ENGINEERING AND DESIGN ASPECTS OF A HIGH LEVEL RADIOACTIVE WASTE EVAPORATOR

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ABSTRACT

In 1988, United Engineers and Constructors, Inc., a full service subcontractor to Westinghouse Savannah River Company at the U. S. Department of Energy's Savannah River Site (SRS), was asked to provide preliminary (Title I) and detailed (Title II) engineering and design services for a high level radioactive waste evaporator to be constructed at SRS. This evaporator, which will replace aged, existing evaporators, incorporates state-of-the-art design while maintaining features that have proven reliable from previous SRS operating experience. Title I design has been completed. Title II is scheduled for completion in September 1992. Construction is to begin in Spring 1991. This paper discusses unique engineering and design aspects of the SRS high level radioactive waste evaporator.

BACKGROUND

At SRS, high level radioactive liquid waste that has been generated from defense nuclear fuel cycle operations is stored in alkaline form in double-walled, 4.9 million liter (1.3 million gallon) underground storage tanks. Fresh waste ages for one to two years to allow sludge to settle (sludge consists primarily of magnesium oxide, ferrous hydroxide, and small amounts of uranium, plutonium, and mercury). The supernate (which is the waste layer above the sludge consisting primarily of water, sodium nitrate, sodium nitrite, sodium hydroxide, sodium aluminate and radioactive contaminants) is concentrated by evaporation to reduce the required storage volume.

Another waste stream that is concentrated by evaporation is the wash water from sludge processing, a high level radioactive waste treatment operation at SRS. It is also planned to evaporate a low level radioactive recycle solution from the Defense Waste Processing Facility (DWPF) at SRS, when this facility becomes operational. DWPF processes high level radioactive waste into a borosilicate glass for long-term geologic disposal.

Two of the four existing high level waste evaporators at SRS are approaching the end of their design life. In order to maintain existing waste concentration capabilities and provide for future requirements, it was decided that a new high level radioactive waste evaporator was justified. This new evaporator will replace one existing evaporator and allow another existing evaporator to be placed in a standby mode. In addition, the new evaporator will incorporate design improvements and will conform to the requirements of DOE Order 6430.1A, General Design Criteria.

OBJECTIVE

The primary objective of the SRS high level radioactive waste evaporator is to concentrate high level liquid nuclear wastes, in a safe manner, with containment of all radioactive materials. This concentration reduces the volume required for storing the wastes until they can be processed further. A secondary objective of the evaporator is to reduce waste mobility. The concentrate, a semi-solid salt cake, does not flow readily at ambient temperatures. Thus, it is a more desirable form of storage.

Another project objective is to sufficiently decontaminate the water evaporated from the waste so that it can be discharged to an existing SRS effluent treatment facility. In order to accomplish this, a decontamination factor for cesium-137 of 100 million is required (decontamination factor as used here is defined as the ratio of radioactivity in the evaporator feed to that in the evaporator overhead stream).

PROCESS DESCRIPTION

Evaporator feed, held in a 4.9 million liter (1.3 million gallon) underground storage tank, is continuously pumped to the evaporator vessel at a design flowrate of 150 liters per minute (40 gallons per minute) (Fig. 1). A vertical shaft centrifugal pump is used to transfer the waste feed. A constant level is maintained in the evaporator and the waste is heated to its boiling temperature by a steam tube bundle located within the evaporator vessel. Depending upon the feed composition, the evaporator temperature is maintained between 403 to 453 K (130 to 180°C).

Vapor which is generated in the evaporator contains liquid droplets that are contaminated with radioactive cesium and other trace radionuclides. The vapor is passed through a high efficiency de-entrainment unit to remove all liquids and thus remove the radioactive contaminants. The

