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MECHANICAL DESIGN AND FABRICATION OF A PROTOTYPE FACILITY FOR PROCESSING NaK USING A CHLORINE REACTION METHOD

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ABSTRACT

A prototype facility has been built at the Idaho National Engineering Laboratory (INEL) to dispose of 180 gal (0.68 m^3) of radioactively contaminated NaK (sodium-potassium) that have been stored on site for 35 years. The NaK was used as primary coolant for the Experimental Breeder Reactor I (EBR-I) at the INEL and was contaminated during a meltdown of the Mark II core in November 1955. The NaK then was transferred to four containers for temporary storage. The facility process will react the NaK with elemental chlorine using a batch process to produce chemically stable sodium chloride and potassium chloride salts. The first use of the facility will be on a prototype level to verify the method. If results are favorable, the facility will be modified to eventually dispose of the EBR-I NaK. The design and intended operation of the prototype facility are described.

INTRODUCTION

The Decontamination and Decommissioning (D&D) Program at the Idaho National Engineering Laboratory (INEL) has the responsibility for disposing of 180 gal (0.68 m^3) of radioactively contaminated NaK (sodium-potassium) that have been stored on site for 35 years. The NaK was used as primary coolant for the Experimental Breeder Reactor I (EBR-I) at the INEL and was radioactively contaminated during a meltdown of the Mark-II core in November 1955. During the EBR-1 core replacement in 1955, the NaK was transferred from the reactor to four containers for temporary storage.

The D&D project requirement for disposal is to change the EBR-I NaK from a mixed hazardous waste to a radioactive waste. Chemical engineering analysis and laboratory testing indicated that the preferred method to eliminate the chemically hazardous waste component would be to react the NaK with elemental chlorine using a batch process to produce chemically stable sodium chloride and potassium chloride salts.

Mechanical engineering personnel were enlisted to design and head up the fabrication of a facility that would provide scaled up hardware with respect to that used in the laboratory testing. First use of the facility will be on a prototype level to verify the proposed NaK/chlorine reaction method. If the results of the prototype testing are favorable, the facility would be further modified to meet the requirements of handling the radioactive EBR-I NaK. Any needed modifications identified during the prototype testing also will be incorporated at that time. The emphasis of the facility would then change from that of research and development to production for the disposal of the EBR-I Mark-II NaK.

The operation of the prototype NaK disposal facility consists of the following phases:

1. Place a NaK container in the secondary containment vessel
2. Remove the NaK from the container, draining it in the secondary containment vessel to await final processing
3. Using a batch process, transfer the NaK to the reaction vessel and react the NaK with chlorine gas
4. Dissolve the reaction products (salt) with water in the reaction vessel and transfer the saline solution to waste drums
5. Solidify the saline solution in the waste drums using a stabilization agent.

PROTOTYPE FACILITY PROCESS DESCRIPTION

A simplified flow diagram of the prototype process used to remove the chemical hazard associated with NaK is shown in Fig. 1.

NaK Container Description

The EBR-I NaK is a eutectic mixture of approximately 22% sodium (Na) and 78% potassium (K) and has been stored since 1955 in two stainless steel 55-gal (0.21 m^3) Mine Safety Appliance (MSA) drums and in two carbon steel containers fabricated from pipe sections. The two fabricated containers are right circular cylinders, with capacities of 10 and 60 gal (3.8×10^{-2} m^3 and 0.23 m^3).

The four containers were internally purged and an argon cover gas was provided after their filling with NaK in

