

## **TROJAN SPENT FUEL POOL DEBRIS REMOVAL PROJECT**

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### **ABSTRACT**

Portland General Electric's (PGE) Trojan Nuclear Power Plant Spent Fuel Pool contained stored debris requiring remediation. The debris consisted of greater than class "C" (GTCC) and fuel bearing wastes mixed with used reactor core components known as Non-Fuel Bearing Components (NFBCs); organic and inorganic fines and debris; and organic filters in various stages of decay. The waste debris required segregation, size reduction, processing and packaging to meet requirements for long term dry spent fuel storage in accordance with the Nuclear Regulatory Commission's (NRC) specification. Because the high radiation levels expected from the waste, all waste handling had to be performed under water or in heavily shielded equipment.

GTS Duratek, Inc. conducted underwater operations in the Trojan Spent Fuel Pool area from April to December, 1997. The fuel bearing and GTCC materials were removed from the pool and processed on-site in the mobile steam reformer to remove the hydrogen gas producing materials. The processed wastes were seal welded into dry, inert capsules and temporarily stored in the Spent Fuel Pool until dry storage casks become available. Low Level Wastes (LLW) were removed from the pool for disposal. NFBCs were separated, sized and packaged for temporary storage in the Spent Fuel Pool; processing of these items was not required since they did not contain hydrogen bearing compounds.

### **INTRODUCTION**

The purpose of the Trojan project was to remove organics and other hydrogen bearing compounds from wastes in the Trojan Plant's spent fuel pool. The objective was to produce a concentrated residue with sufficiently low hydrogen content to mitigate the formation of hydrogen gas from radiolytic decomposition in long-term storage casks. The requirement, to maintain hydrogen at less than 5 volume percent of the container's void space, comes from Nuclear Regulatory Commission requirements for transportation (1). GTS Duratek conducted underwater segregating, size reducing, and packaging of the waste materials in the Trojan Spent Fuel Pool and adjoining transfer canal with the assistance of specialists from Master Lee Services, Inc., from April to December, 1997 (Figure 1). On-site steam reforming with GTS Duratek's mobile steam reformer was conducted from August to December 1997.

