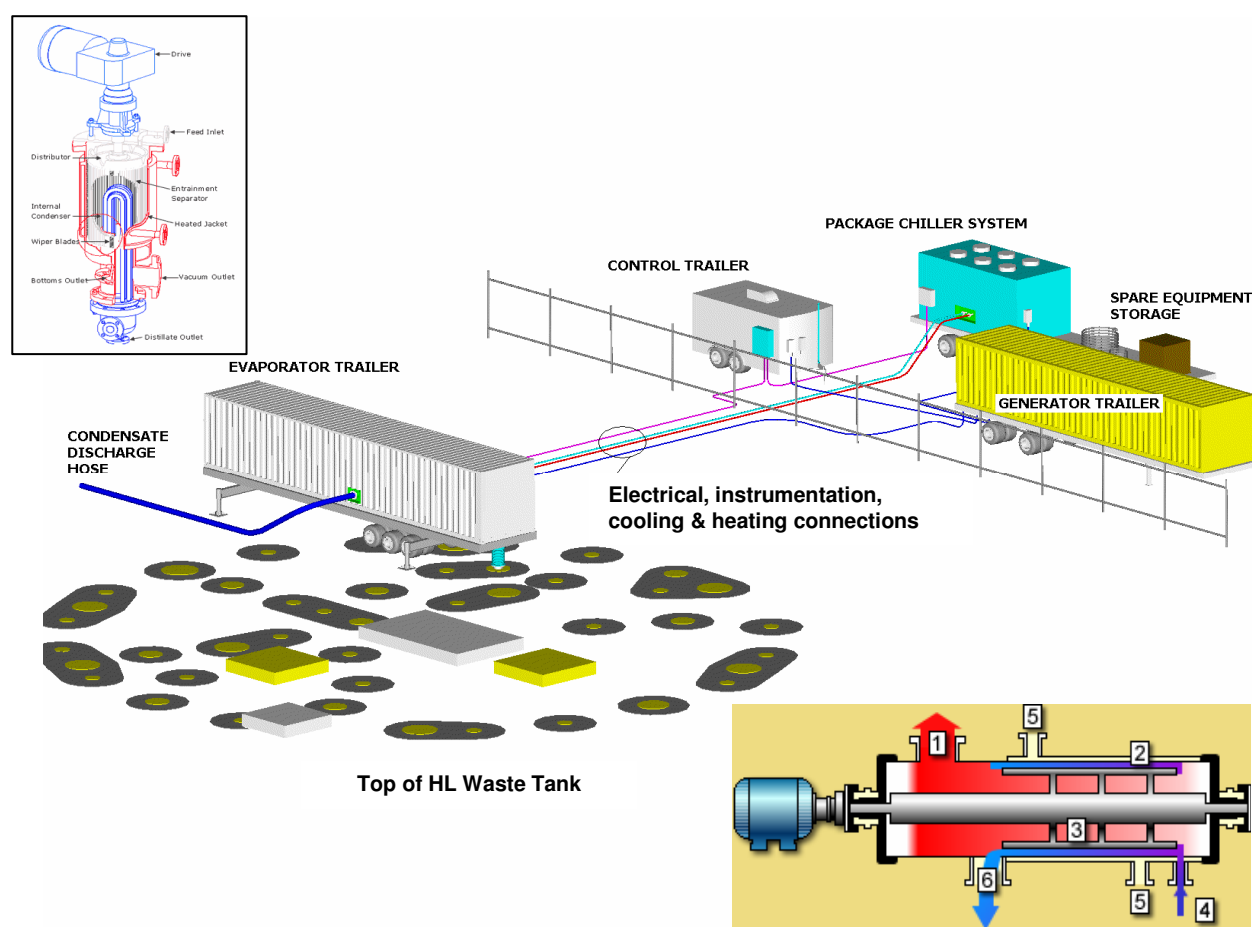


Fig. 4. Illustrative Installation of a Wiped film Evaporator on a Hanford HL Waste Tank

Advantages of WFE systems for nuclear applications include:

- Centrifugal force holds a thin film of material (approximately 1/8 inch thick) against the heated wall; increasing heat transfer and keeping the holdup and residence time very low.

- The low holdup of the radioactive liquid within the unit reduces the thickness of shielding necessary to meet radiation dose exposure constraints, and the evaporator is easily washed out prior to maintenance interventions
- The evaporator is designed to operate under vacuum providing operation at lower temperatures. Such low temperature operation limits volatile component carryover into the vapor.
- The motor can be positioned outside the radiation shielding for ease of maintenance. If the shaft and wipers need attention, they can be readily withdrawn into a flask for containment and either discarded or maintenance work performed in a suitable active maintenance facility while a spare assembly is installed.

