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SEFOR COLD-TRAP EXPERIENCE

A. D. GADEKEN

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U. S. ATOMIC ENERGY COMMISSION

CONTRACT AT(04-3)-540

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ABSTRACT

The SEFOR cold traps installed in the primary sodium service system developed flow control problems very early in life. These early flow problems, aggravated by large temperature differences between plugging temperatures and cold-trap control temperature, soon degenerated into complete flow blockage of both cold traps. After approximately 1500 hours of operation for each cold trap during sub-power testing, the cold traps were removed from the system and replaced by cold traps of similar design.

The two plugged cold traps were drained of sodium in a procedure which was designed to leave the oxide precipitation intact in the cold trap. The cold traps were then disassembled, inspected, and photographed in an inert atmosphere. This inspection procedure revealed that: (a) the cold traps had only trapped about one-quarter of their design capacity of oxide, (b) the mesh inside the cold traps had been compressed to about one-third of the original size, and (c) except for the first mesh wafer seen by the oxide-laden sodium, there was very little oxide precipitate in the five succeeding mesh wafers.

The SEFOR cold-trap experience has resulted in an operating procedure for the new cold traps which eliminates the large temperature differences between sodium plugging temperature, and a much better understanding of the initial cold-trap plugging problems.

1. INTRODUCTION

This report describes the operating experience and inspection of the SEFOR primary cold traps.

The Southwest Experimental Fast Oxide Reactor (SEFOR) is a 20-MW(t) fast spectrum reactor fueled with mixed $\text{PuO}_2\text{-UO}_2$ and cooled with sodium. SEFOR will have characteristics similar to large, soft-spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-UO}_2$. Economic studies of these large power reactors indicate significant potential for producing low-cost power. SEFOR will be used to obtain physics and engineering data on fuel compositions, temperature, and crystalline states characteristic of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

The SEFOR Project consists of two major parts: the design and construction of the reactor, and a related research and development program. Funds for the design and construction of the facility were provided by the Southwest Atomic Energy Associates (a group of 17 investor-owned utility companies located in the southern and southwestern parts of the United States), together with Karlsruhe Laboratory of the Federal Republic of Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the research and development program which consists of two phases:

Phase I—Preoperational Research and Development

Phase II—Post-Construction Research and Development

The Southwest Experimental Fast Oxide Reactor (SEFOR) was designed and built to investigate the Doppler coefficient of mixed-oxide-fueled, fast-flux, sodium-cooled reactors, and to provide operation and maintenance experience applicable to fast breeder power reactors.

Purification equipment for the primary sodium systems includes two forced-circulation-type cold traps and one plugging indicator (see Figure 1).

The function of the cold trap is to remove sodium oxides from the sodium and to thereby prevent possible formations of plugs of sodium oxide in piping, fuel channels, orifices, or other locations in the sodium system.

There are two primary cold-trap units so that one can be operated while the other is idle, permitting decay of radioactive sodium prior to removal. The primary units are located in a separate concrete enclosure below grade level, which provides shielding protection during access to other primary sodium equipment. The two cold traps are also separated from each other by a shield wall. This 2-foot-thick concrete barrier provides shielding from the more active operating unit when the other cold trap is being replaced.

Plugging indicators are included to monitor sodium plugging temperatures as a measure of oxide concentration in the sodium. Each detector assembly consists of a flowmeter, a cooler (nitrogen cooled), and a flow restriction. The temperature of the sodium stream is slowly lowered by the cooler, which is located immediately upstream of the flow restriction. When the saturation temperature is reached, sodium oxide precipitates, plugs the flow restriction, and causes a sharp break in the sodium flow rate. The oxide concentration is determined by comparing the temperature and flow values with a plot of saturation temperatures for sodium oxide in sodium. A two-pen recorder, which simultaneously records flow and temperature, is used to record the necessary plugging data.

The sodium streams that feed the purification cold traps or plugging indicators are normally taken from the cold legs of the primary and secondary sodium loops in order to minimize the heat loss from the service equipment (see Figure 1A).