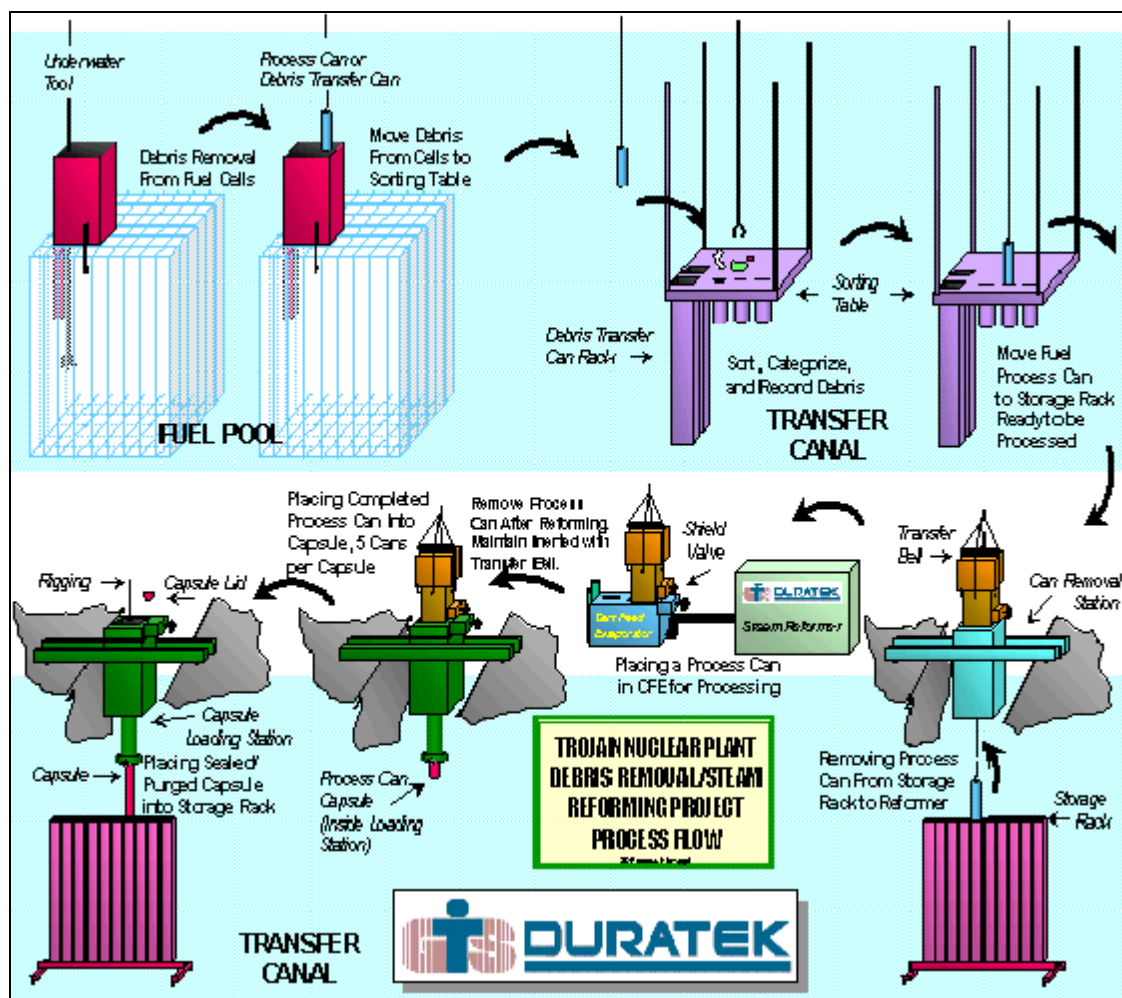


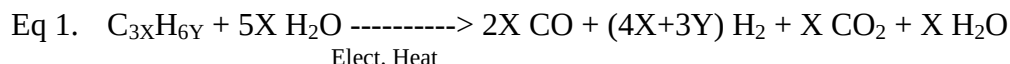
**Figure 1. Trojan Nuclear Plant Steam Reforming Project Process Flow**

The wastes which were processed consisted of debris baskets filled with debris, fuel pellet fragments, and fines vacuumed from the pool, transfer canal, and reactor vessel during maintenance and refueling outages. These materials were captured in sock or cartridge filters made from organic materials such as Dacron, polyester, polypropylene, polyvinyl chloride, and bonded nylon. The sock filters had thin polypropylene flanges at one end while the cartridge filters had black flanges at both ends. The manufacturer of the cartridge filters identified the black filter flange material as neoprene. Available metal objects were added to the filters to prevent floating. For years the filters have been subject to radiolytic decomposition. As a result the waste became a mixture of debris, dirt, metallic and organic fines, fuel pellet fragments, and partially decomposed filter materials. In addition, highly activated, discarded reactor components, designated as NFBCs, were dropped into these debris cans over the years.

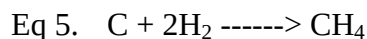
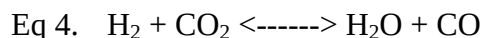
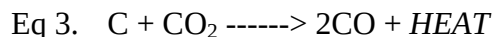
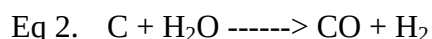
Hydrogen bearing components, primarily organic hydrocarbons, hydrated salts, and moisture were destroyed and/or driven off, using a mobile, electrically heated steam reformer.

## BASICS OF STEAM REFORMING

The basic steam reforming chemistry, which is considered as chemical reduction, is as follows:



Even for the simplest hydrocarbons, at least 30 intermediate steps have been identified. A few are illustrated:

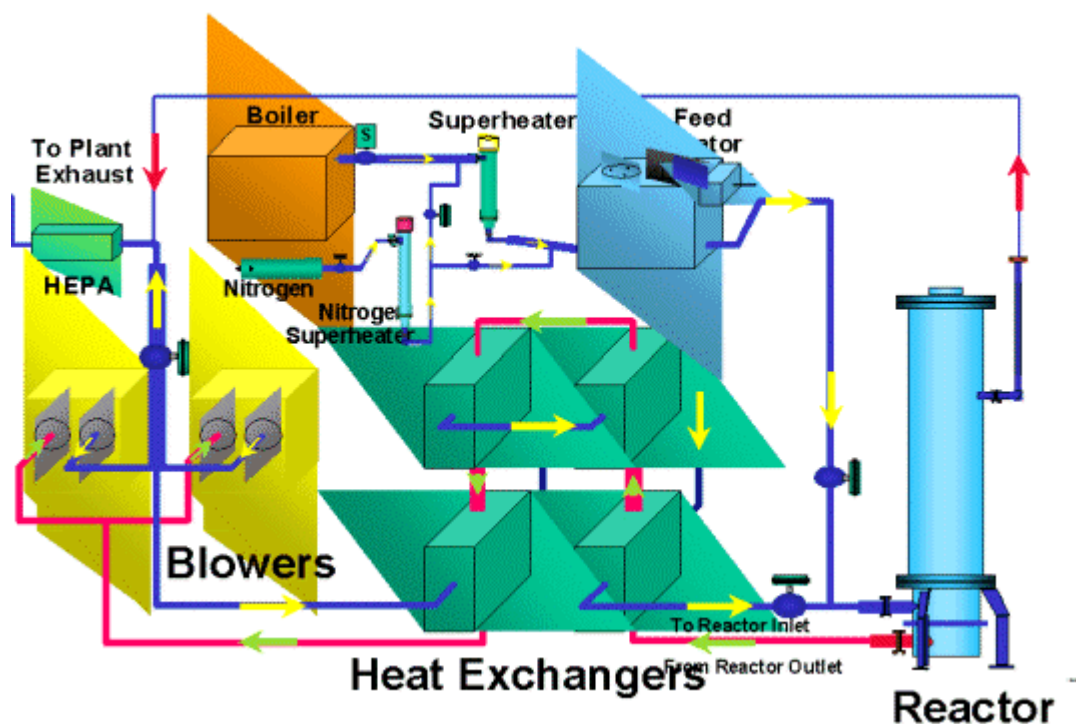


Steam reforming is started in the evaporator where the hydrogen bearing components are vaporized for transport to the steam reformer reactor. Temperature in the evaporator is maintained over 600 C, high enough to drive out moisture and drive off water from hydrated salts that may be present. The reactions continue to very near completion (99.99+%) as the gas temperatures increase along the path through the system to approximately 1,100 C in the reactor. The residence time of 1 second in the reactor is entirely at the elevated, nearly isothermal conditions in the steam reformer reactor.

The steam reformer achieves near-thermodynamic equilibrium and generates very small concentrations of “thermodynamically reformed compounds” (TRCs), from the recombination of the reactive molecular fragments resulting from the high temperatures. Thermodynamic equilibrium is approached in any high temperature organic destruction process, whether it is incineration by combustion or reduction by steam reforming. Incineration tends to form very toxic chlorinated debenzo-p-dioxins, dibenzofurans, and benzo<sub>(a)</sub>pyrenes, whereas the GTS Duratek steam reforming type chemistry tends to form very small amounts of light olefins and aromatics. Trace amounts of benzene, toluene, naphthalene, and acenaphthenes, just above detection limits have been detected in untreated steam reformer off gasses. Chlorine atoms from hydrocarbons such as PVC are rapidly stripped off by superheated steam to form HCl gas (2). Figure 2 shows the mobile steam reforming process flow.

## PREPARATIONS

Preparations for processing spent fuel pool debris included: developing design specifications, drawings, and procedures; performing nuclear safety analyses, conducting full scale tests, controlling procurement and fabrication applying quality assurance, and training of personnel.



### Figure 2. Mobile Steam Reformer Process Flow

## Design and Procurement

Design, procurement, and testing were subject to GTS Duratek's quality assurance processes to meet the requirements of PGE's Specification (3). All vendors used to procure or fabricate underwater, lifting, and shielded equipment were approved by the GTS Duratek Quality Assurance (QA) organization with PGE QA overview.

## Nuclear Safety Analysis

A Failure Modes and Effect Analysis (FMEA) and a safety analysis of the Spent Fuel Debris Project and its equipment was conducted. The results were delivered to PGE prior to mobilizing at the Trojan site.

