Savannah River Site Canyons—Nimble Behemoths of the Atomic Age

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Abstract

Processing extremely radioactive materials for nuclear weapons is accomplished at Savannah River in chemical separations facilities called "canyons". These large, remotely operated, heavily shielded facilities were constructed early in the Cold War to provide raw material, initially plutonium-239, for the U.S. nuclear arsenal. As the chemical separations processes developed and matured, these canyons showed a versatility not in their original scope. They were used to process a variety of materials in ways not envisioned by the original designers. With some renovation or revision, these facilities have been used to support the needs of the United States for other radioactive materials. Savannah River canyon facilities provided the raw material, neptunium-237, which was irradiated at the Savannah River Plant (SRP) to produce plutonium-238 used to power U.S. space probes that go where solar panels are too weak to suffice. Though almost 50 years old, the canyon facilities still function well, a real tribute to the original designers, builders, and the subsequent remodelers. Significantly, they have also operated without a nuclear criticality incident.

Introduction

The chemical separations plants of Savannah River have had an interesting and proud history. This paper about the flexibility of these huge concrete and steel chemical processing plants is only a part of that story.

Original Scope of Facilities

Initially, the Site's two separations plants were designated Building 221-F and Building 221-H and are commonly called, respectively, F Canyon and H Canyon. They were designed to separate weapons-grade plutonium (Pu-239) from irradiated uranium. In the beginning, the heavy-water-moderated reactors at SRP used natural uranium for fuel and target elements. F Canyon and H Canyon were designed to be identical to provide redundancy in case one was lost for any reason.

In 1950, when the U.S. government asked Du Pont to construct and operate the Site, Du Pont had an extensive engineering staff and vast construction capabilities. Also, Du Pont had already constructed and operated the Hanford Works in Washington State, which produced much of the weapons material in the early days of the nuclear age. At Hanford in 1944-45, Pu-239 was separated and purified by a precipitation process. By the start of construction of the Savannah River Plant in 1950, work at Oak Ridge National Laboratory, Knolls Atomic Power Laboratory (KAPL), and Argonne National Laboratory, among others, showed that separation could be achieved successfully in two-phased liquid systems. A countercurrent flow of an acidic aqueous stream with an immiscible organic phase containing a complexing extractant was selected for Savannah River. The process was called Purex and used nitric acid in the aqueous phase and tri-n-butylphosphate (TBP) dissolved in a lightweight organic liquid, such as n-paraffin, for the organic phase. SRP selected mixer-settlers for this operation, while Oak Ridge selected pulsed columns. Both mechanical configurations were successful and have been the subject of many reports (Joyce 1959; McKibben et al. 1979; McKibben 1989; Orth 1964a; Orth 1964b; Orth and McKibben 1969; Orth and Olcott 1963).

The SRP canyons were designed to be operated and maintained remotely to minimize worker exposure to radiation. These structures are called canyons for the long, narrow spaces in which processing takes place. The processing portions are segregated into a hot canyon with very heavily shielded protection and a warm canyon which, while still radioactive, requires less shielding. The canyons are parallel to each other and are separated by the shielded and inhabited parts of the buildings. All the radiochemical operations, including the receipt of targets, dissolving, feed clarification, solvent extraction (and later, ion exchange), and waste handling are performed remotely in these concrete-shielded buildings.

Each building is 255 m (850 ft) long, 37 m (122 ft) wide, and 20 m (66 ft) high (Starks 1977). Each canyon consists of 17 13.1-m (43 ft) sections and a 25.9-m (85 ft) section. Each canyon has 12 processing sections with each section having four cells. Each cell is capable of receiving a piece of equipment and siting it, via trunions, in a specific known location. The pattern of embedded piping is duplicated over each of the 12 identical sections; that is, each section is an exact replica of all other sections in locations of tank positioning guides and wall nozzles. The precision of this replication is such that equipment that fits in one location will fit in another similar location to within 1/16-inch. Each section of the canyon with its imbedded piping was constructed as one continuous concrete pour.