An illustrative scheme for using a transportable WFE on the Hanford HL Waste Tanks is shown in Fig. 4. The evaporator trailer is positioned over a tank, and a horizontal WFE interfaces with one of the tank risers, thus sharing the tank ventilation provisions and obviating the need for separate ventilation arrangements. Control, heating and cooling equipment are positioned in trailers outside the HL Waste Tank controlled area. The concentrated evaporator product drops directly back into the tank, so it can be evaporated to much higher densities than if it had to be transferred via long transfer lines where crystallization could be a problem. The evaporator overheads are condensed and then fed to Hanford effluent plants via Hose-in-Hose systems (Fig.7.). The system can readily be moved from tank to tank, avoiding the long transfer line lengths required by the older fixed position evaporators.

TRANSPORTABLE SOLVENT EXTRACTION SEPARATION SYSTEMS

Compact Cesium Processing Unit (CCPU)

At both the Hanford and Savannah River sites, it is intended to vitrify the stored HL wastes for ultimate permanent storage at Yucca Mountain. Because each site's waste was neutralized with sodium hydroxide before storage in the carbon steel storage tanks, these wastes have a high inactive sodium content, which unfortunately is incompatible with the glass, reducing its capacity for the highly active components in the waste. There is therefore a need to separate the highly active cesium and other species from the sodium. This allows the low active sodium stream to be grouted in cement, or vitrified in a low active process.

Cesium removal processes have been developed and proven using both ion exchange (to be used at the Hanford Waste Treatment Plant (WTP)) and solvent extraction (to be used at the Savannah River Salt Waste Processing Facility (SWPF)). The "Caustic Side Solvent Extraction" (CSSX) process was developed for SWPF by the US National Laboratories and uses compact centrifugal contactors to bring the solvent and aqueous phases in contact with each other. EnergySolutions is working with the prime contractor for the SWPF to design and commission a large scale fixed separation plant to use the CSSX technology to pre-treat Savannah River Tank Waste before it is vitrified in the Defense Waste Processing Facility (DWPF).

EnergySolutions has now adapted the CSSX process so that it can be contained within transportable ISO-containers, by exploiting the compact dimensions of centrifugal contactors and utilizing its solvent extraction plant design and operating expertise. This system is known as the Compact Cesium Processing Unit (CCPU). Such a transportable cesium removal unit could be particularly useful at the Hanford site, where there is a developing need to carry out early pre-treatment of certain HL waste tanks. This will allow these wastes to be fed to the WTP Low Active Vitrification plant several years in advance of the WTP ion-exchange based Pretreatment Facility coming on stream. The CCPU could also be used to allow higher cesium content tanks to be treated before feeding to the proposed Hanford Bulk Vitrification facility.

The equipment is located in 4 standard ISO-containers (Fig. 5.) with an overall footprint of 70 ft by 30 ft and a total weight of <150 tons, including an adjacent HVAC skid. It comprises:

- A 40 ft long container housing process equipment in two tank modules and one centrifugal contactor module
- A 40 ft container above the first container, forming a service, maintenance and sampling enclosure, with shielding between the two containers
- A 20 ft long container, housing electrical distribution and reagents preparation room, and formed in an "L" shape with the 40 foot containers.
- A 20 ft long container above the first 20 foot container, housing the control room, personnel & equipment airlock and personnel change room.

The containers provide radiation shielding, by suitable steel or lead additions between and around the outside of containers, tertiary containment, structural support to the process and protection of equipment from the external

elements. Located external to the containers are a roof-mounted Air Conditioning Unit for air drawn into the containers and a skid-mounted HVAC exhaust unit, with integral stack.

Primary containment of radioactive material is provided by the pipework, vessels, & other process equipment, while secondary containment is provided by module liners, designed to contain any breach of primary containment. Tertiary containment is provided by the ISO-container structure.