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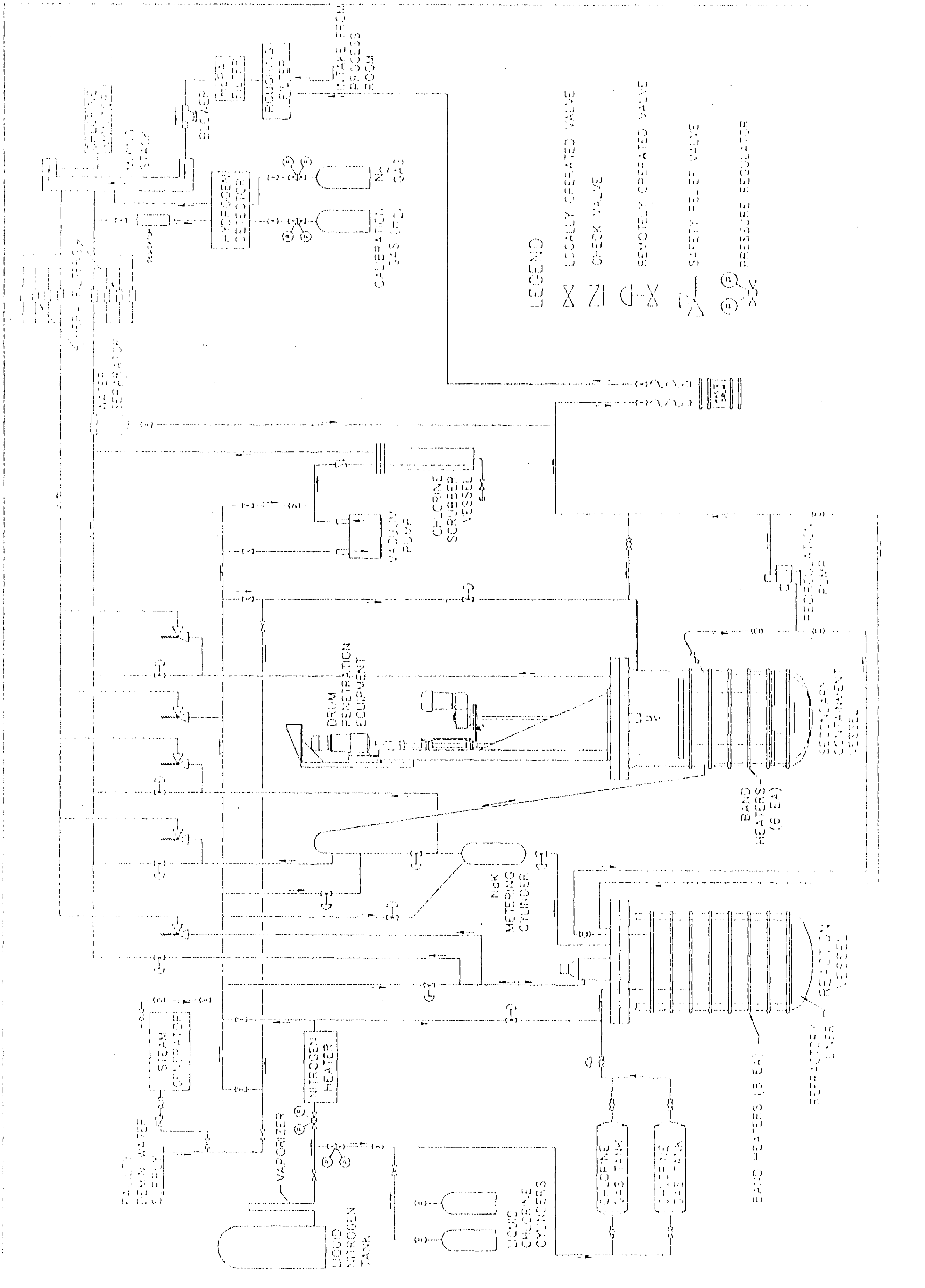

Fig. 1. Flow Diagram of Prototype Process Used to Remove the Chemical Hazard Associated With NAK.

1955. In 1974, the four NaK containers were placed inside a sheet metal dumpster and covered with sand to a depth of approximately 12 in. (0.30 m) above the containers. The dumpster and contents have been stored inside an underground bunker since 1974.

A 30-gal (0.110-m^3) MSA drum of nonradioactive NaK will be used to simulate a radioactive NaK container for the prototype process phase.

Reaction Vessel, Secondary Containment Vessel, and Associated Hardware

Figure 2 provides an elevation view of the reaction vessel, secondary containment vessel, and associated hardware that will be used to process the NaK. The vessels were fabricated using 36-in. (0.91-m) standard piping components, e.g. pipe caps, 1/2-in. (1.3 x 10^{-2}-m) wall pipe, 150-lb weld neck flanges, and 150-lb blind flanges. They were designed and analyzed to comply with American Society of Mechanical Engineers (ASME) Section VIII Division I requirements and were qualified after fabrication using magnetic particle inspection and pneumatically tested to 125% (125 psig or 8.6 x 10^5 n/m^2) of design pressure (100 psig or 6.9 x 10^5 n/m^2).