Much of the flexibility of these canyons can be attributed to the remarkable quality of the work of the craftsmen who built these behemoths. All the services (electrical, steam, hydraulic fluid, and chemical transfers) are available from piping at every processing section. The high-quality construction along with an accessible "cold" (non-radioactive) mockup shop section guarantees that new or replacement equipment will fit. This has contributed greatly to the canyon flexibility and undoubtedly reduced the amount of solid waste generated by canyon operations. In fact, being able to design and install different equipment that utilizes the previously installed services has enabled increased performance under the original flowsheet from 3 metric tons uranium per day to 15 metric tons per day. It has also allowed the installation and use of equipment not visualized in the original design, as this paper will illustrate.

Equipment is moved or replaced in the canyons by means of overhead cranes. In the hot canyon, the operator is shielded from direct radiation by a thick concrete wall and must view the operation through an optical arrangement. Originally, these optics were of early submarine periscope style. In the mid 1980s, the canyon cranes were replaced, and the optics were upgraded to include a bevy of remote television cameras, so the view can be not only shared but also recorded for instructional or any other purposes.

Waste Handling

The solid waste from the canyons themselves is almost completely either damaged or obsolete equipment. This equipment, whether jumpers, tanks, evaporators, mixer-settlers, or ion exchange columns, was decontaminated, wrapped, boxed, and transported to the Site's burial ground.

The liquid waste from canyon operations had several components (Starks 1977). The non-contact cooling water used to control the temperature in some tanks and provide cooling water to evaporator condensers and other non-contact cooling operations exited the canyons to a diversion canal with monitoring, which was initially periodic, then continuous as monitoring capabilities improved. This stream also contained the condensate from steam used in heating coils in process operations in the canyons. Non-contaminated water was discharged to plant streams, which eventually flowed to the Savannah River. In the event contamination was detected, the water was diverted to a lined holding basin for cleanup prior to discharge. Though not a frequent event, the holding system was used on several occasions, usually as the result of a failed steam coil in an evaporator. The system successfully prevented significant radioactive releases to the environment.

The radioactive liquid waste from the canyons was released from the canyon as high activity waste. It contained the long-lived fission products and the dissolved aluminum cladding from both fuel rods and targets. This material was transferred to large underground steel storage tanks for later treatment. This body of waste eventually reached some 40 million gallons and is currently being converted through a vitrification process to a solid waste form for eventual geologic disposal. The low activity liquid waste was evaporated to recover nitric acid wherever practical and to reduce volume. The reduced waste is now being converted to a solid form, saltstone, and stored onsite in bunkers.

Ventilation and Contamination Control

The air system in the canyons operates on directed air flow and pressure differentials. Building space that is occupied or could be occupied by people is fed chilled air from an external source. This air is heated as needed and maintained at slightly lower pressure than the outside air pressure. The process area operates at air pressure below that of the personnel space so that contaminated air does not escape into the personnel space.

Some processing facilities within the canyon buildings are not in the canyons themselves. These are areas where the desired radioactive product, such as U-233, Pu-238, or Pu-239, is converted to solid form. Because these radioactive materials pose serious alpha particle contamination threats but much smaller beta-gamma radiation threats, these processes are usually carried out in gloveboxes. In these process areas, air flows from the "uncontrolled" personnel area to the process area to the glovebox, so that the flow of air is always toward the radioactivity and works to prevent the spread of contamination. In the canyon process area of the building, which operates at air pressure negative to the office and working spaces, all process tanks are connected to a vessel vent system that operates at a pressure below that of the general canyon process space. All the canyon gases are filtered through a large and elaborate sand filter before discharge through a tall exhaust stack. This system has been extremely effective in controlling the release of radioactive solids to the environment. Radioactive gas release was minimized by extending the cooling time of the fuel to be processed to allow time for radioactive decay of xenon and I-131 and by using silver absorbers to remove iodine.

Purex Solvent Extraction

As mentioned earlier, both canyons were designed and initially started up using the Purex process. This process has seen many variations. The TBP in the solvent has varied in different applications from 3.5% (ref) to 50% (ref) with 30% being most common (Orth 1965). Purex has been used to process fuels and targets varying in U-235 from depleted (~0.2%) to over 93%. It has also been used to process highly irradiated plutonium, recovering plutonium as well as actinides with higher atomic numbers.