## Proof of Principle Testing

Proof of Principle testing was conducted in September, 1996 to verify that steam reforming can reduce the hydrogen content of spent fuel pool debris residues below the required maximum to prevent dangerous levels of hydrogen gas formation in dry fuel storage configuration (4). Testing was conducted in GTS Duratek's production steam reformer at Oak Ridge, TN. The processed surrogate waste char was maintained in an inert atmosphere and sent to IT Corporation's Technology Development Laboratory in Knoxville, TN. Using a patented analysis technique developed specifically for these tests by GTS Duratek (5), IT analysts measured the residual hydrogen content in the processed char. All three test runs successfully met the maximum hydrogen limitations. Trojan Quality Assurance personnel witnessed all phases of the testing and analyses.

### **Integrated Testing**

Integrated testing was conducted in the high-bay area of the Turbine Building at the unused Washington Public Power Supply System (WPPSS) Nuclear Plant #1 (WNP-1) at Richland, WA. Actual equipment planned for the Trojan project was assembled and tested to verify that the Trojan underwater and steam reforming equipment would perform satisfactorily prior to mobilizing to the Trojan site. The high-bay provided an area where the long underwater tools could be tested, and WNP-1's 240 ton bridge crane was available to handle equipment movement under conditions similar to those at Trojan. Use of actual equipment provided time to test, operate, and modify, as required, all newly designed components, rigging equipment, and operating procedures before they were exposed to radiological contaminants. The testing period was also used to train and certify operators prior to mobilizing.

**First Integrated Tests:** The first set of Integrated Tests verified the operability of the underwater components and tools (6). Operators were trained and qualified in underwater segregating and packaging. The equipment was then mobilized and underwater operations began at Trojan in May 1997.

**Second Integrated Tests:** Integrated Testing of the steam reforming and shielded handling equipment was conducted in May and June 1997 (7). As a result of the testing, minor improvements were made to the CFE heaters and the steam reformer control software. Operating procedures were finalized, processing limits were defined, and End-of-Run criteria were established. In addition, operator training was conducted to qualify the equipment operators.

### **Project Equipment**

Specially designed, shielded handling equipment was used to reduce radiation levels from a maximum limit of 350 Rem/hr to 50 millirem/hr (mr/hr) on contact (listed in Table I).

| <b>Table I. Trojan Spent Fuel Pool Debris Removal Equipment</b> |                                                                                                                                                                                                                                                                                                                                                                                        |
|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Item</b>                                                     | <b>Description</b>                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Shielded Equipment</b>                                       |                                                                                                                                                                                                                                                                                                                                                                                        |
| Can Removal Station (CRS)                                       | Provided shielded area to lift process cans containing debris out of the pool.                                                                                                                                                                                                                                                                                                         |
| Can Feed Evaporator (CFE)                                       | Processing component in which organics were vaporized and steam reforming initiated. Vapors were filtered to trap radioactive particulates and volatile cesium                                                                                                                                                                                                                         |
| Capsule Loading Station (CLS)                                   | Provided a shielded, inert, dry enclosure for loading process cans into the process can capsule. A removable shield gate allowed seal welding of the capsule and lowering the capsule into the Spent Fuel Pool for storage.                                                                                                                                                            |
| Transfer Bell                                                   | Device used to move process cans from the transfer canal to the CFE and CLS. The transfer bell contained internal, remotely operated hoisting equipment and a lower shield gate to provide inert gas transfers.                                                                                                                                                                        |
| Process Can                                                     | A stainless steel can with high efficiency filters at the top and bottom for processing debris in the CFE.                                                                                                                                                                                                                                                                             |
| Process Can Capsule                                             | A stainless steel capsule designed to hold up to five process cans, be seal welded, and fit into a dry fuel storage cask. The capsules were loaded into the CLS, inerted and filled with process cans. When full, a shield plug was placed on the capsule, the shield gate removed, and the plug seal welded in place. The capsule was then lowered into the underwater storage racks. |
| <b>Underwater Equipment</b>                                     |                                                                                                                                                                                                                                                                                                                                                                                        |
| Underwater tools                                                | These were used in sorting and handling in underwater operations. Many remotely operated grippers, cutters, sieves, miscellaneous tools, vacuums, closed circuit television (CCTV) cameras, and lights were provided for this work.                                                                                                                                                    |
| Can/Capsule Storage Rack (C/CSR)                                | Provided interim storage for Trojan debris baskets, filled process cans, and filled process can capsules.                                                                                                                                                                                                                                                                              |
| Work Platform                                                   | Provided an underwater table to conduct segregation, sizing, and packaging. Racks and slots were provided to hold two debris cans, three process cans, and an underwater vacuum attachment.                                                                                                                                                                                            |
| Coffer Dam                                                      | Provided a work area over spent fuel racks which held debris with no removable debris can.                                                                                                                                                                                                                                                                                             |
| <b>Processing Equipment</b>                                     |                                                                                                                                                                                                                                                                                                                                                                                        |
| Steam Reformer                                                  | Skid mounted, electrically heated, high temperature, chemical reactor system with PLC and sensors.                                                                                                                                                                                                                                                                                     |
| Boiler                                                          | Skid mounted boiler, condensate, and cooling systems, plus steam booster and superheater units.                                                                                                                                                                                                                                                                                        |
| Off Gas System                                                  | Consisted of a moisture trap for recycling fluids back to the boiler, HEPA filters, and off gas monitoring sensors.                                                                                                                                                                                                                                                                    |