Specially designed stands support the vessels in cradle fashion and provide a three point attachment for lifting purposes. Three lift arms extend from the cradle portion of the stand and are used for attachment to three 10-ft (3.1-m) wire ropes which in turn are attached to a lift fixture. The attachment points on the lift arms are above the center of gravity of the vessels to prevent tip over during movement. The lift fixture is made from 1/2-in.(1.3 x 10^{-2} m)-thick plate with one lift ear on top for the crane hook and three lift ears on the bottom. The lift fixture also is used for removal and installation of the reaction vessel blind flange. Installation and removal of the secondary containment vessel blind flange is accomplished using a chain that is permanently attached to the drum penetration equipment support structure which is permanently attached to the secondary containment vessel blind flange.

When not on the vessels, the vessel blind flanges are stored on stands at an elevated position. The elevated position provides protection for and access to hardware located on the underside of the flanges.

Mounted to the top of the secondary containment vessel blind flange is a task specific drill press mechanism called the drum penetration equipment. The function of this equipment is to drill holes vertically through the tops and bottoms of the NaK containers while the containers are in the controlled internal atmosphere of the secondary containment vessel.

Three different electric motors are used to operate the drum penetration equipment. The first motor is the drill motor and attaches to a 72-in. (1.8-m)-long drill shaft. This drill motor sits on a platform that translates on two 1-1/2-in. (3.8 x 10^{-2}-m) steel ways. A slow-drive motor and a fast-drive motor are mounted on the drum penetration equipment support structure. These motors, independently but through a common 1-in. Acme threaded lead screw, move the drill motor up and down through its 48-in. (1.2-m) travel. The change from one drive motor to the other is accomplished by removing or installing a connecting collar to the slow-drive-motor output shaft. When the collar is installed, the slow-drive motor is functional and the fast-drive motor is turned at the same rate as the slow-drive motor. The slow-drive motor moves the drill motor at a rate of 1 in. (2.5 x 10^{-2} m) every 5 minutes. This rate is used during the actual drilling operation. The fast-drive motor drives the Acme lead screw using a chain and a sprocket mounted on the Acme screw below the connecting collar. This motor moves the drill motor at a rate of 10 in. (0.25 m) every minute and is used for quicker positioning than is possible with the slow-drive motor.

A unique alignment bracket for each NaK container serves to position the container in the secondary containment vessel and keep it from rotating during the drum drilling operation. Only the 30-gal (0.11-m) NaK container will be used during the prototype phase.

Mounted on top of the reaction vessel blind flange are the NaK metering cylinder, the chlorine injection tubing drive mechanism and the ultrasonic level detection instrument. The NaK metering cylinder is made from 4-in. (0.10-m) pipe and pipe caps and has an internal volume of 1/2 gal (1.9 x 10^{-3} m^3). It is used to measure the amount of NaK transferred into the reaction vessel. The drive mechanism provides a means for moving the injection tubing up and down inside the reaction vessel to accommodate the changing levels of NaK and reaction product. The ultrasonic level instrument is used to indirectly determine the level of product in the reaction vessel, thereby avoiding placement of a sensor directly in the harsh environment caused by the reactions in the vessel.

Clamped to the outside of both the reaction vessel and the secondary containment vessel are electric band heaters. These heaters are used during various process steps when the temperatures inside the vessels must be elevated.

NaK Removal From the Containers

After the NaK container has been placed in the secondary containment vessel, the secondary containment vessel blind flange is installed using spiral-wound metal gaskets. This will complete the pressure boundary protection between the NaK container and the atmosphere.