Figure 1. SEFOR Cold Trap

Figure 1A. Primary Service System

The primary sodium system is also capable of cold-trapping from the pump around the loop which operates at approximately the reactor outlet temperature. The sodium service piping is arranged so that sodium from either the drain tank or the individual coolant loops can be cold-trapped. Normally, cold-trapping of sodium from the drain tank is performed prior to filling the coolant systems and during reactor operation because flow initiation has, on occasion, momentarily lowered the vessel level. In this operation the sodium is transferred from the drain tank, through a cold trap, and back to the drain tank. A small sodium stream from either loop (main or auxiliary primary) is discharged through the service pump, sent through the cold trap and returned to the loop. To measure the oxide concentration, the sodium is periodically passed through the plugging detector.

To avoid potential plugging problems during operation, it is important that the sodium coolant systems, including attached appendage lines, be maintained at temperatures above the maximum plugging temperature.

The SEFOR cold-trap design utilizes an integral vertically-installed economizer with a finned cooling section (see Figure 1). The vessel consists of a 39-in. length of 24-in., Schedule 20, Type-304 stainless steel pipe. Both upper and lower vessel heads are of the elliptical dished type with a wall thickness of 3/8 in. The external envelope for the economizer (a 42-in.-length section of 8-in., Schedule 40, Type-304 stainless steel pipe) is inserted into the top dished head.

The economizer is a straight-tube, single-pass, 55-tube, tube-and-shell-type heat exchanger. The tubes are 3/4 in. o.d. X 0.049 in. wall, and are welded at both ends into the tube sheets on a 15/16-in. triangular pitch. Three shell-side baffles are installed which increase the economizer heat transfer, as well as provide lateral stability for the tube bundle.

Approximately 215 37-in.-long fins of carbon steel are welded to the cooling section. Each fin is segmented into approximate 4-in. sections along its length. The fins are 0.050 in. thick and 1 in. wide.

The cold-trap lower head has an extension of an additional elliptical 16-in.-diameter dished head. This "cold dome" operates as a diffusion cold trap when normal cold-trapping operation is shut down, and provides additional oxide storage capacity during normal operation.

Inside the finned tube cooling section is a mesh container consisting of an 18-in. o.d. X 3/16-in. wall, Type-304 stainless steel tube, 36-1/2 in. long. The mesh container is supported by the tubes of the economizer attached to an 18-in.-o.d. X 3/8-in.-thick circular plate. Inside the mesh container are six wafers of stainless steel, knitted wire mesh rolled into a right circular cylinder 17-1/2 in. diameter X 6 in. high. The wire diameter is 0.005 ± 0.005 in. at a density of from 5 to 10 lb/ft³.

Operation of the Cold Traps

Nitrogen coolant enters through a duct at the bottom of the carbon steel coolant can in which the cold-trap vessel is suspended, flows upward around the cold dome, and up through the annulus formed by the finned tube section and the coolant can. The nitrogen coolant outlet ducts are located at an elevation approximately at the lower end of the economizer.

Oxide-laden sodium enters the cold trap on the shell side of the economizer, flows downward over the vertical economizer tubes, and into the annulus formed by the finned tube section wall and the mesh container. As the impure sodium flows downward, it is cooled to, or below, its saturation temperature. Sodium flow direction then reverses up into the stainless steel knitted wire mesh inside the mesh container, and flow velocity decreases by approximately 20% while sodium oxide precipitates from the solution and plates onto the mesh. The oxide-depleted sodium continues upward through the mesh, increasing in temperature by regenerative heating of the incoming warm sodium flow. Sodium flow continues upward through the tube side of the economizer and increases in temperature to within 100°F of inlet sodium temperature as it leaves the cold trap. Table 1 contains the SEFOR cold-trap design and operating conditions.

Table 1
SEFOR COLD-TRAP DATA SHEET

General

Type	Forced circulation, nitrogen cooled
Number	Two
Capacity, lb Na ₂ O	200, minimum
Sodium residence time	5 minutes, minimum

Normal Operating Conditions

Sodium flow rate, gpm	10 at 700°F
Cold-trap temperatures, °F	
Minimum	250
Maximum	600
Economizer temperatures, °F	
Shell side inlet	820
Tube side outlet	700, minimum

Design Conditions

Sodium flow rate, gpm	10 at 700°F
Temperature, °F	
Cold Trap	900
Economizer	900
Gas Coolant	Nitrogen
Inlet	90
Outlet	150, maximum
Pressure	
Max/min, psig	100/vacuum
Clean ΔP, psi maximum	3
Nozzles and piping	
Schedule	40
Diameter, inch	2

2. OPERATING HISTORY

The cold traps were installed in the SEFOR plant in mid-1968 and were initially filled with sodium at the time of the initial fill of the Primary Service System (PSS) on November 14, 1968. The traps were operated about one hour, at that time, for general checkout of the PSS and cold-trap operability.

