STUDSVIK PROCESSING FACILITY UPDATE

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ABSTRACT

Studsvik has completed over four years of operation at its Erwin, TN facility. During this time period Studsvik processed over 3.3 million pounds (1.5 million kgs) of radioactive ion exchange bead resin, powdered filter media, and activated carbon, which comprised a cumulative total activity of 18,852.5 Ci (6.98E+08 MBq). To date, the highest radiation level for an incoming resin container has been 395 R/hr (3.95 Sv/h).

The Studsvik Processing Facility (SPF) has the capability to safely and efficiently receive and process a wide variety of solid and liquid Low Level Radioactive Waste (LLRW) streams including: Ion Exchange Resins (IER), activated carbon (charcoal), graphite, oils, solvents, and cleaning solutions with contact radiation levels of up to 400 R/hr (4.0 Sv/h). The licensed and heavily shielded SPF can receive and process liquid and solid LLRWs with high water and/or organic content.

The SPF employs the THERmal ORganic REDuction (THOR\textsuperscript{sm}) process, developed and patented by Studsvik, which utilizes pyrolysis/steam reforming technology. THOR\textsuperscript{sm} reliably and safely processes a wide variety of LLRWs in a unique, moderate temperature, pyrolysis/reforming, fluidized bed treatment system. The THOR\textsuperscript{sm} technology is suitable for processing hazardous, mixed, and dry active LLRW with appropriate licensing and waste feed modifications.

Operations have demonstrated consistent, reliable, robust operating characteristics. A wide variation of processing efficiencies and ultimate volume reductions have been experienced due to the widely varying characteristics of the incoming waste streams. Input waste has varied in total inorganic content (the determining factor for volume reduction) from 1% to >90%. A substantial element of this variability has been the “soluble salt” content of the input waste streams, which have been found to vary from 1% to 83% of the input waste material.

Final reformed residue comprises a non-dispersible, granular solid suitable for long-term storage or direct burial in a qualified container. THOR\textsuperscript{sm} effectively converts hexavalent chromium to non-hazardous trivalent chromium and can convert nitrates, if present, to nitrogen with over 99 percent efficiency in a single pass.

This paper provides an overview of the last four years of commercial operations processing radioactive LLRW from commercial nuclear power plants. Process improvements and lessons learned will be discussed.

INTRODUCTION

Since 1947 Studsvik has been actively involved as a research center for nuclear power in Sweden. Studsvik operates a research test reactor and hot cell facility for production of medical isotopes, commercial nuclear fuel testing, and materials irradiation. Studsvik operates a Dry Active Waste (DAW) incinerator, which has been in commercial operation since the early 1970s. Full metal melting and recycling capabilities for carbon and stainless steels, and aluminum have been in use for several years.
PROCESS OVERVIEW

The THOR™ process utilizes two fluid bed contactors to process a wide variety of solid and liquid LLRWs. Figure 1 provides an overview flow diagram of the THOR™ process. Radioactive waste feeds are received at the SPF and stored in holdup tanks. As waste is needed in the process, waste is transferred to the waste feed tanks for metering and injection into the first stage fluid bed pyrolyzer/reformer. Solid, dry, granular wastes such as charcoal, graphite, soil, etc are metered into the pyrolyzer by the solids feeder. Liquids and slurry wastes such as IER, oils, antifreeze, solvents, cleaning solutions, etc are metered into the pyrolyzer by a pump.

Figure 1 - THOR™ Process Flow Diagram
The pyrolyzer fluid bed serves to evaporate all water from the IER slurry and liquid waste feeds, and pyrolyzes the organic components through destructive distillation. Fluidizing gases, volatile organic vapors, and steam released in the pyrolyzer fluid bed comprise a synthesis gas, which passes through the high temperature filters and to the gas handling system. The low-carbon, metal oxide-rich residue removed by the high temperature filters can be further processed in the second stage steam reformer to remove any final carbon or to convert the oxidation state of selected metals. The stage-two Reformer can also be used as a primary waste processing unit by the direct injection of liquid wastes. The radioactive, volume reduced residue is packaged in qualified High Integrity Containers (HICs) for burial at licensed burial sites or return to the generator for storage.