Prior to the drilling operation, a purge of the air in the secondary containment vessel is performed using nitrogen gas drawn from a liquid nitrogen tank located just outside

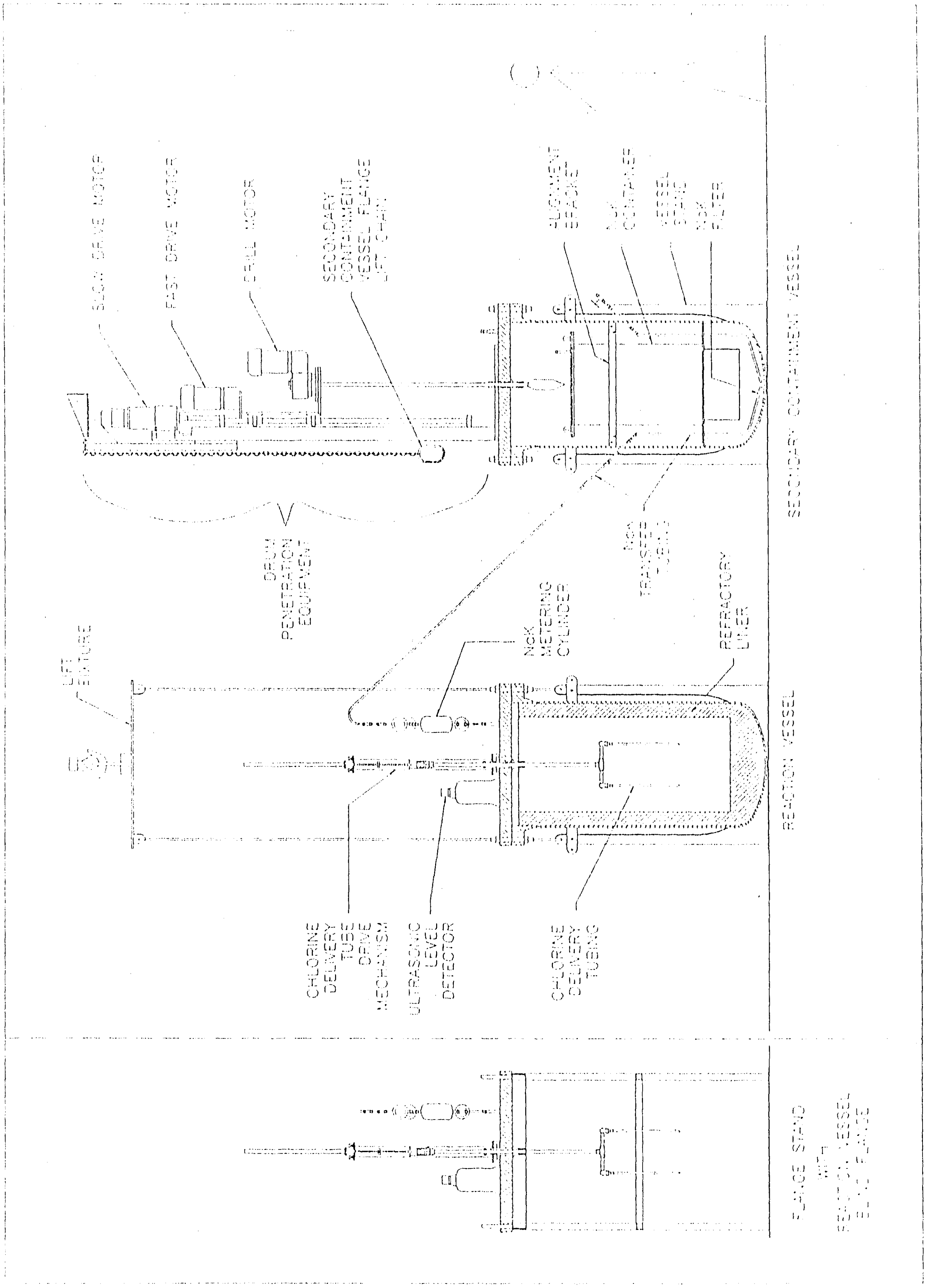

Fig. 2. Elevation View of Reaction Vessel, Secondary Containment Vessel, and Associated Hardware.

the facility. After purging, a vacuum of 20 in. Hg (6.7×10^4 n/m^2) is drawn on the vessel. This provides a differential pressure that keeps potential leakage flowing into the vessel and not out to the atmosphere.