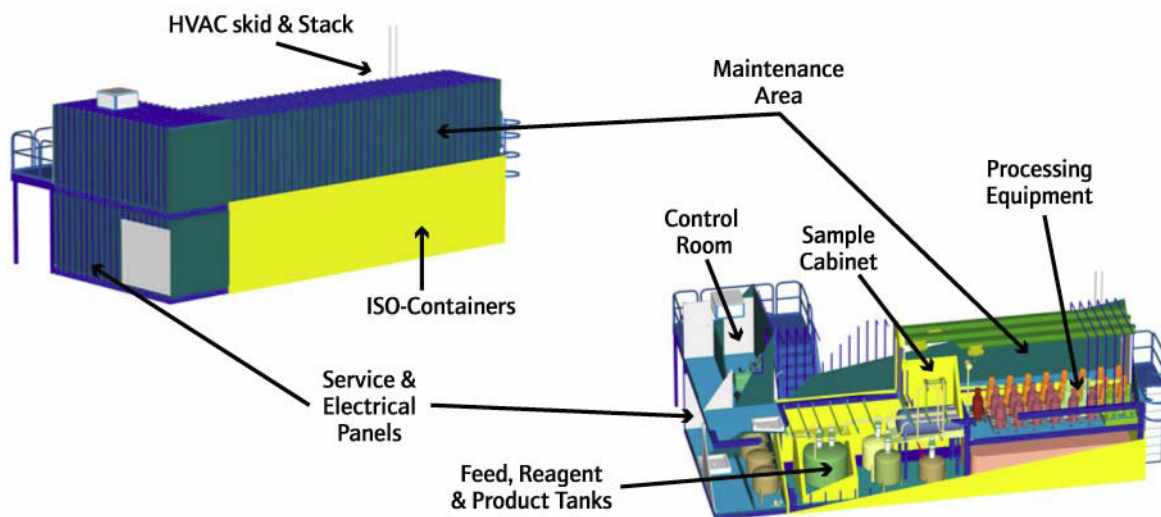


Fig. 5. The Compact Cesium Processing Unit

Maintenance is carried out by entry into the upper 40 foot container via the personnel entry airlock. Roof hatches are provided for equipment removal if required. Maintenance features are designed into the CCPU system, including wash down racks provided to internally flush the process equipment to facilitate limited contact maintenance for mechanical pumps, centrifugal contactors and valves. Centrifugal contactor motors are located in the upper 40 foot container and so can be replaced without breaching primary containment. Any failed process equipment that has been in contact with radioactive process fluids can be flushed in situ, bagged and removed for maintenance or disposal.

Key Design Features of the CCPU

- Throughput of 1M gallon/year is the current baseline and can be readily scaled down. Increased throughput would typically be provided by using multiple units
- Feed is filtered to remove tank sludge by a proprietary inline solids separation centrifuge
- Six extract centrifugal contactors will give a cesium decontamination factor (DF) of up to 100,000 (typically a DF of 134 -1200 is required)
- Space for 12 extract contactors exists. If used, these extra contactors provide robustness against process upsets
- Suitable adjustment of the solvent-aqueous ratios in the contactors gives up to 15-fold concentration of the cesium into the aqueous product.
- In-unit cesium concentrate product tankage is minimized to reduce cesium inventory and thus shielding requirement
- Entrained solvent recovery from the aqueous product streams is achieved by proprietary high speed centrifuges
- A barium decay tank on the sodium product stream gives 30 minutes delay time to allow Ba-137 to decay and the gamma monitor to confirm cesium removal
- A Drain/Recycle Tank provides the means of recycling out-of-specification material
- Buffer tanks are provided to sentence out sodium product to low active Vitrification

SOLID WASTE RETRIEVAL WITH MOVABLE EQUIPMENT

Silo Emptying Plant (SEP) Mobile Cell

At the Sellafield nuclear processing site in the United Kingdom the B38 facility consists of 22 large above-grade, water-filled concrete walled compartments (“Silos”), each approximately 500 m³ (17,500 ft³) in volume. The facility was constructed as a temporary storage system for waste magnesium-aluminum alloy cladding (“swarf”) created when irradiated “Magnox” uranium metal fuel elements were decanned prior to dissolution and reprocessing. The original building comprised 6 silos, onto which were added three extensions of 6, 2 and 8 silos respectively, providing 22 silos in total. In addition to the regular swarf, the silos were used over the years to temporarily dispose of larger pieces of radioactive equipment, creating a range of different sized pieces to retrieve from underwater, in a highly radioactive environment. This swarf and other contaminated equipment is retrieved from the silos and encapsulated in cement, in a purpose-built plant for long-term safe disposal. To enable safe retrieval and disposition of this varied waste, a number of mobile Silo Emptying Machines were built. The first of these was the Silo Retrieval Facility (SRF) which was deployed in 1993 for removal of sludges and swarf from silos 19 through 22. These silos were selected for early emptying due to the better characterization of the wastes within them and the absence of non-swarf wastes. To retrieve the more challenging wastes in the remaining compartments, a second generation mobile Silo Emptying Plant (SEP) was built. This machine (Fig. 6.) consists of a Retrieval Module, a Transfer Tunnel for the retrieved waste and a Transfer Flask to contain the retrieved items and allow their removal to other plants for final encapsulation and disposal. The whole assembly forms a Mobile Cell or “Cave”.