Through selection of autothermal steam reforming operating conditions it is possible to produce an inert, inorganic final waste that consists of only the radioactive elements, metal oxides and inorganic calcium and silica compounds initially absorbed/trapped on the LLRW. Another significant improvement realized by the THOR™ process is the ability to process wastes with high water content. Aqueous wastes do not need to be dried prior to processing, but can be injected directly into the fluid bed using reliable slurry pumping equipment. Sodium nitrate slurry, oils, activated carbon, antifreeze solution, steam generator cleaning solvent, and several types of IERs have all been successfully processed by the THOR™ process.

STUDSVIK PROCESSING FACILITY

Studsvik has completed three years of full commercial operation. Commercial operation of the Studsvik Processing Facility (SPF) began in July 1999 with limited operations as the plant was brought up to capacity. The SPF and THOR™ process systems are described below. The SPF is designed to meet all laws, codes, and standards related to processing LLRW. A photograph of the SPF is shown in Figure 2.

![Figure 2 - SPF Overview](image)

The SPF is designed to meet the following criteria:

- **Facility Curie Inventory**: up to 2,000 Ci (74 TBq)
- **LLRW Input Activity**: up to 4.0 Ci/ft³ (5.2 TBq/m³) Contact dose of up to 400 R/h (4.0 Sv/h)
- **LLRW Inputs**: Ion Exchange Resins, Activated Carbons (Charcoal), Powdered Filter Medias, Graphite, and Organic Solvents and Oils, Aqueous Decon and Cleaning Solutions

The SPF consists of a heavily shielded Process Building, unshielded Ancillary Building, and an Administration Building. The Process and Ancillary Buildings are licensed for receipt, handling, processing, and packaging of LLRW.

**Process Building**

The Process Building contains all radioactive processing, handling, and packaging systems for volume and weight reduction of incoming LLRW. Major areas include truckbuys, LLRW input holding tank vault, pyrolysis/reforming vault, gas handling vault, salt dryer room, final residue packaging vault, and auxiliary equipment rooms.
Truckbays

LLRW is shipped to the SPF in unshielded containers or shielded casks qualified by Department of Transportation (DOT) or Nuclear Regulatory Commission (NRC). Most LLRW is received in the truckbays where containers and casks are surveyed, opened and the waste transferred to shielded waste input holding tanks located in shielded vaults. Cask operation activities are performed in the truckbays where an overhead bridge crane provides lifting capability.

Waste Input Holding Tanks

Three large stainless steel slurry holding tanks are provided for receipt and holdup of incoming liquid and slurry wastes. A separate liquid waste tank is used to receive more volatile organic solvents, cleaning solutions, and oils. A lockhopper feeder is used to receive and feed granular and powdered LLRW, such as charcoal. A separate waste feed tank with injection pumps is used to meter slurry and liquid wastes from the slurry holding tanks into the stage-one pyrolysis vessel.

Pyrolysis/Reforming System

The Pyrolysis/Reforming THOR™ system comprises: stage one pyrolysis contactor (pyrolyzer), stage two reformer contactor and associated filters. The pyrolyzer is a vertical, cylindrical fluid bed gasifier designed to operate at up to 1472°F (800°C). LLRW is injected into the fluidized pyrolyzer where: 1) water is instantly vaporized and superheated, and 2) organic compounds are destroyed as organic bonds are broken and resulting synthesis gas (principally carbon dioxide, carbon monoxide, and steam) exits the Pyrolyzer. Residual solids from the pyrolysis of the LLRW (including fixed carbon, >99.8 percent of the incoming radionuclides, metal oxides, and other inorganics and debris present in the LLRW feed) are removed from the pyrolyzer and collected in the stage one high temperature filter vessels. The pyrolyzer is fluidized with superheated steam and additive gas. Figure 3 is a photograph of the reformer process area.

![Figure 3 - Process Area - Reformer](image)

The stage two reforming contactor is a vertical, cylindrical fluid bed designed to operate at up to 1472°F (800°C). Pyrolyzed solid residues from the stage one filters or additional LLRW feed can be transferred to the reformer, which is an electrically heated, fluidized bed. The reformed, low-carbon, final residue is collected in the stage two high temperature filter vessel. The reformer is fluidized with superheated steam and additive gas.
Gas Handling System

The gas handling system comprises an energy recovery heater, submerged bed evaporator, scrubber/mist eliminator, condenser, Continuous Emissions Monitoring System (CEMS), process blower, High Efficiency Particulate Absolute (HEPA) filter, vent blower and radiation monitor. The purpose of the gas handling system is to convert synthesis gas constituents to carbon dioxide and water, recover energy from the synthesis gas, convert acid gases to stable salts, control water content of exiting process gases, and control negative pressure levels throughout the THOR™ pyrolysis/reformer system.