The cold traps were operated by the following procedure:

- a. Determine plugging temperature of system to be cold-trapped.
- b. Set cold-trap temperature controller setpoint to 25°F below plugging temperature.
- c. Secure cold-trap preheat.
- d. Start primary service system pump and slowly raise flow to 10 gpm.

The No. 1 cold trap was the first cold trap used to purify the primary system. After 30 hours of operation, the bypass valve in the PSS was opened while No. 1 cold trap was in service. This opening caused a temperature drop in the cold trap to 210°F for about 1 hour. The cold trap was then brought back on the line, without heating up the cold trap, and flow returned to 10 gpm. The No. 1 cold trap was in operation 10 more hours when flow decreases first occurred. The first flow decreases were very small: initially a drop from 9 gpm to 7.5 gpm in 10 hours, and then from 9 gpm to 6 gpm in 10 hours. The cold trap was secured at 6 gpm flow rate after a total of 65 hours operation. The next time the No. 1 cold trap was placed in operation, its flow decreased from 10 gpm to 8 gpm in 2 hours; it was reset to 10 gpm, and the flow decreased to 8 gpm three more times. Finally, the No. 1 cold-trap flow decreased from 10 gpm to less than 2 gpm and was secured. The No. 1 cold trap had 80 hours operation and had passed approximately 800 gallons of sodium.

The No. 2 cold trap was put in service after the ostensible plugging of the No. 1 cold trap. It successfully lowered the primary plugging temperature from 300 to 258°F in 30 hours. Two days later, when the No. 2 cold trap was again put in operation, the flow started decreasing. After 40 hours of operation, the flow would decrease from 10 gpm to 8.5 gpm over a 4-hour period. The No. 2 trap was secured after 54 hours of operation. The No. 2 cold trap was not put in service again for 4 months. Flow problems recurred almost immediately when the No. 2 trap was put in service again. After 78 hours of operation, the No. 2 cold trap was found frozen solid at 180°F and zero flow. Flow problems occurred very early in both cold traps. The cold traps could not be considered plugged; however, they had to be watched carefully as flow would drop off quickly.

After the initial plugging of No. 1 cold trap, a series of diagnostic tests were made to determine why flow decreased. The No. 1 cold trap was operated exclusively during this period, January 1969 to mid-April 1969. The operation of No. 1 cold trap was characterized by erratic flow, often decreasing to less than 2 gpm. The flow was very sensitive to initial temperature difference between plugging temperature and cold-trap control temperature. Each time the cold trap was brought on the line with a temperature difference greater than 25°F, the flow decreased rapidly. After a few days soaking time, the cold trap would operate satisfactorily but with slightly erratic flow.

From mid-April until mid-June, the cold traps were operated during fuel loading with the reactor vessel head removed. The No. 2 cold trap was operated continuously from April 18, 1969 to May 28, 1969. After flow decreases during the first day's operation, the flow of No. 2 cold trap was fairly stable during this period. Except for two significant events, both cold traps were effective in keeping sodium impurity down. The first event was detected on May 3, 1971. An oxide scum was noticed, forming on the sodium surface in the reactor vessel. The scum formation was the result of repair activity in the refueling cell, using a tunnel suit. A glove was accidentally pulled off the tunnel suit and oxygen-laden air was exhausted directly into the refueling cell. The sodium level was raised to allow the sodium oxide scum to overflow to the drain tank. The primary system plugging temperature increased from 220 to 300°F as a result of this incident.

The cold trap temperature was adjusted for this increase in plugging temperature, but a large temperature difference of 50°F occurred during the incident of high O₂ content in the cell. Plugging temperatures decreased inordinately slowly after this incident. Diagnostic tests indicated another source of oxygen, and cell pressures were adjusted to minimize intercell leakage. This intercell leakage was later determined to be approximately 125 ft³/h and was confirmed by analyses of the N₂ zone atmosphere, which showed 30 to 40% argon. Flow in No. 2 cold trap varied from 10 to 5 gpm, and when flow had dropped to below 2 gpm on May 28, 1969, No. 1 cold trap was placed in service.