With an inert atmosphere in the secondary containment vessel, a hole is then drilled through the top of the NaK container using the drum penetration equipment. After the top hole is made, the drum penetration equipment connecting collar will be removed and the fast-drive motor will be used to position the drum penetration equipment drill head to about 2 in. (5.1×10^{-2} m) above the bottom of the NaK container. The connecting collar will then be reinstalled and the bottom hole drilled in the NaK container. The NaK will then flow from the NaK container into the lower portion of the secondary containment vessel. The secondary containment vessel was designed to be intrinsically safe in containing the NaK prior to processing because there are no leak paths in the lower portion of the vessel.

NaK Transfer to the Reaction Vessel

The NaK/chlorine reaction occurs in the reaction vessel. The dynamics of the NaK/chlorine reaction and the system configuration limit the amount of NaK that can be reacted in the reaction vessel at any one time. The maximum amount of NaK that can be reacted per cycle will be determined during this prototype testing. For protection against the NaK/chlorine reaction, the reaction vessel is lined with 4 in. (0.10 m) of high alumina refractory. The cap portion of the vessel is filled with the refractory forming a horizontal flat surface at the bottom of the vessel.

Prior to putting NaK in the reaction vessel, a nitrogen purge of the air in the vessel is performed. After purging, a vacuum of 20 in. Hg (6.7×10^4 n/m^2) is drawn on the metering cylinder and the reaction vessel. The secondary containment vessel is then pressurized to 10 psig (6.9×10^4 n/m^2) pushing the NaK through the 1/2-in. (1.3×10^{-2}-m) transfer line to the metering cylinder inlet valve. The valve is opened and the NaK flows into the metering cylinder equalizing at 10 psig (6.9×10^4 n/m^2). A liquid level indicator is mounted in the metering cylinder and is activated when 1/2-gal (1.9×10^{-3} m^3) of NaK is in the metering cylinder. The metering cylinder inlet valve is closed and the outlet valve is opened allowing the NaK to flow into the reaction vessel. The size of the metering cylinder limits the amount of NaK that can be transferred at one time to 1/2-gal (1.9×10^{-3} m^3). A 1/2 gal (1.9×10^{-3} m^3) of NaK in the reaction vessel will form a layer 1/5 in. (5.1×10^{-3} m) deep.

Chlorine Gas Operations

Two liquid chlorine cylinders are connected to two 350-gal (1.3-m^3) chlorine gas tanks. Tubing from the gas tanks passes through a sealed housing mounted in the center of the reaction vessel blind flange. Inside the reaction vessel, the main chlorine delivery tube branches into four equally spaced delivery tubes. The delivery tubes can be moved up or down to position the chlorine exit point at the desired position above the surface of the NaK. Prior to a reaction cycle, chlorine will be vaporized from the liquid cylinders into the gas tanks to 40 psig (2.8×10^5 n/m^2).

NaK/Chlorine Reaction Operations

The NaK/chlorine reaction is initiated by blowing down chlorine gas from the gas tanks to the reaction vessel. The chlorine gas passing through the delivery tubes is directed very closely to the surface of the NaK in the reaction vessel. After each reaction cycle, a small amount of chlorine gas will remain in the reaction vessel. This gas will be purged from the reaction vessel using nitrogen gas. The purged chlorine gas is sent through a scrubber vessel filled with a solution of 30% sodium hydroxide in water. The reaction between the chlorine and sodium hydroxide provides a means of preventing chlorine gas from escaping to the atmosphere. The scrubber vessel is made from 12-in.(0.31-m) pipe and is 10 ft (3.1 m) long. Column packing in the scrubber vessel is used to increase the residence time the chlorine is in the scrubber vessel thus ensuring a complete reaction of the chlorine with the sodium hydroxide The chlorine/nitrogen gas enters the scrubber vessel from the bottom and bubbles up to the top and exits through the off gas system. The off gas system includes a HEPA filter bank through which all process gas effluent passes before exiting the facility through the off gas stack. Although the HEPA filters are not required during the prototype phase for radioactive contamination control, their interaction with the rest of the equipment requires their presence.

The products of the NaK/chlorine reaction form a salt layer in the bottom of the reaction vessel. Subsequent reactions will take place on the previously formed salt layers. The metering/reaction process continues until all the NaK that will transfer from the secondary containment vessel to the reaction vessel has been reacted.