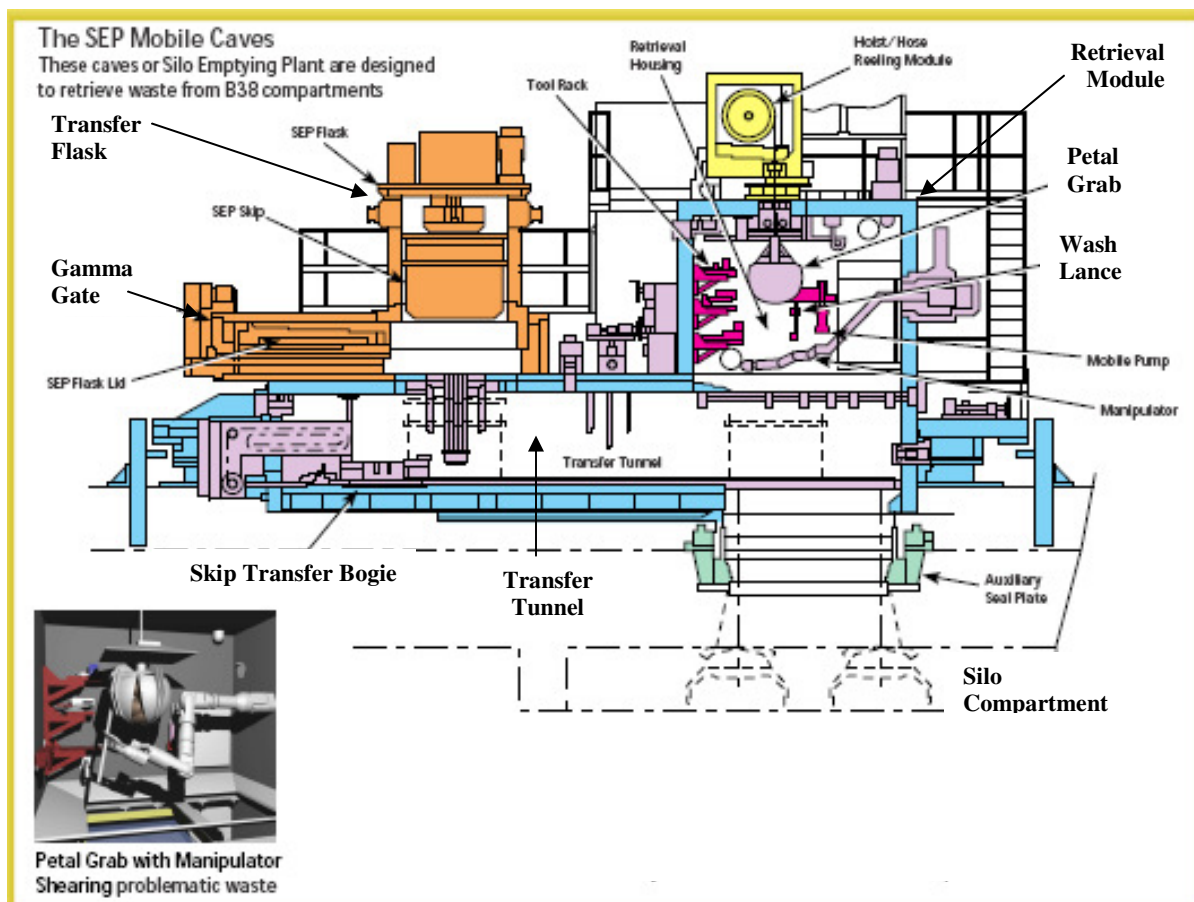


Fig. 6. The Silo Emptying Plant Mobile Cell at the Sellafield Nuclear Plant in the UK

The SEP is positioned over the required B38 Silo compartment and sealed to it. An operator, positioned at a workstation outside the retrieval housing, uses the petal grab to remove items from the silo compartment, making use of CCTV cameras to view the silo compartment. A remote manipulator mounted shear is available to cut up

larger items as required, and wash-down and decontamination facilities are used to clean the retrieved items before they are placed in a skip on the transfer bogie within the Transfer Tunnel. The bogie is then moved under the Transfer Flask and the retrieved items winched into the flask. The gamma gate is then moved to seal both the flask and the transfer tunnel, allowing the flask to be moved away.

