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The Sodium Process Facility at Argonne National Laboratory-West*

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THE SODIUM PROCESS FACILITY AT ARGONNE NATIONAL LABORATORY - WEST

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ABSTRACT

Argonne National Laboratory - West (ANL-W) has approximately 680,000 liters (180,000 gallons) of raw sodium stored in facilities on site. As mandated by the State of Idaho and the United States Department of Energy (DOE), this sodium must be transformed into a stable condition for land disposal. To comply with this mandate, ANL-W designed and built the Sodium Process Facility (SPF) for the processing of this sodium into a dry, sodium carbonate powder. The major portion of the sodium stored at ANL-W is radioactively contaminated.

The SPF was designed to react elemental sodium to sodium carbonate through two-stages involving caustic process and carbonate process steps. The sodium is first reacted to sodium hydroxide in the caustic process step. The caustic process step involves the injection of sodium into a nickel reaction vessel filled with a 50 wt% solution of sodium hydroxide. Water is also injected, controlling the boiling point of the solution. In the carbonate process, the sodium hydroxide is reacted with carbon dioxide to form sodium carbonate. This dry powder, similar in consistency to baking soda, is a waste form acceptable for burial in the State of Idaho as a non-hazardous, radioactive waste.

The caustic process was originally designed and built in the 1980s for reacting the 290,000 liters (77,000 gallons) of primary sodium from the Fermi-1 Reactor to sodium hydroxide. The hydroxide was slated to be used to neutralize acid products from the PUREX process at the Hanford site. However, changes in the DOE mission precluded the need for hydroxide and the caustic process was never operated.

With the shutdown of the Experimental Breeder Reactor-II (EBR-II), the necessity for a facility to react sodium was identified. In order to comply with Resource Conservation and Recovery Act (RCRA) requirements, the sodium had to be converted into a waste form acceptable for disposal in a Sub-Title D low-level radioactive waste disposal facility. Sodium hydroxide is a RCRA regulated waste. It was decided to convert the hydroxide to sodium carbonate, a substance that is not RCRA regulated. ANL-W

undertook the task of upgrading the SPF, and designing and constructing the additional carbonate process. At the time of preparation of this paper, the facilities were undergoing testing and startup activities.

The sodium will be processed in three separate and distinct campaigns: the 290,000 liters (77,000 gallons) of Fermi-1 primary sodium, the 50,000 liters (13,000 gallons) of the EBR-II secondary sodium, and the 330,000 liters (87,000 gallons) of the EBR-II primary sodium. The Fermi-1 and the EBR-II secondary sodium contain only low-levels of radiation, while the EBR-II primary sodium has radiation levels up to 0.5 mSv (50 mrem) per hour at 1 meter. The EBR-II primary sodium will be processed last, allowing the operating experience to be gained with the less radioactive sodium prior to reacting the most radioactive sodium.

The sodium carbonate will be disposed of in 270 liter (71 gallon) barrels, four to a pallet. These barrels are square in cross-section, allowing for maximum utilization of the space on a pallet, minimizing the required landfill space required for disposal.

BACKGROUND

ANL-W has stored the primary sodium from Detroit Edison's Fermi-1 reactor since the 1970s. In the mid-1980s, a facility was designed and constructed to react this sodium into a 50 weight percent (wt %) solution of sodium hydroxide, to be shipped to the Hanford site to neutralize acidic wastes from the PUREX process. This caustic facility was constructed, but never tested as the need for caustic went away with the change in mission at Hanford. This facility was located outdoors, and allowed to degrade with time.

In September, 1994, the Department of Energy mandated the shutdown of EBR-II. This added 380,000 liters (180,000 gallons) of sodium to the ANL-W inventory of sodium that required disposal. With the State of Idaho requirements for storage of RCRA regulated wastes invoked, ANL-W had to design a method for disposal or treatment of the sodium on site. It was decided to refurbish the caustic facility, and to design and build a facility to convert the caustic into sodium carbonate, a waste form acceptable for disposal in the State of Idaho.

The Fermi-1 primary sodium is stored in 210 liter (55 gallon) barrels, and the existing facility was designed with provisions to melt the sodium in these barrels and drain the sodium into the 19,000 liter (5,000 gallon) sodium storage tank. The sodium from the EBR-II primary and secondary systems needed to be transported to the SPF, so a pipeline was designed and constructed. This pipeline originates at the Sodium Boiler Building (SBB), and traverses approximately 300 meters (950 feet) to the SPF.