The second significant event occurred on June 1, 1969, when the argon compressor malfunctioned, making argon purification of the refueling cell impossible. Also, during this time, the plugging meter recorder malfunctioned. The reactor vessel head was removed, and the plugging temperature increased rapidly with No. 1 cold trap in service. The highest temperature difference (between cold-trap temperature and plugging temperature) was 50°F, and it was immediately after this maximum temperature difference that No. 1 cold trap plugged completely. The No. 2 cold trap was then placed in service with a specified cold-trap temperature of 260°F. By this point, the plugging temperature had risen to 340°F. the resulting 80°F temperature mismatch was rapidly followed by complete flow blockage in the cold trap. At this point, both cold traps were completely plugged.

On June 26, 1969, assistance was requested from the Breeder Reactor Department (BRD), Sunnyvale, California, and representatives arrived at the site to investigate the cold-trap problem. The cold traps were restored to service by placing the cold trap in service on the primary drain tank. The body of the cold trap was raised to 500°F and flow was started. Temperature of the cold trap was increased to 505°F, and flow was increased to maximum (generally ≥ 20 gpm). These conditions were maintained for 18 hours, and then the cold-trap temperature was decreased slowly at 5°/h. The plugging temperature decreased as the cold-trap temperature decreased. In this manner, the flow was restored to both traps, but was very sensitive to the temperature difference between plugging temperature and cold-trap temperature. At this time, the operating procedure was changed to increase flow to 20 gpm and to bring minimum cold-trap temperature to plugging temperature before initiating the cold-trap flow. The operating philosophy was to hold the temperature at plugging temperature for an hour before decreasing cold-trap temperature in 5°/h increments. Also, the non-operating cold trap was to have a temperature gradient imposed to promote oxide diffusion toward the lower main body of the trap.

From July until November 1968, the cold traps were operated as described above. This period was characterized by many short runs of the cold trap and erratic flows. The plugging temperatures were maintained below 300°F until October 22, 1969. The reactor vessel head was removed twice during that period, but no significant sodium impurity problems resulted. The philosophy of operation was successful after implementation of one additional point: not to change cold-trap temperature in 5°/h decrements until a new plugging temperature had been obtained which was lower than the initial plugging temperature. The cold trap is believed to be effective in removing impurities even when cold-trap temperature is greater than plugging temperature. The cold traps required constant attention during this final period as flow tended to drop rapidly. By adjusting pump voltage, the flow could be restored, and sometimes the flow could be made to jump up. This was assumed to be indicative of a breakthrough of the oxide plug.

It was decided to replace the cold traps prior to power operation, and the cold traps were used carefully through the final month of operation. The cold traps were prepared for replacement by draining the service system to remove as much sodium as possible in the process. On November 6, 1969, the No. 2 cold trap was cut out of the system, and the inlet and outlet nozzles were capped. On December 12, 1969, the No. 1 cold trap was removed and capped.

The total number of hours of operation on No. 1 cold trap was 1440 hours, and on No. 2 cold trap was 1500 hours. There were 1,260,000 gallons of sodium flow through No. 1 cold trap, and 1,340,000 gallons of sodium flow through No. 2 cold trap.

3. COLD-TRAP INSPECTION

After the primary cold traps had been removed from the primary system, they remained undisturbed in the SEFOR fuel service area until September 1970. Plans were made to inspect cold trap 302-2. A procedure was written to drain the cold trap of the excess sodium. The cold trap was prepared by installing purge connections on the inlet and outlet nozzles and installing a drain line to the bottom cold dome. The drain connection consisted of a 3/4-in. gate valve and a 1/2-in. nipple welded to the cold dome. When a 1/2-in. hole was drilled through the cold dome, some sodium was noted on the drill. The drill residue was not analyzed but appeared to be pure sodium.