When retrieval of all material in one compartment is complete, the entire mobile retrieval cell is moved to the next compartment. These systems have been in successful use at Sellafield for over 15 years.

HOSE-IN-HOSE RADIOACTIVE WASTE SLURRY TRANSPORT SYSTEMS

EnergySolutions has developed transportable systems for the mobilization and transfer of radioactive sludges from basins or vessels to encapsulation plants. These systems generally mobilize the sludge using a dilution system, transfer pumps, a flexible Hose-in-Hose (HiH) transfer line, and booster pumps sited along the transfer line, if necessary. The dilution system provides priming, dilution, and forward-flush water for the HiH system. A solids suspension meter, usually in combination with a coriolis flow meter, in the outlet line from the vessel controls the dilution water flow and records the quantity of sludge pumped to the downstream process. Depending on the distance and characteristics of the sludge being transferred, pumps can be incorporated adjacent to the originating vessel to provide the motive force necessary to initially transfer the diluted sludge, and additional booster station pumps can be provided to maintain head through the HiH transfer line to the upstream mobile encapsulation plant. The booster stations also provide leak detection monitoring for the outer hose.

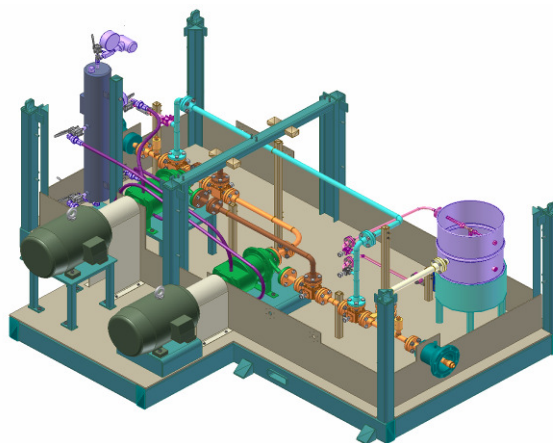
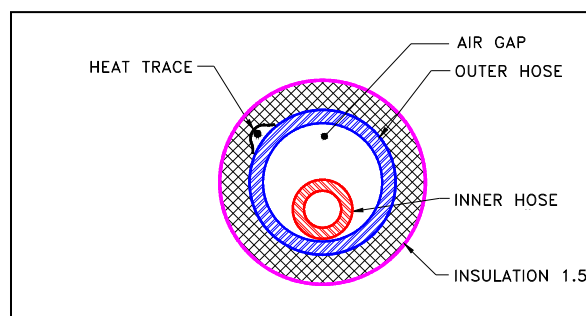


Fig. 7. Hose-in-Hose Installation, Engineered Coupling, Cross-Sectional View and Pump Booster Station

The HiH system consists of a coaxial hose arrangement with an annular air gap (Fig.7.). Trace heating and an outside insulation layer can be added if required. The inner/primary hose is used to transfer the diluted sludge and flush water while the outer hose provides secondary containment for the primary hose and, in the unlikely event of

leakage from the primary hose, routes this leakage to the leak detector elements located at the pump booster stations and leak detection boxes located at intervals along the pipe route.

HAZOP studies determined that these hoses and the leak detection instruments required to be classified as Safety Significant and therefore a stringent Quality Level 2 procurement contract was placed with the specialist suppliers to ensure that all the necessary quality requirements were satisfied. Shielding analysis also determined the amount of additional biological shielding materials required between the hose assemblies and operating personnel. This was achieved by the use of thick steel hose “barns” local to manned facilities and by the addition of soil berms on top of the hose assemblies for the longer runs between facilities.

The hose is constructed of Ethylene Propylene Diene Monomer (EPDM), with double spiral wound wire reinforcement. The outer hose is normally covered with 1.5 inch (3.8cm) thick Armaflex¹ insulation. Hose couplings are fully engineered stainless steel devices (Fig.7.). The hoses are factory tested to burst pressures for the inner (2000 psig, 14 MN/m²) and outer (1000 psig, 6.9 MN/m²) hoses. The inner hose assemblies are pressure tested to 750 psig (5.2 MN/m²) after site installation, in order to qualify a 500 psig (3.4 MN/m²) working pressure of the inner hose. Additional hose protection is achieved by the use of rupture disks located at the pump booster stations.