Steam/Nitrogen Operations

Residual NaK remaining in the secondary containment vessel and the empty NaK container is removed using a steam/nitrogen process. Steam is generated using an electric steam generator capable of producing between 2 and 8 lb (0.91 and 3.6 Kg) of steam an hour. The steam, at a controlled rate, is injected into a heated nitrogen gas stream that carries it to the secondary containment vessel. Through the use of the band heaters, the secondary containment vessel internal temperature is raised to at least 250^{0}F (121^{0}C) to prevent steam condensation. The nitrogen is heated using a 3 kW-rated flow through heater.

The steam reacts with NaK producing hydrogen gas and sodium hydroxide. The nitrogen gas stream that delivered the steam to the secondary containment vessel is used to carry away the hydrogen gas through the off-gas system. A hydrogen gas analyzer samples the off-gas stream and determines the amount of hydrogen present. Project personnel can use this information to help determine steam rates and determine when the NaK/steam reactions have been completed. After steam cleaning, the secondary containment vessel will be filled with demineralized water. The water will react with any small amounts of residual NaK and ensure that no NaK remains in the secondary containment vessel or the empty NaK container. A diaphragm pump can be used to circulate the water in the secondary containment vessel or nitrogen gas could be bubbled into the secondary containment vessel to agitate the water to ensure that any residual NaK left in any crevices is contacted by water.

Salt Dissolution Operations

To meet the final waste disposal criteria, it is necessary to certify that no NaK remains imbedded in the salt layers formed in the reaction vessel. To accomplish this, the weak hydroxide solution in the secondary containment vessel generated from the steam/water cleaning phase is transferred to the reaction vessel through the NaK transfer line and the metering cylinder reacting with any residual NaK encountered on the way. The weak hydroxide solution and subsequently added water will dissolve the salt in the reaction vessel and react with any NaK that may have been trapped in the salt layers. During this entire phase, nitrogen gas is flowing through the reaction vessel to carry off any hydrogen generated if the water reacts with any NaK. The hydrogen gas analyzer is used to determine if any NaK is found in the salt layers. During this phase it is possible to increase the dissolution rate by agitating the water/saline solution using the recirculation pump or by bubbling nitrogen gas through the solution. Because of the limited reaction-vessel volume and the amount of water required to dissolve the salt, the dissolution process incorporates the batch method.

Waste Disposal Operations

The waste acceptance criteria at the radioactive waste facility where the waste drums will be stored requires that no free liquid exists in a waste drum. This requires that the saline solution produced in the reaction vessel be mixed with a stabilization agent in the waste drums prior to shipment from the NaK processing facility.

Transfer of the saline solution to waste drums is made after the solution reaches a salinity of between 75 and 90%. The reaction vessel is pressurized to 10 psig (6.9 x 10^3 n/m^2) using nitrogen gas and the saline solution is transferred to 55-gal (0.21-m^3) waste drums. This operation is done one drum at a time. A feed hopper mounted on a modified waste drum lid is used to meter a given amount of stabilization agent at a predetermined rate. The hopper filled with stabilization agent temporarily is placed on a waste drum. After a predetermined amount of saline solution is added to the waste drum, the stabilization agent is added. No post mixing is required in the waste drum.

Equipment Dry Out Operations

After all the waste liquids have been removed from the reaction vessel, the secondary containment vessel, the NaK metering cylinder, and the interconnecting tubing, these components are dried out. This is a requirement prior to processing each EBR-I NaK container and prior to disposal of the equipment after all processing has been completed. The band heaters on the vessels and heat tape on the remaining components are the source of heat used to boil off any residual liquids. A nitrogen gas flow through the various components is used to aid in carrying off the vapors. The effluent from this process also is filtered out through the off gas system.

SUMMARY

This paper has described a prototype facility that has been built at the INEL to react NaK with chlorine. Radioactive NaK is considered to be a mixed hazardous waste and as such cannot be disposed of at current radioactive waste storage sites. The reacting of NaK with chlorine would remove the chemical hazard and render the generated salts as radioactive waste only. The salts could then be stored at designated radioactive waste storage areas. The prototype facility will be used to react nonradioactive NaK with chlorine to determine if the proposed reaction method is a viable process that can be used to dispose of the 180 gal (0.68 m^3) of highly radioactive EBR-I NaK. The prototype facility is task specific to the EBR-I NaK disposal.

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