**Installation at Trojan.** Installing (and later, removing) the large underwater and shielded equipment into position around the Trojan Spent Fuel Pool presented some unique challenges. The low overhead clearance, limited reach of Trojan's bridge crane, and the very limited access areas required the design of special rigging equipment and detailed rigging plans. The requirement to certify all rigging equipment with a 10 times safety factor increased the size of rigging equipment and added more challenges. GTS Duratek's engineers and technicians successfully overcame all challenges to install the equipment safely and on schedule.

## **UNDERWATER OPERATIONS**

Underwater equipment included a storage rack, the Can/Capsule Storage Rack (C/CSR), designed to hold debris baskets, process cans, and process can capsules; an underwater work (segregating) platform with slots and fittings to hold process cans, debris baskets, and underwater vacuum equipment; a coffer dam to retain clouds of fines during waste removal; and various remote operating underwater tools, sieves, and cameras. The underwater equipment designed for use at Trojan is listed in Table 1.

Initially, two spent fuel storage racks containing debris without a basket, were emptied with the aid of the coffer dam and underwater grappling tools, the CCTV, and PGE's underwater vacuum system. The vacuum system, located in the transfer canal, did not provide sufficient suction to remove debris from the cells. This problem was solved by moving the vacuum into the Spent Fuel Pool, closer to the coffer dam.

Nine debris baskets containing flux thimbles, other NFBC, metallic and organic fines, and decomposing organic filters, were removed from the spent fuel pool racks and relocated to the C/CSR. Four of the debris baskets were known to contain failed fuel fragments and spent fuel pellets, classified as Special Nuclear Material (SNM). Each of these baskets were emptied and the debris segregated for processing and packaging.

The flux thimbles were segregated, cut into approximately three foot lengths and placed into containers provided by PGE. Identifiable spent fuel pellets or fragments and NFBCs were segregated from the debris and placed into separate process cans. Larger debris items, about 50 kg total, were segregated and removed from the pool as LLW for disposal at an appropriate disposal site. The rest of the debris and the spent fuel pellets and fragments were placed into filters and packaged into process cans and treated. The packaged NFBC, totaling about 300 kg, was returned to the Spent Fuel Pool for temporary storage. All underwater sorting and packaging was documented with the CCTV.

As original work scope, GTS Duratek removed a spent fuel pellet from a storage cask and processed sludge contaminated with spent fuel from a separate cask. As additional scope, GTS Duratek sorted debris captured in filters during the Spent Fuel Pool and Cask Load-Out Pit cleaning projects. Black filter flange material particles and spent fuel fragments were segregated, placed in process cans for steam reforming.

### **Problem Areas**

Several unexpected items contributed to the length and complexity of the underwater segregating project (8). Each of the problems required innovative engineering support to fabricate specialized sorting equipment. The cooperative spirit and team effort among PGE, GTS-Duratek, and their sub-contractors were essential to the ultimate success of the project.

**Raschig Rings** made from stainless steel were originally added to all process cans to shorten processing times in the steam reformer. Initial tests during the Integrated Testing revealed that the rings created sheltered spots of insufficiently processed material. Test runs without the rings took excessively long to complete. Further testing found that a modified ring, similar to a Berl Saddle, worked satisfactorily.