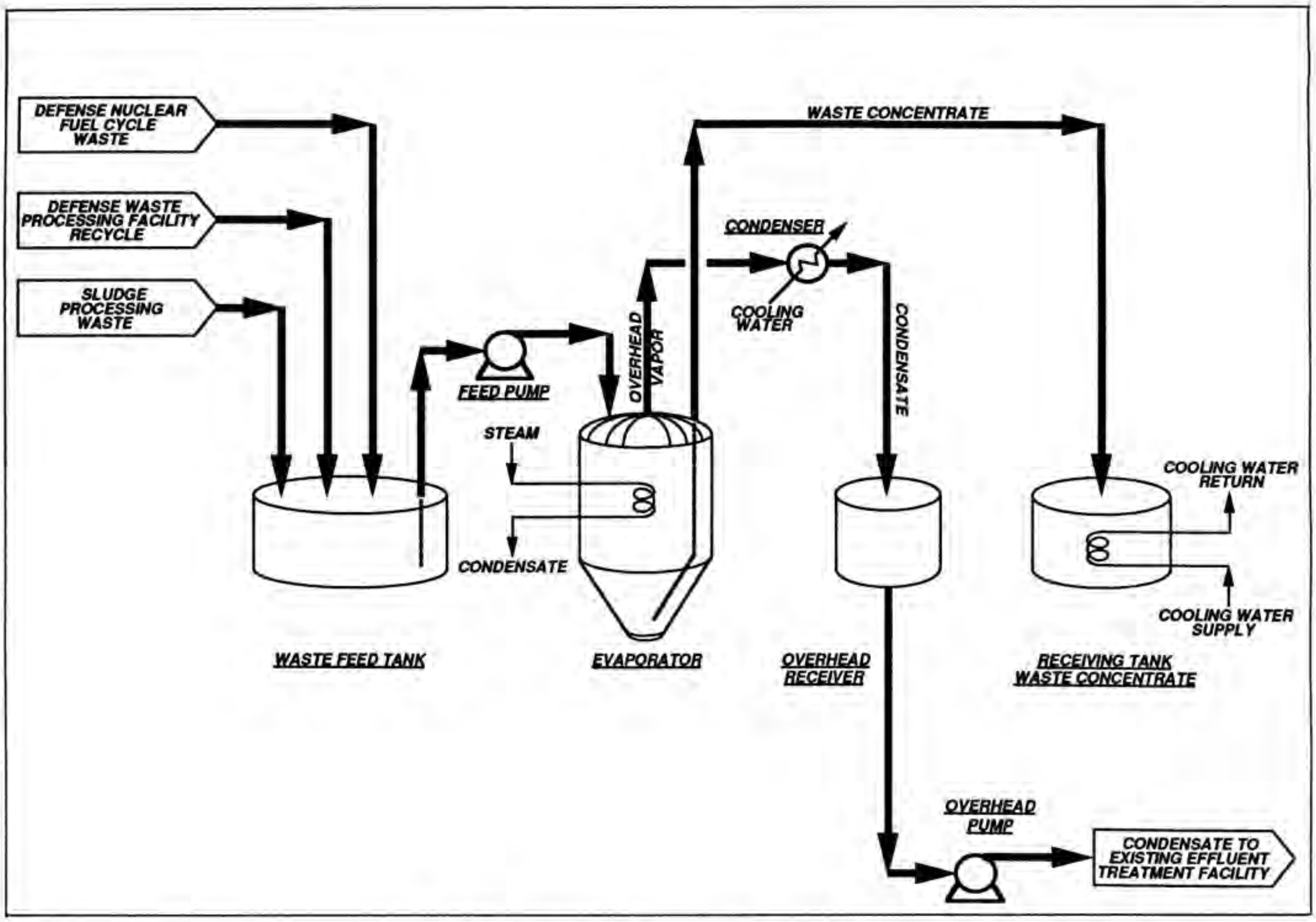

Fig. 1. Evaporator process flow schematic.

de-entrainment unit is located on the top center of the evaporator vessel, and is actually a part of the vessel itself.

Overhead vapor is condensed in a shell and tube heat exchanger. The condensate is passed through a gravity settler for removal of mercury which is sometimes present in the feed, monitored by an in-line gamma detector, and then collected in one of two overheads tanks. After further monitoring ensures acceptable radioactivity levels, the condensate is transferred to an existing SRS effluent treatment facility. Condensate is collected at a design flowrate of 86 liters per minute (23 gallons per minute). Should the condensate contain unacceptable levels of radioactivity, it can be returned to the evaporator feed tank for further processing. Noncondensible gases coming off the overheads condenser are passed through high efficiency particulate (HEPA) filters and monitored for radioactivity before being vented to atmosphere.

Waste concentrate is removed from the evaporator by a steam lift at a design flowrate of 64 liters per minute (17 gallons per minute). The concentrate passes through a vapor-liquid separator and is then transferred by gravity to another 4.9 million liter (1.3 million gallon) water-cooled underground storage tank. Here, a portion of the dissolved solids in the concentrate will precipitate, forming a salt cake. The supernate in the storage tank is periodically recycled to the evaporator feed tank for further concentration.

DESIGN FEATURES

The evaporator system is located in a dedicated multi-level concrete structure, in order to ensure containment of all radioactive materials (Fig. 2). The major areas of the evaporator containment structure include an evaporator cell, an overheads condenser cell, and an overheads tank cell. In addition to the concrete containment structure, a service area is housed in an adjacent steel frame building. A standby power system is also located near the evaporator building.