A modification of the Purex process called Thorex, developed at KAPL and the Savannah River Laboratory (SRL), has been used to recover U-233 and thorium from irradiated thorium targets.

Np-Pu Ion Exchange Frames

As the enriched portion of the reactor fuels increased from natural to about 93%, the enriched uranium that was recycled began to increase in U-236. Further irradiation of this U-236 produced neptunium, specifically Np-237, which in turn was recovered and further irradiated to produce Pu-238. This isotope has been used as a power-generating heat source to provide onboard electric power for satellites sent into deep space.

When the need arose to process highly radioactive materials where the quantities were less than a ton, the solvent extraction system designed for metric tons per day was simply too large for the task. The holdup in the solvent in the mixer-settlers alone is about 5000 gallons. Sometimes, ion exchange processes have advantages over solvent extraction, especially so in batch operations where the quantities of material to be handled are small, relatively, and the desired product concentrations are high.

After splitting out the Np-237 in a modified Purex flowsheet, it was recovered and purified on ion exchange columns. To accomplish this, a small-scale, by industrial standards, ion exchange processing plant was constructed on three 10 x 10 x 17-ft steel frames, which were set in a canyon cell and connected to appropriate services (Mottel and Proctor circa 1963). The equipment system included a dissolver, 8 ion exchange columns, and 16 solution adjustment and collection tanks complete with instrumentation and solution transfer devices. Each frame, with its complement of tanks, columns, and piping, was capable of being installed or removed as a single unit. Only those few items subject to periodic failure could be removed individually from the frame, while the majority of the equipment, including the tankage and piping, were permanently fastened to the frame structure. These frames were fed, serviced, controlled, and sampled remotely from common canyon services and connections, albeit, some interesting modifications were employed; for example, six 1/2-inch tubes were pulled as a bundle through a single 3-inch pipe to permit flow control and sampling of the ion exchange columns.

These frames, certainly not envisioned by the original designers, processed irradiated neptunium targets to provide the desired Pu-238 and recover the residual Np-237 (Poe et al. 1963). Plutonium-238 from this effort provides heat, which via thermoelectric conversion to electric power, has provided on-board power for U.S. space exploration vehicles including the original Viking Explorer, the Voyager series, and, more recently, the Magellan spacecraft to Jupiter.

Electrolytic Dissolver

Just as in the case of the frames, the flexibility of the canyons was demonstrated once again in the need at SRP to process non-SRP fuel. These fuels from various federal programs were clad with either stainless steel or various zirconium-based alloys. These claddings are not amenable to dissolution in a nitric-acid-based system. Also, the safety of the existing process vessels and piping, which are constructed of stainless steel, would be severely threatened by any chemical process that would dissolve stainless steel cladding or zirconium cladding. After design and testing, an electrolytic dissolver utilizing a liquid cathode concept was installed in H Canyon. Here again, the preciseness of a canyon location coupled with normal canyon services augmented by a special DC power connection capable of 25 volts and 10,000 amps enabled installation and use of equipment previously demonstrated in cold pilot plant studies. This dissolver operated successfully through five campaigns over a span of ten years. After dissolution, the fuels were successfully processed by a normal Purex flowsheet.

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Acknowledgments

I have been fortunate to be involved with several very talented teams in my assignments. Also, I had as co-workers and supervisors some of the very finest technical minds, which make my memories of the years at Savannah River very satisfying. I am grateful for the experience.

Biography

LeVerne P. Fernandez obtained his Ph.D. from the University of Virginia. He worked over 35 years at Savannah River with the majority of the time in technical support of the chemical separations processes, especially HM and Purex flowsheets, the electrolytic dissolver, and frame operation for Np-237 and Pu-238 recovery. The technical support for the first General Purpose Heat Source Pu-238 heat source capsules fell to his group. He led the group that designed and built the M-Area Liquid Effluent Treatment Facility and the M-Area Air Stripper for the removal of volatile chlorocarbons. These facilities made possible the closing of the M-Area Seepage Basin and the restoration of Lost Lake.

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