**Black Filter Flange Material** found on some of the used cartridge filters mixed in with the debris was previously identified by the filter manufacturer as neoprene. Initially GTSD planned to cut the black filter flanges from the fabric filter material and dispose of the flanges as LLW. During the initial underwater segregation efforts, it became apparent that many of the flanges had deteriorated and crumbled into varying size pieces down to micron size. Since complete segregating was no longer possible, research into the ability to process the black material was conducted.

Finding successful processing conditions with this material was the major contributor to extending the Integrated Tests from three test runs up to nine, and increasing the scope of laboratory studies to determine the exact nature of the black flange filter material and conditions for successfully processing the material. Further research and testing determined that the black material was actually polyvinyl chloride mixed with 30 percent, by weight, heavy crude oil plus inorganic fillers and binders.

Experiments determined the material could be processed, at the planned CFE operating temperature of 607 C, if the material was reduced to less than 1/4 inch particles and limited in quantity to less than 52.5 grams per process can. Sorting was performed to remove the >1/4 inch pieces of black material as LLW. The finer pieces were screened out, measured into 50 gram batches, and placed in process cans. It was determined that the particles too small to screen out of the organic and metallic material collected for processing would make up less than 2.5 grams per batch. Future testing is planned to determine operating conditions for processing black flange filter material which eliminates the need for segregating.

**Lead Shot** was discovered mixed in with the debris during sorting operations. Trojan personnel determined that lead could not be permitted in the dry fuel storage casks; therefore, a means to segregate the lead shot was required. Several special tools were fabricated to deal with the lead, including various sized sieves. Approximately 30 kg of lead shot was removed and packaged separately as LLW.

**A Lead Pig** containing a fuel pellet, specified in PGE Specification TD-012, was lowered into the transfer canal and opened on the work platform. The spent fuel pellet was found to have completely disintegrated into the putty compound. Research was conducted to determine the nature of the putty and its compatibility with steam reforming. It was determined that the putty could be steam reformed without modifying the planned operating parameters. The putty was cut up into small pieces and spread onto three filters. These filters were placed into three different process cans and steam reformed.

**A Cask** containing spent fuel pool debris sludge material was processed by GTS Duratek as added scope. The cask was carefully lowered into the transfer canal so as not to spread the liquids into the water. The material was vacuumed through filters and the filters packaged in process cans for steam reforming.

## **WASTE PROCESSING**

The shielded handling equipment and the steam reformer system operated successfully to remove hydrogen from the debris and maintain an inert atmosphere throughout processing and handling (8).

**Can Removal and Capsule Loading Stations.** To allow for easy indexing of the heavily shielded CRS and CLS over the storage positions of the C/CSR, rails were installed on both sides of the transfer canal. The CRS and CLS operated satisfactorily per design specifications.

**Transfer Bell.** The transfer bell proved to be an effective device for transferring highly radioactive process cans while providing more than adequate shielding and maintaining an inert atmosphere. Exposure levels outside of all shielded equipment never exceeded 5 mr/hr even when process cans exceeding 200 rad/hr on contact (measured under water) were processed. Total measured dose for all technicians did not exceed the 3.43 Rem estimated exposure for the project.

**Process Cans.** A total of 40 process cans were each loaded with approximately 20 kilograms of moisture laden debris, processed in the steam reformer, and seal welded into eight process can capsules. Each can was fitted with 5 micron filters at top and bottom to facilitate processing while maintaining solid residues in the can. One additional process can was filled with NFBC and stored in the Spent Fuel Pool.

**Process Can Capsules.** All capsules were fabricated to NQA 1 quality assurance standards. The certified welder designated for final on-site seal welding conducted practice welds which were subjected to rigorous dye penetrant, helium leak, and physical strength testing.

The eight process can capsules containing all of the processed debris were placed in spent fuel pool fuel storage racks for temporary storage. All of the final seal welding of these capsules passed nondestructive examination, both visual and dye penetrant. Data packages detailing process data for each can and summarized for each capsule were provided to PGE in separate packages as the processing was completed.

**Steam Reformer.** The steam reformer system performed as designed, successfully processing 40 process cans. The process cans contained varying mixtures of spent fuel pellet fragments, stainless steel dross and elemental carbon from electric discharge machining (EDM) of the upper

reactor core support plate, polypropylene and paper filter media, black filter flange material, water, boric acid, general debris, clays, sediment, and stainless, carbon steel, Inconel and zirconium metal pieces. The main components of the steam reformer system are listed in Table 1 and shown in Figure 2.