The capital, installation, operating and decommissioning costs to implement these Hose-in-Hose systems is considerably lower than fixed pipe, flexible pipe-in-pipe or casking systems for radioactive liquid and slurry transfer. Installation of the HiH simply requires it to be unrolled and placed into position (Fig. 7.) either on the ground surface or in a trench for shielding. Although the hose route is usually trenched and a traffic exclusion area, extensive testing has shown that the hose keeps its integrity even when run over by trucks and other heavy vehicles. When the duty is complete, the HiH system is flushed with water and then simply rolled up ready for deployment elsewhere.

To confirm the design and service life of HiH systems for transferring abrasive slurries, a test program was carried out to demonstrate the suitability and resistance to wear of hose, fittings, and pumps. A test circuit of inner hose and a scaled-down pump was set up and a sludge slurry simulating the highest expected abrasiveness was recirculated through it for the equivalent of twice the maximum volume of sludge likely to be pumped in a single system. It was found that negligible wear occurred on the HiH, but that significant wear occurred within the pump impeller housings.

To allow for this wear, the pumps are always duplicated within the Booster stations, with a duty and standby pump. In addition:

- Wetted parts, including the front, back, and vanes of the pump impeller, are fabricated from ½-inch (1.3 cm) thick 2507 duplex stainless steel to reduce and allow for erosion.
- The impeller has cleaning vanes on the back side (opposite the suction inlet) to prevent solids from entering the mechanical seal behind the impeller.
- Mechanical seals in the pump are double cartridge type containing a tungsten carbide (inboard), and carbon (outboard) rotating face, plus viton elastomer and tungsten carbide (inboard), and silicon carbide (outboard) stationary face.
- Cartridge seals are cooled and flushed through the use of API Plan 53A seal systems.
- Seal systems contain a 5 gallon (19 liter) reservoir of a propylene glycol/water mix.
- Reservoirs are provided with level, pressure, and temperature monitoring instrumentation.

In early 2007, a HiH system of this type was successfully used to transfer 1000 ft³ (30 m³) of highly radioactive sludge from the Hanford K East Basin to engineered containers in the K-West, allowing decommissioning to commence in the K-East Basin. This action removed one of the major outstanding hazards on the Hanford site.

¹ Armaflex is a trademark of Armstrong World Industries, Inc.

CONCLUSIONS

Transportable systems for the retrieval, processing, transfer and encapsulation of radioactive wastes have now been developed to the point where they are a viable and cost-effective alternative to traditional large-scale fixed plant. Their use is complementary to the Passive Secure Cells and Canyons that EnergySolutions designs for plants required for longer term processing of radioactive materials. They are particularly valuable when only a short term need exists for radioactive material handling, avoiding the need for costly fixed plant construction and subsequent decommissioning and cleanup.

Transportable systems are also valuable when the waste to be processed is located over a wide geographical area and it is not cost effective or desirable to use long pipe runs to move the waste to a fixed processing plant. In these cases, moving a portable processing plant to the various waste locations in turn is an excellent alternative.

With transportable systems, increased throughput is readily provided by employing further transportable units, thus maintaining flexibility in plant provision and avoiding unnecessary costs.

REFERENCES

1. CHRIS BURROWS, CHRIS PHILLIPS, “A UK Company’s Experience of Working in the US Department of Energy Nuclear Cleanup Marketplace”, ICEM-05, The 10th International Conference on Environmental Remediation and Radioactive Waste Management, September 4-8, 2005, Scottish Exhibition & Conference Centre, Glasgow, Scotland
2. CHRIS PHILLIPS, PAUL CAVANAH, JOHN RICHARDSON, “The Use of Passive, Secure Cells for Processing of Highly Active Nuclear Wastes”, Waste Management 07 Conference, February 25 to March 1, 2007, Tucson, AZ, Paper 7462
3. P. KNOLLMEYER, C. PHILLIPS, P.S. TOWNSON, “Progress with K Basins Sludge Retrieval, Stabilization and Packaging at the Hanford Nuclear Site”, Waste Management 06 Conference, February 26 to March 2, 2006, Tucson, AZ, Paper 6415
4. A. SIMPSON, N. ABDURRAHAM, “High Sensitivity Assay of Cement Encapsulated Spent Nuclear Fuel Sludge using the Imaging Passive Active Neutron (IPAN)”, Waste Management 07 Conference, February 25 to March 1, 2007, Tucson, AZ