Synthesis gases from the pyrolyzer and reformer are filtered and then oxidized in the energy recovery heater to carbon dioxide and water. The heater recovers energy from the synthesis gas and provides heat to the submerged bed evaporator where excess water is evaporated from the scrubber water. The heater is a vertical, refractory lined vessel that operates at up to 2192°F (1200°C).

The submerged bed evaporator is an energy recovery system that channels the hot heater outlet gases through a volume of scrubber water, thereby evaporating excess water. The evaporator concentrates scrubber solution to 10 to 20 percent salts. The wet evaporator gases pass through the rotary atomizer scrubber where sulfur and halogen gases are efficiently converted to salts. Sodium hydroxide is metered into the scrubber to neutralize sulfur and halogen gases that are absorbed by the scrubber solution. The outlet of the scrubber is fitted with a mist eliminator that removes particulates and mists from the scrubber outlet.

The clean, moisture-laden gases exit the scrubber and excess moisture is condensed for recycle/reuse in the process. The condenser serves as the process heat sink and serves to control water balance in the SPF. The cool, clean gases are then compressed to atmospheric pressure by the process blower. A CEMS is provided on the process blower outlet to monitor and record the release of any traces of carbon monoxide, acid gases, total hydrocarbons, and Nitrogen Oxides (NOx).

The clean, cool process gases commingle with the building ventilation airflow. The combined gases flow through a HEPA filter bank, vent blower and are then released through a monitored vent stack. A complete radiation monitor system measures and documents any trace radionuclides that may pass through the stack. The radiation monitor system includes gamma, beta, alpha, iodine, carbon¹⁴, and tritium samplers and detectors.

Salt Handling System

The salts that are formed in the scrubber and concentrated in the evaporator are transferred to the salt handling system, which comprises a filter, an ion exchange system and to one of two salt dryer systems: a steam heated rotary drum or a spray dryer. The concentrated salt solution is filtered to remove any trace particulates that may pass through the pyrolyzer and reformer filters. Any trace radioactive species are removed from the scrubber solution by a high-efficiency, metals selective ion exchange medium. The salt dryer dries the purified salt solution to form a salt cake suitable for direct disposal. The dry salt is very low in activity.

Residue Handling System

The reformed, low-carbon residue from the pyrolyzer and reformer is transferred to the HIC packaging vault. Qualified HICs are filled with the solid, inert residue. Filled HICs are transferred from the packaging vault to a shipping cask by means of a shielded transfer bell. Dual containment and seals are provided on residue handling components. The packaging vault is provided with separate HEPA filtered ventilation system and water washdown capability.

The HIC packaged residue is suitable for direct burial at any of the Class A, B, and C LLRW burial sites currently licensed (e.g., Barnwell, Envirocare, or Hanford). The packaged residue is also suitable for long-term storage due to its solid, inert, all inorganic nature.

Waste Form Improvement
Thermal processing alleviates many of the concerns associated with the long-term storage or shallow land disposal of IERs:

- Organic materials are destroyed thus eliminating the generation of flammable gases from biological attack and/or radiolysis.
- “Foreign chemicals” have been destroyed that could react with packaged waste and generate undesirable reactions. Thus the potential for damage to waste packages, which could promote radionuclide migration, is removed.
- Volume is reduced yielding a small sized source term for storage, disposal and/or long-term monitoring and the overall waste form is improved to enhance environmental protection.

An additional benefit of the thermal processing of the IERs is that the long half-life radionuclides (Tritium and Carbon-14), which are two major concerns for shallow land disposal because of radionuclide migration, is alleviated.

**Spill Protection and Contamination Control**

All interior surfaces of the SPF are provided with durable, easy-to-decon coatings. The interior wall and roof panels are of interlocking and sealed construction to eliminate leakage paths from the inside of the SPF to the outdoors. Interior concrete and steel surfaces have a special multi-layer coating to prevent migration of spills or contaminants from the SPF to the environment. The Heating Ventilation Air Conditioning (HVAC) filter system also maintains the inside of the SPF at a slight negative pressure relative to the ambient outdoors, effectively eliminating potential airborne releases. Dikes, berms and sumps are located so as to prevent tank leaks and even potential large firewater events from escaping to the outdoor environment.