**Can Feed Evaporator.** Nearly all radiological contamination was contained in the CFE's 1 micron filter and boron-silicate cesium trap, greatly simplifying steam reformer maintenance. One process can contained spent fuel pellets and fragments of pellets totaling nearly 80 fuel pellets and emitting over 200 Rad/hour on contact. Radiation readings outside of the CFE never exceeded 5 mr/hr. Temperatures in the CFE were limited to 607 C to minimize the volatilization of cesium isotopes. Uranium remained in or was driven to its most stable form,  $\text{UO}_2$ .

**End of Run Criteria.** During Integrated Testing, the End of Run criteria were established empirically as:

Operate the CFE at 607 C temperature with incoming steam at 621 C.

Observe hydrogen concentrations, measured at the steam reformer vent, at or below 200 ppm for at least three hours.

Observe carbon monoxide at background levels during the three hours as a confirmation of the proper operation of the hydrogen analyzer.

Oxygen had to remain less than 3% to prevent interfering with hydrogen readings.

The criteria were observed for each process can, and a data plot of hydrogen, carbon monoxide, and oxygen verses time was included in each data package to provide a permanent record. The successful use of the end of run criteria eliminated batch sampling of each run of processed material, saving considerable radiation dosage and expense (8). Figure 3 is an example of actual process run data plot (Process Can Number 45). Figure 4 represents data at the end of a processing run (Process Can Number 45).

**Steam Reformer Performance.** The steam reformer operated as designed. The nitrogen supply, boiler, condensate, blowdown, steam booster and superheater systems operated properly with only minor maintenance required. A few equipment problems interrupted processing. However, the process allowed for interruptions without affecting the outcome or the end-of-run criteria.