The major components of the caustic facility are the 19,000 liter (5,000 gallon) sodium storage tank, the two 2,800 liter (750 gallon) day tanks, the reaction vessel, the 3,800 liter (1,000 gallon) caustic cooling tank, and the 15,000 liter (4,000 gallon) caustic storage tank. These components and associated instrumentation had degraded over time, and a major refurbishment effort was required to bring the facility up to current regulatory and operational standards.

The carbonate facility was designed, built, and tested under tight schedule constraints. The building was designed and procured by ANL-W, while a specification was prepared for the carbonate process. It was determined that a thin-film evaporator (TFE) would be used in the conversion process, so the system was designed around the TFE. A design engineering firm was contracted to perform the detailed system design and equipment specification, then a contract was issued for the procurement, installation, and fabrication of the process equipment. The major components in the carbonate facility include the thin-film evaporator, bulk solids cooler, drum fill machine, and palletizer.

Due to the radioactive nature of the carbonate powder product, the system was required to contain the powder to preclude additional unnecessary radiological constraints within the facility.

The SPF was designed to process the sodium in two distinct phases: raw sodium into a 50 wt% solution of sodium hydroxide and sodium hydroxide into sodium carbonate. The sodium is reacted with water to form sodium hydroxide per the following chemical equation:

$$Na + H_2O \rightarrow NaOH + \tfrac{1}{2} H_2$$

This exothermic reaction is performed in a nickel reaction vessel and controlled by controlling the temperature of the 50 wt % solution of sodium hydroxide in the vessel. The sodium hydroxide is then reacted with carbon dioxide in the TFE to form sodium carbonate. The chemical equation governing this reaction is:

$$2\,NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

This exothermic reaction product exits the TFE as a dry powder that is packaged in 270 liter (71 gallon) drums. The Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory, a Subtitle D landfill, will be used as the disposal site.

BARREL MELT AND DRAIN SYSTEM

Fermi-1 sodium arrives at the SPF in 210 liter (55 gallon) barrels. The purpose of the sodium melting and draining system is to liquefy and remove the sodium from its storage container. This is accomplished by heating the sodium, which is solid at room temperature, and transferring the sodium to the sodium storage tank. The transfer of the liquid sodium is achieved by drawing a vacuum on the storage tank.

At the beginning of the sodium melting and draining process, the openings in the barrels are replaced with fittings to be used in the draining process. The barrels are then hoisted into one of the eight barrel container assemblies, sized to contain the contents of a barrel in the event of a leak. The barrel container assemblies are arranged in two banks of four. Each barrel container assembly has eight 800-W heaters and a thermocouple, which are held in contact with the bottom of the barrels by springs. Once the barrels are placed in the assembly, two 3,000-W strap heaters are clamped to the barrels. These strap heaters each include an internal thermostat used to interrupt heater power in the event of an over-temperature condition. In addition, two magnetically-held thermocouples are placed on the side of the barrel to monitor the barrel temperature. Following this, an insulating cover is placed over each barrel. Around the rims of each container assembly are four nozzles for discharging MET-L-X fire suppressant in the event of a leak and resulting fire.

To initiate sodium transfer, a nitrogen purge gas is supplied to the barrel and the strap heaters are energized, starting with the top strap heater. Heating of the barrels is computer controlled. The top heater is energized first to accommodate for the expansion of the sodium as it melts. The sodium is heated initially from the free surface. The remaining heaters automatically receive power in computer-programmed sequences. The control computer uses the input from the three thermocouples to control the barrel heating sequence. The barrel melt and drain system supports the transfer of sodium from two barrels at once, one per manifold.

When the sodium has reached 150°C (300°F), a dip tube is inserted into the barrel. The dip tube is curved slightly to reach the intersection of the barrel wall and bottom. Once the barrel heat-up sequence is complete, and the sodium storage tank is at the appropriate vacuum, the operator initiates flow, transferring the sodium to the sodium storage tank. The sodium flow path from each barrel to the sodium storage tank is identical. The molten sodium flows from the barrel through a flexible drain line fitted with an electromagnetic flowmeter, into a drain manifold and into the sodium storage tank. After approximately 10 minutes of flow, the drum is tilted 7° from vertical by an air cylinder that tilts the barrel support plate. This maximizes the amount of sodium removed from each barrel.

The transfer piping is Schedule-40, Series-300 stainless steel. The piping joining the two drain manifolds to the storage tank is 1-inch nominal diameter. The piping in each drain manifold is 3/4-inch nominal diameter. The temperature of the piping is controlled by the control computer by activation of heaters on the piping.

SODIUM TRANSFER PIPELINE

In addition to receiving bulk sodium from 210 liter (55 gallon) barrels, sodium will also be transferred to SPF via a transfer pipeline from the SBB. This sodium will be transferred from the EBR-II primary and secondary sodium systems. The transfer line provides a pathway for batch transfers to the sodium storage tank for processing in SPF.