A large glove box was made of 4 ft X 8 ft sheets of 1/4-in. plexiglass for the cold-trap disassembly. The glove box concept was utilized to: (a) reduce fire hazard to a minimum, (b) help preserve the purity of samples taken for chemical analyses, and (c) allow photography of the cold trap during disassembly. Four glove ports were placed in one end to allow for cutting the welds, and the opposite end included a sliding trap door to permit "bagging parts in or out of the box without degradation of nitrogen purity." Connections for the nitrogen gas purge supply and vent were also placed in the box. Figure 2 shows the glove box set up for cutting No. 2 cold trap.

A radiography firm was employed to take x-ray pictures of the cold trap to nondestructively determine the source of the blockage and distribution of the oxide. The cold trap was prepared for radiography by the removal of the fins on the finned tube section, giving two projection-free, vertical, 6-in.-wide, smooth areas 180 degrees apart. On October 31, 1970, the radiography firm took 16 films using an Ir-102, 92-curie source. The results were not successful in showing the source of the blockage nor the distribution of the oxide. However, the radiography did show:

Figure 2 Glove Box

- The economizer section was very clean of any deposition. Although the negatives of the economizer were overexposed, the economizer tubes lined up in several places giving the correct exposure and sufficient information to verify a lack of sodium deposits on the baffle plates
- Compared with other radiography films, lack of contrast between mesh and inlet plenum region also indicated a deposit free zone.
- A transition zone appeared about 14-1/2 in. below the top of the mesh section. At this time, the transition was attributed to sodium level. Other radiographs in this area would have been very interesting and perhaps would have shown the true nature of the blockage.
- There appeared to be some horizontal stratification of the mesh in the upper part of the mesh section.

The expense of bringing the radiographer back to the site was not justified, and it was decided to visually inspect the cold trap rather than refine the radiography techniques.

The cold-trap draining procedure was rewritten and approved. Cold trap 302-2 was again made ready for draining. The cold-trap heaters were installed and consisted of

- a. Three each 2.0-kW heaters on the top head,
- b. Six each 2.5-kW heaters on the economizer, and
- c. Six each 3.5-kW heaters on the finned tube section.

Two additional 2.0-kW heaters were installed on the cold dome to ensure thorough heating throughout the cold dome. The heaters were connected to three Volt Pacs which were rated 240/480 volt input, 0-480/560 volt output, 30 amps max output. Sheathed, chromel-alumel thermocouples were installed and connected to a thermocouple readout system. One extra thermocouple was installed on the cold dome to monitor cold dome temperature. The cold trap was then insulated with a layer of sheet aluminum flashing and 2 in. of high-temperature glass insulation. Asbestos cloth was wrapped around the glass insulation to protect the insulation and personnel.

An argon purge was connected to the cold-trap inlet and outlet nozzles. A sodium drum was connected to the drain line and purged with argon. The drain line was then insulated in the same manner as the cold trap. The cold trap was slowly heated up at 60°F/h to 250°F. The final temperature of 250°F was chosen because it was high enough to melt the sodium and to maintain good sodium flow, but low enough to keep the oxides from dissolving into the solution. The goal was to remove all sodium but leave the oxide buildups intact. The cold trap was held at 250°F for 6 hours to ensure a uniform temperature throughout. The sodium flowed freely when the drain valve was opened, and 305 lb of sodium were collected in the barrel.

The cold trap was allowed to cool to ambient, the insulation was removed, and the trap was lowered onto a dolly for cutting. The dolly was specially constructed to fit inside the glove box and to allow rotation of the trap on rollers.

The weld, located 1 in. below the support flange that joins the finned tube section and the economizer section was partially cut away by grinding. The weld was cut 1/4 to 3/8 in. deep. This cut was a preliminary cut to minimize the cutting necessary inside the glove box. Care was taken not to heat the grinding area excessively, and not to cut completely through the weld.

The cold trap was then placed in the glove box, with the economizer extending through one end. Supports were placed on the economizer section so that the finned tube section would be free to break loose onto the dolly after the weld was cut through. Figure 3 shows the cold trap in this position, ready for the final cutting. A Black & Decker, No. 433, heavy-duty, portable, electrical, industrial sander, with a Norton 1/8 in. X 9 in. A24QBDA grinding wheel, was installed in the box. Nitrogen was selected over argon as a purge gas in the glove box to allow use of the electric grinder.