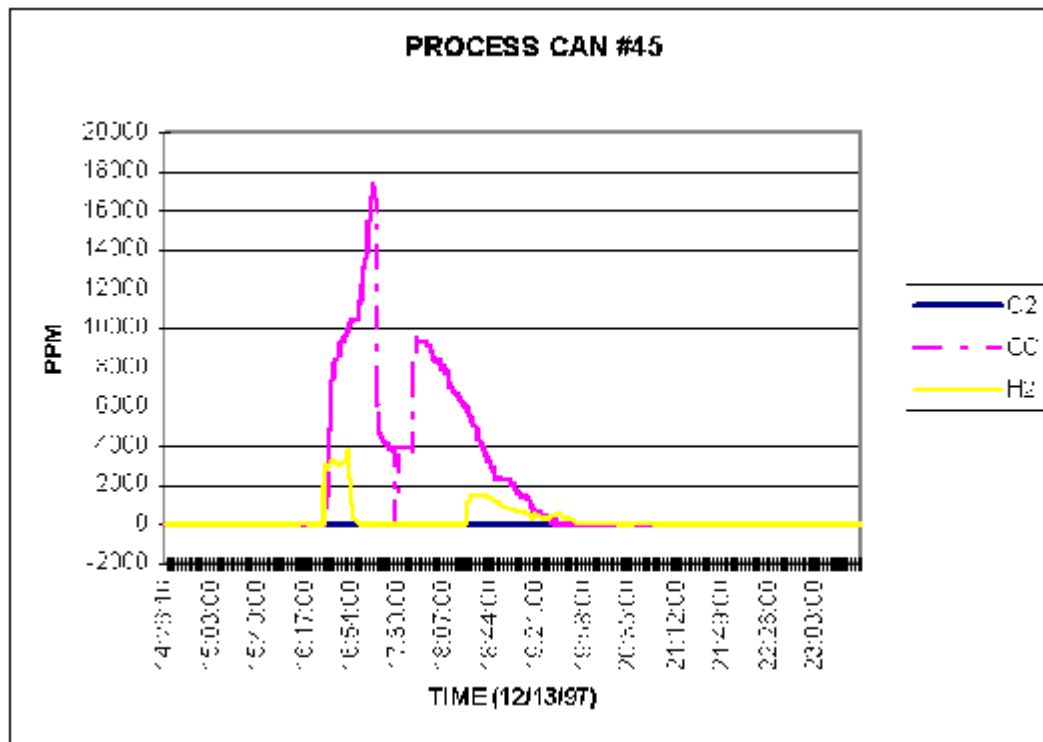


Figure 3. Process Can No. 45 Off Gas Data

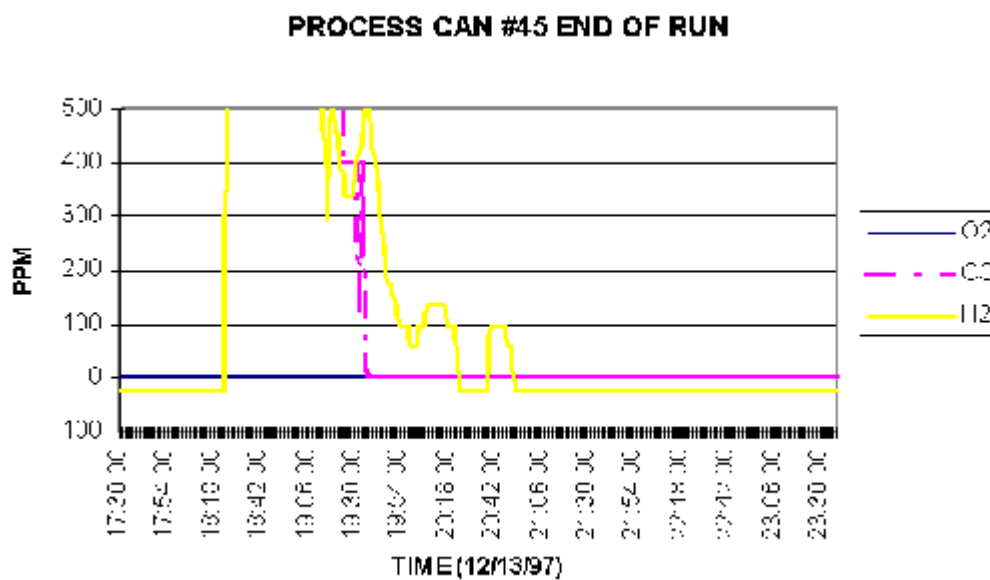


Figure 4. Process Can No. 45 End of Run Data

The steam reformer vent gasses, consisting of  $H_2$ , CO,  $CO_2$ ,  $N_2$ , and  $H_2O$ , were mixed with about 10 times as much air as the emissions were drawn through a moisture separator, a HEPA filter, and into the fuel pool building's existing monitored and filtered ventilation exhaust system. The high steam content and absence of oxygen in the system eliminated any potential for explosive gas mixtures. The high dilution rate of the exhaust system ensured that  $H_2$  and CO concentrations stayed well below any safety limits. Moisture collected from the exhaust was successfully recycled back to the boiler's condensate system.

System control was user friendly through the use of a personal computer graphic display and interface program to operate the steam reformer's programmable logic controller (PLC). Automated data logging and safety logic operated smoothly.

## CONCLUSIONS

Steam reforming of spent fuel pool debris proved to be an effective and successful method of processing high level radioactive wastes to meet the same long term dry storage requirements as spent nuclear fuel. The steam reformer successfully removed organics, moisture, and hydrates from sludge, fine metallic dross, and mixtures containing bits of spent fuel pellets, deteriorated organic filters, and miscellaneous debris. The processing equipment provided a reliable, repeatable means to determine end of run for each batch without having to perform sampling on individual batches. Eliminating individual batch sampling saved considerable expense and personnel exposure to radiation.

The underwater segregation of spent fuel pool debris was ultimately successful in sorting and sizing 300 kg of non-fuel bearing, highly activated metallic components (NFBC); 50 kg of low level wastes; and 30 kg of lead shot from 800 kg of moisture laden spent fuel pellet fragments, organic and metallic fines, black filter flange material, and other waste sludges. Unexpected materials and conditions required innovative engineering support to fabricate specialized sorting devices and procedures. The successful resolution and implementation of all segregation issues required the combined cooperative efforts of PGE, GTS Duratek, and their sub-contractors working together as a team.

All steam reforming and underwater equipment was disassembled, decontaminated as required for transportation, and shipped to GTS Duratek, Oak Ridge, TN by January 30, 1998.

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