The evaporator cell houses the evaporator vessel, which is approximately 4.25 meters (14 feet) diameter by 9.15 meters (30 feet) tall. The evaporator vessel is designed to withstand a design basis earthquake (DBE). The cell is

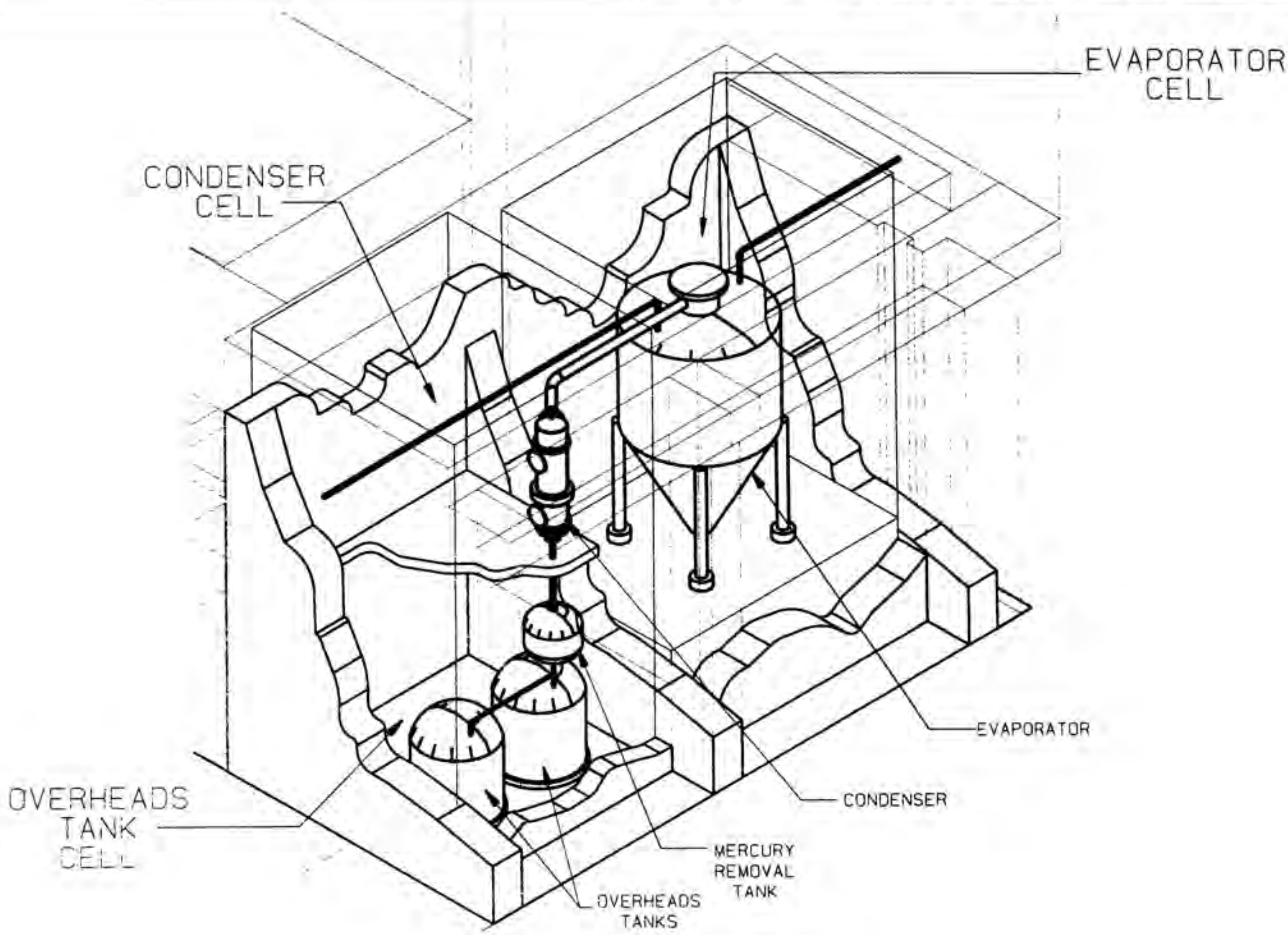

Fig. 2. Evaporator process area.

shielded, seismic-rated to withstand a design basis accident (DBA), and stainless steel lined to facilitate decontamination. The entire cell can be decontaminated by a built-in flush water spray system. Concrete walls up to 1.1 meters (42 inches) thick are used to limit radiation exposure to personnel in normally occupied areas to less than 0.5 millirem per hour (as specified in D.O.E. Order 6430.1A, General Design Criteria), while handling process streams containing radioactive levels of up to 26 curies per liter (100 curies per gallon).

The evaporator cell was designed using a remote maintenance and operation philosophy. Access to the cell is through stainless steel lined concrete covers which are removed by an overhead bridge crane. This crane is also used to replace the evaporator, if necessary, and to make all evaporator process connections. Jumpers with Hanford connectors are used for all evaporator process and instrument connections.