The transfer line connects to the secondary sodium recirculation system downstream of the secondary recirculation pumps. It is routed out of the SBB just above grade level, run west of the Sodium Components Maintenance Shop (SCMS), and then back toward SPF. It is elevated to 5 meters at the point where it crosses the road just behind SPF. Six concrete filled posts are installed along each side of the road at this spot to protect the transfer line pipe supports. The transfer line extends through the west wall of the SPF process area where it terminates at the sodium storage tank.

The transfer line is constructed of seamless stainless-steel pipe. The transfer line is heated and insulated with a 5 cm (2-inch) layer of fiberglass finished with metal weatherproof jacketing. Inspections to ensure integrity of all exterior portions of the transfer line will be performed daily during sodium transfer operations.

Isolation of the transfer line is provided by two stainless-steel bellows sealed globe valves, one at each end of the transfer line. The transfer line will transfer liquid sodium at approximately 175°C (350°F) at pressures of 70 to 400 kPa (10 to 60 psig). The transfer line has been designed to maximize draining of the pipe when pumping ceases. The transfer line slopes from its high point over the road near SPF back to the SBB. Minimum slope for pipe draining is 1 cm/3 m. When not in operation, the sodium remaining in the line that was not drained will be frozen. Therefore, liquid sodium will not be present when the line is not in use and this condition plus the relative isolation of the transfer line from high traffic areas will minimize the potential for personnel and environmental exposure.

Once full operations are achieved, it is expected that the transfer line will be operated for approximately 8 to 10 hours to fill the sodium storage tank. It will then take 5 to 6 days to process the sodium from that transfer at design processing rates. The process will then be repeated and should only operate for approximately 10 hours every five days.

CAUSTIC PROCESS

The caustic process is comprised of the equipment necessary to convert sodium into sodium hydroxide. The major equipment includes the 19,000 liter (5,000 gallon) sodium storage tank, the two 2,850 liter (750 gallon) day tanks, the reaction vessel where the conversion occurs, the 3,800 liter (1,000 gallon) caustic cooling tank, and the 15,000 liter (4,000 gallon) caustic storage tank.

As mentioned, the sodium enters the sodium storage tank from the barrel melt and drain station or from the sodium transfer pipeline. The sodium storage tank is a carbon steel vessel, and is maintained at 120°C (250°F) by the use of external heaters, and a blanket of nitrogen is maintained in the gas space above the sodium.

From the sodium storage tank, the sodium is transferred into the day tanks by pressurizing the sodium storage tank. These two sodium day tanks are identical carbon-steel tanks. They are sized to contain sufficient sodium for one day of operation, hence the term *day* tank. Each sodium day tank will be filled on alternate days, and on alternate days each sodium day tank will be the source of the sodium processed. The on-line sodium day tank is pressurized at 200 to 350 kPa (30 to 50 psig) with nitrogen gas to provide the driving force for the injection of sodium into the reaction vessel. The sodium in each day tank is maintained at 120°C (250°F) via external electric heaters.

From the day tanks, the sodium is transferred into the reaction vessel at the rate of 115 liters (30 gallons) per hour. The motive force for transfer is pressurization of the day tanks. The reaction vessel is a 75 cm (30 inches) diameter by 4.7 meter (15.5 feet) high vertical cylinder with American Society of Mechanical Engineers (ASME) heads constructed from alloy 200. In the reaction vessel, sodium is reacted exothermically with water to form a caustic solution. By controlling the atmospheric boiling point of the solution, the concentration of the caustic product is fixed. The boiling point, and hence the concentration of the solution, is controlled by the addition of water. The simultaneous injection of water and sodium results in a vigorous but not violent reaction. Sodium is injected into the reaction vessel through specially designed nozzles that provide the capability to add steam or nitrogen gas or both simultaneously at the point of injection for atomization of the sodium. Also, the capability exists for initiating a nitrogen and/or steam purge of the nozzles whenever sodium flow is terminated to preclude plugging of the injection nozzles. A separate electromagnetic (EM) flowmeter is provided for each of the two injection nozzles. The caustic recirculation line provides for continuous recirculation of the 50 wt% caustic solution to aid in the homogeneity of the caustic solution. The caustic recirculation pump takes a suction from the bottom of the reaction vessel and discharges it near the top of the reaction vessel. The caustic solution is pumped from the reaction vessel to the caustic cooling tank through a control valve that is operated by the control system. Input from load cells located on the legs of the reaction vessel provide level indication, and the control valve is operated to maintain a constant level during sodium processing. The caustic recirculation pump will provide capabilities of completely draining the reaction vessel during maintenance activities.