**Auxiliary Equipment and Utility Services**

The Process Building contains all auxiliary and utility subsystems required to support SPF operations and THOR\textsuperscript{sm} operations including:

<table>
<thead>
<tr>
<th>Steam Supply</th>
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<tr>
<td>Nitrogen Supply</td>
<td>Steam Superheaters Demineralized Water</td>
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<tr>
<td>Steam Condensate</td>
<td>Potable Water</td>
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<tr>
<td>Instrument Air</td>
<td>HVAC and Ductwork Dryer Condensate</td>
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<td>Natural Gas Supply</td>
<td>Cooling Water</td>
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<tr>
<td>Additive Gas</td>
<td>Motor Control Center</td>
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<tr>
<td>Hot Laboratory</td>
<td>DAW Compactor</td>
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**ANCILLARY BUILDING**

The Ancillary Building is designed for storage of spare parts, empty waste shipping containers and equipment for use at customers’ locations. A spray dryer and collector have been installed to provide additional salt drying capability for the process. Full salt containers are accumulated for shipment for disposal. Low activity LLRW can also be received and offloaded in the Ancillary Building. Maintenance of plant equipment is also performed in a controlled area. A modular, skid-mounted, pilot-scale THOR\textsuperscript{sm} system can be located in the Ancillary or Process Building to perform testing on surrogate and low activity wastes.

**ADMINISTRATION BUILDING**

The Administration Building has offices for plant staff and management, control room, switchgear and Uninterrupted Power Supply (UPS), health physics and personnel contamination monitoring areas, and count room. The THOR\textsuperscript{sm} control room provides remote readout of all process parameters. Trained operations personnel utilize the fully automated Supervisory Control and Data Acquisition (SCADA) system to monitor and control all system operations. The SCADA provides a comprehensive human-machine-interface that monitors the Programmable Logic Controller (PLC) panels, instruments, and equipment located in the
Process and Ancillary Buildings. Automated safety systems, alarms, and interlocks are provided together with real-time data acquisition and trending. The SCADA provides the operators automated flow diagram windows to monitor and control the process through graphical interfaces.

LESSONS LEARNED

The Studsvik Processing Facility commenced limited commercial operations in summer of 1999; however, many of the facility’s balance of plant systems designed by the facility’s design/build contractor were not capable of achieving their design capacities. This resulted in an extensive ramp-up period. Over the past three years, Studsvik has conducted an extensive program to bring the facility to its original specifications. The following is a partial list of “lessons learned” during the three years of facility operation. It is presented to provide the reader with an understanding of the importance of the support systems for a radioactive waste processing facility.

**Agglomerations/Eutectics** – As with any thermal treatment process, strict controls and thorough screening of the incoming waste streams are required to ensure long-term operating reliability. This is especially true when utilizing thermal fluid bed technology such as that used in the patented THOR™ process. Incoming waste streams can contain a wide variety of soluble inorganics (e.g., salts). Each can have individual melting points that are non-problematic, but when combined in a unique thermal environment can form new compounds (via eutectics), which are problematic. These problematic “eutectics” can promote “agglomerations” within the fluid bed. Studsvik has developed a simple approach to the treating of incoming wastes to prevent the formation of agglomerations.

**Non-Studsvik High-Rad Empty Containers** - The ability to disposition incoming non-Studsvik containers, once the waste is removed, becomes a serious challenge when the incoming radiation levels are in excess of 5 R/h (0.05 Sv/h). The consumable (use once) dewatering filters remain impregnated with radioactivity and continue to have radiation levels >0.4 R/h (0.004 Sv/h). Off-site vendors, that offer services for empty container processing, have proven to be unreliable in their consistency in taking these high-rad empty containers. This further supports the importance of utilizing “Studsvik Approved” reusable containers that use back-flushable stainless steel filters.

**Resin Transfer Lines** – Efficient transfer of resins requires a substantial amount of water to prevent line plugging. When resins are transferred with a vacuum assist, the potential exists for significant line blockage. All resin transfer systems must be equipped with numerous backflush and blowdown connections at all points where line plugging can occur.

**Resin Filtration** – When transferring resins, it is necessary to filter large quantities of sluice water utilized for the transfers. Resin slurry contains fractured resin particles, high concentrations of ion oxide, and other “filter blanking” particulate. The sluice water filter systems must be designed with appropriate particle filtration capability and at the same time these systems must have sufficient filter surface area to ensure that the filters don’t require excessive backwashing.