The evaporator cell is maintained at a negative pressure with respect to surrounding areas in order to prevent outleakage of any airborne contaminants. The cell has primary and secondary ventilation systems and all exhaust cell air is passed through dual HEPA filters before being discharged. The primary ventilation system is connected to normal, standby, and emergency power supplies and is normally used to maintain negative cell pressure. The secondary system is used to sweep air through the evaporator cell when any cell covers are removed for maintenance, but its main function is to provide ventilation for the remainder of the evaporator facility.

The evaporator itself is designed as a single stage, bent tube unit. The diameter of the evaporator was primarily determined by the area required to house the steam tube bundle that provides the evaporator heat input. The evaporator vessel is constructed of 304L stainless steel and the tubes are constructed of hastelloy G-3, to resist sodium fluoride attack. In order to remove scale, the tube bundle is designed to flex when thermally cycled, a procedure that can be done up to 200 times a year. A system is provided to pressurize the tube bundle with air if steam pressure is lost, in order to prevent steam condensate contamination in the event of a tube leak.

The evaporator vessel as received at SRS from the vendor does not have any Hanford connectors attached.

These are welded on the vessel in a mockup facility by specially trained SRS personnel. This is necessary in order to obtain the stringent dimensional tolerances required for remote equipment installation.

The height of the evaporator was influenced by the design decontamination factor of 100 million. Mist and liquid droplets in the evaporator vapor space contain radioactive contaminants such as cesium and strontium. Increasing the height of the evaporator allows more of these droplets to fall back down to the evaporator liquid, thus increasing the decontamination factor. Final removal of mist in the overheads is accomplished by a de-entrainment unit located on the top-center of the evaporator. This unit consists of a 304L stainless steel wire mesh pad, 0.46 meters (18 inches) high by 0.91 meters (36 inches) diameter, which coalesces and removes any mist.

Because of the high levels of radioactivity present in the evaporator, it is impractical to do any maintenance work on the vessel itself or the steam tube bundle. Based on previous experience and by making design improvements, it is believed that the evaporator should have a service life of 7 to 14 years. When it is necessary to replace it, the outside surfaces will be decontaminated by using spray nozzles located in the evaporator cell. The inside surfaces will be decontaminated as much as possible and then the evaporator will be removed by the overhead bridge crane, placed in a container, and held in interim storage.

Evaporator concentrate is transferred from the evaporator by steam lift to a separation vessel located in the evaporator cell. From here the concentrate flows by gravity through a jacketed underground pipe to a 4.9 million liter (1.3 million gallon) drop tank. Pipe jackets are monitored for core-pipe leakage. The gravity drain lines are provided with clean-out ports where catheters can be inserted to unblock pluggage. The clean-out system is designed so that personnel exposure to radiation is minimized. A system is also provided to back-flush the drain lines with hot water.

Evaporator overheads are condensed in a shell and tube heat exchanger of conventional design. Because of the potential for radiation contamination, however, the condenser is located in its own concrete cell with a removal concrete cover. Radiation levels in the condenser are normally low enough to allow hands-on maintenance, and this was the design philosophy for this area. Should it be required, however, the condenser was designed to be removed by the overhead crane after removal of the cell cover.

The last process area with a potential for radiation contamination is the overheads receiver tank area. A concrete cell is used to house the tanks that hold evaporator overheads condensate. Normally, however, radiation rates are low enough to allow hands-on maintenance in this area.

All piping and equipment in the evaporator system is designed for a minimum of liquid holdup (e.g., all piping is sloped to drain and designed with no pockets). All finishes of surfaces which could become contaminated with radioactivity are controlled to facilitate decontamination. No absorbent materials (such as insulation) are used without being sealed with an impermeable jacket. Concrete which could become contaminated is lined with stainless steel or coated to reduce permeability.

The entire evaporation process is controlled by a state-of-the-art distributed control system (DCS). This DCS also monitors all building radiation monitors, alarms, and heating and ventilating systems. The DCS is provided with an uninterruptible power supply. Safety class equipment and monitors are provided with standby and emergency power supplies to permit continued operation after loss of main power.

SUMMARY

Throughout the entire project, top priority was given to a design which ensures containment of all radioactive materials and the safety of operating personnel. In order to achieve such a design, SRS operating experience with existing high level waste evaporators was utilized extensively. Technological improvements were evaluated and implemented where they were warranted. State-of-the-art control systems were used to provide a highly reliable operation. Extensive studies were done to prove adequacy of design.

The end result of this effort will be a state-of-the-art, high level radioactive waste evaporator which should begin concentrating high level radioactive waste in 1995. Construction is scheduled to begin in Spring 1991.

REFERENCES

1. M. D. Abel, D. T. Zador, Replacement High Level Waste Evaporator CAC Basic Data, WMP-88-2269, E. I. du Pont de Nemours & Co., Savannah River Plant, November 10, 1988.
2. DOE Order 6430.1A, General Design Criteria, April 6, 1989.