Following transfer into the caustic cooling tank, the sodium is either directly transferred to the thin-film evaporator, located in the carbonate section of the facility, or cooled prior to transfer to the caustic storage tank.

The caustic cooling tank is a 1.2 meter (4 feet) diameter by 3.5 meter (12 feet) long horizontal cylindrical tank. It is used to cool the caustic before it is transferred to the caustic storage tank. The caustic storage tank will be used for backup storage only. Caustic will be stored in this tank when it is necessary to secure the carbonate process (i.e., maintenance). Capability will exist to transfer caustic from the cooling tank to the reaction vessel. Cooling of the caustic solution is provided by a heat exchanger in the bottom of the caustic cooling tank. The heat exchanger consists of an 20 cm (8 in) diameter bundle of 2.5 cm (1 in) diameter U-tubes that extend essentially the full length of the tank. Tube material is Series-200 nickel. Ethylene glycol is circulated through the tubes to remove the heat. External heaters are provided for the lower one-third of the caustic cooling tank in case it should be necessary to recover from a situation in which the caustic in the tank had been allowed to solidify.

CARBONATE FACILITY

The sodium carbonate facility was designed and built as an addition to the existing caustic facility to provide a method to convert 50 wt% sodium hydroxide (caustic) into a dry, non-hazardous sodium carbonate waste. This waste is acceptable for land disposal at the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory.

The 50 wt% caustic is transferred from the caustic facility to the TFE in the carbonate facility, where it is combined with carbon dioxide in the variable temperature controlled section of the TFE to form sodium carbonate product and water. The sodium carbonate product and water are heated in the evaporation section of the TFE to evaporate the water and dry the sodium carbonate product to a powder. Excess vapor from the TFE evaporation process is directed through a condenser where the water is recycled and the vapor effluents are directed to the off-gas system. The sodium carbonate product leaves the TFE, and if the product is in powder form, it is gravity fed into the bulk solids cooler where it is cooled from 150°C (300°F) to less than 40°C (100°F). After the sodium carbonate powder is cooled, it is gravity fed into a drum fill machine which is used to package the sodium carbonate powder in barrels. If the product from the TFE is not a powder, it is considered off-specification and is directed to a process tank where it can be made into a slurry and returned to the TFE for reprocessing. The sodium carbonate powder is packaged in specially fabricated 270 liter (71 gallon) square barrels since the cross section allows more product to be packaged in the same space as conventional 210 liter (55 gallon) cylindrical barrels. The barrels are filled with the sodium carbonate powder through a primary containment glovebox. The barrels are weighed and capped before they are moved into a secondary contamination enclosure where the barrels are surveyed for radiation and radioactive contamination. The decontamination area is equipped with a side track so that contaminated barrels can be directed to an isolated area to be decontaminated. Barrels free of radioactive contamination are moved to the end of the track, then gently pushed off of the dolly and onto the roller conveyer of a semi-automatic palletizing system. Once four barrels are palletized, they are banded and moved by a forklift into the full barrel storage area until a full truck load of barrels can be shipped.

All of the systems are equipped with process monitoring and control instruments. Many of the instruments tie into a computerized control system for normal process control, simple recording, alarms for upset conditions, and automatic shutdown. In addition, some systems are equipped with local direct reading instruments and visual inspection systems.

The process equipment vapor effluents and entrained particles are collected and controlled in the off-gas system to prevent releases to the process areas or the environment. Effluents from the sodium carbonate process are combined into a common header and passed through a baghouse. The baghouse provides rough filtration for entrained sodium carbonate powder. Effluent gas from the baghouse passes through a prefilter and HEPA filter which removes the remaining particulate. A blower provides the motive force for the off-gas system, which maintains the required effluent flows from the process equipment. The clean effluent is discharged to the atmosphere through a vent that is equipped with radiation monitoring.

Shielding systems, including concrete, lead, and steel materials, are utilized throughout the facility to minimize personnel radiation exposures. The HVAC system provides ventilation air to both the caustic and carbonate processes, as well as assists in the control of contaminated materials generated during the sodium carbonate process.

SUMMARY

The SPF at ANL-W was designed and constructed to react 680,000 liters (180,000 gallons) of elemental sodium to a dry, sodium carbonate powder for land disposal at the Idaho National Engineering and Environmental Laboratory. The facility, when fully operational, will react 2,700 liters (720 gallons) of sodium per day. Currently under final startup testing, it is anticipated that the SPF will be fully operational in early 1998, and operate for approximately two years.