**Waste Resin Storage** - The IER is transferred to the slurry holdup tanks where the resin/water mixture is allowed to settle and excess water is then decanted off the top of the settled resin. Resins of different types have slightly different densities and without adequate storage tank mixing ability, resins will “layer” in a tank. This reduces the ability to efficiently achieve the optimum blend of input waste for processing.

**Resin Feed Systems** - For efficient thermal processing it is necessary to maintain a constant, low water content feed system to the process. Metering of constant resin/water input is a difficult task and specific attention must be paid to design and equipment considerations to ensure efficient operations with both bead and powdered resins and mixtures of both.

**Off Gas System** – The facility utilizes a pool type quencher system for quenching and final scrubbing of the hot off gas from the process system. Impurities, mostly sulfur salts from the cation resins, concentrate in the scrubber solution. The concentrated solution is transferred to a drying system. Care should be given in
equipment design, specification, and checkout to ensure that systems are operable at design throughput with the actual solution to be dried. Pilot scale test programs on “similar” solutions have proven to be inadequate.

**Materials of Construction** – With any chemical process system, the materials of construction play a large role in the long-term reliability of the systems. We have encountered instances where carbon steel utilized in a high salt environment lead to material failures that have required component replacements.

**OPERATIONS SUMMARY**

The facility has operated throughout the third quarter of 2002 at approximately 76% of its design throughput. Multiple “record runs” have been achieved. Studsvik will continue to improve its THOR™ process utilizing the knowledge acquired from three years of “real life” experience processing a wide variety of LLRW streams generated by nuclear facilities. Table I provides a summary of SPF processing data to date.

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<td><strong>Total Incoming Shipments</strong></td>
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<td><strong>Highest RadLevel (Contact)</strong></td>
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<td><strong>Average RadLevel (Contact)</strong></td>
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**CONCLUSION**

The Studsvik Processing Facility has demonstrated long-term operation in meeting the waste processing needs of the commercial utilities. We have processed a wide variety of LLRW with widely varying chemical composition and activities. Efforts are in progress to enhance our operational capabilities and to provide more cost-effective waste services in the future.

**Filter Cartridges** - Studsvik is presently evaluating the “filter cartridge” market (to include UF/RO membranes). If this evaluation proves that the annual filter volume and potential revenue generation would support a thermal processing technology, Studsvik will modify/upgrade the THOR™ technology to process and thermally volume reduce this new waste stream.
The THOR™ process, as implemented at the SPF, has the following significant advantages:

- Near Atom-for-atom processing mode is possible;
- Inert, inorganic, homogeneous, final waste form;
- Direct disposal in qualified HICs;
- Accept LLRW including: IER, graphite, activated carbon (charcoal), Steam Generator Owner’s Group (SGOG) solvents, antifreeze, oils, resin fines, high-water content wastes, and high-organic content wastes;
- Accept LLRW with contact dose rates up to 400 R/h (4.0 Sv/h);
- Packaged final waste form suitable for long-term storage with no risk of gas generation due to bacterial or radiolysis action (residue has no organic content);
- Final waste form is re-processable to alternative waste forms including vitrification, solidification, encapsulation, cold-sintering, and melting.

Figure 4 provides a summary of potential waste streams that can be processed with the THOR™ technology.
Ion Exchange Resins

Oils

Charcoal Graphite

Organic Solvents

Aqueous Wastes

Nitrates

Phosphates

DAW
- Paper
- Plastic
- Wood

Soils

Waste Feed
- Pump
- Screw Feeder
- Ram Feeder
- Pneumatic

Pyrolysis/Reformer Gasifier

Evaporator Scrubber

Off Gas To Ventilation
- Solids Scrubber
- Solids Filtration
- HEPA Filtration
- Emissions Monitoring

Residue Separator

Salt Separator Salt Dryer

Stabilization Processor
- High Integrity Container
- Cement Solidification
- Polymer Sulfur Solidification
- Thermoplastic Encapsulation
- Vitrification
  * Borosilicate
  * Iron Phosphate

Water

Product/Recycle
- Tramp Metal
- Metal Oxides
- Metal Fines
- Activated Carbon

Disposal
- Salts
- Debris
- Soils

Disposal
- Heavy Metals
- Alkali Metals
- Radionuclides
- Metal Oxides
- Metal Salts
- Silica/Alumina

Figure 4 - Block Flow Diagram