A large, sheet-plastic bag was devised for the trap-door end. This bag was used to remove the finned tube section from the glove box after it was cut free of the economizer section. With the trap door open, the glove box and the bag were then purged with nitrogen. A limit of less than 5% O₂ was selected before the final cutting was to take place. The box was purged to 2-1/2% O₂ content before the grinding was actually done.

The cold trap was easily rotated to facilitate cutting with the grinding wheel. The grinding dust soon made it hard to see through the box, but observation was restored somewhat by cleaning the inside surfaces of the box with a brush. The finned tube section dropped neatly back into the dolly as it separated from the economizer section. The dolly was then drawn back into the bag and the trap door was installed. Figure 4 shows the outer mesh section. The bottom of the mesh section (inlet to the mesh) is toward the left. Note the gradual buildup, starting about 19 in. from the top and building up to approximately 1/2 in. thick at the bottom. Note the "vee" formations of oxides on the upper half of the mesh section. Figure 5 is a closeup of the "vee" formations. Note how the buildup is gradual, starting about 8 in. from the top and building up to approximately 1/2 in. thick at the thickest portion.

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Figure 3. Glove Box

Figure 4. Mesh Container Exterior

Figure 5. "Vee" Formations

Figure 6 shows the bottom of the mesh container and the buildup of oxide on the retaining rods. The buildup was greyish pink and had a plaster appearance.

Figure 6. Mesh Container Bottom

The finned tube section was sealed in the bag outside the glove box. The open end was covered with plastic and the finned tube section removed from the bag. The inside of the finned tube section showed oxide buildup on the sides and bottom. Of particular note is the lack of oxide buildup in the positions corresponding to the heater locations. Also, note in Figure 7 the same gradual oxide buildup from the top of the section to the lower part. Note also the oxide buildup between the heater locations. The "vee" formations shown in Figures 3 and 4 also correspond to the location between the heaters. The lower cold dome area contained a 1/2- to 1-in.-thick crust of oxide on top of pure sodium. This area was probably disturbed during the draining process, which makes it difficult to determine why there was a layer of sodium under the oxide. Core samples taken through the drain line during the preparation phase also showed pure sodium about 1-1/2 in. thick on the bottom, followed by about 11 in. of a mixture of oxide and sodium. The formation in the finned tube section could be explained by "floating" of the loose oxides during the melting of the sodium. As the sodium was drained out, the upper crust, or "scum" lowered itself to the cold dome. The sodium drained into the barrel showed no floating oxide, so the oxide appears to have stayed together in this crust in the cold traps. Note also in Figure 7 that another "vee" formation between the heaters extends inward from the surface about 3/4 to 1 in. The distance between the outside of the mesh section container and the inside of the finned tube section is 2-5/8 in. The oxide extended out from the finned tube section 1 in. and out from the mesh container 1/2 in., which left only about 1 inch of gap. It would have been possible then, if the cold trap had remained in service, to bridge the gap between the two sections and partially plug the downcomer.

Figure 7. Finned Tube Section Interior

The inside of the mesh section was noted for its absence of mesh. The mesh had been compressed more than 20 in. up into the mesh section. Oxides had precipitated on the inside of the mesh section, but no mesh could be seen. Figure 8 shows the mesh section cavity and shows the oxide buildup inside the mesh section.

A sample can was made out of a 20-in., Schedule 40 pipe section 40 in. long. The pipe was blanked off on one end and had numerous 1-1/2-in. sample ports. The can was originally set up to allow "coring" of the mesh, but after the mesh section was observed, the can was used only to keep an argon purge over the mesh section.

The sample can was placed on the dolly and placed into the large bag. The large bag was then purged to less than 5% O₂; the trap door was opened and the sample can placed into the glove box. The mesh section was put inside the sample can where it could drop after it was cut free of the economizer tube sheet. The cut was made just below the economizer tube sheet on the mesh container shell, with the grinding done in the same manner as the first cut. The mesh stuck to the economizer tube sheet, but was easily pried loose with a large screwdriver. Figure 9 shows the tube sheet and its light coat of sodium. The mesh had no oxide globules and was a light pink in color. The mesh had not been distorted into the tubes, and the tubes were very clean. The mesh section was bagged out of the glove box, and a purge was placed on the mesh section.

A bag with two long screwdrivers was then placed over the open end of the sample can and the bag was purged of oxygen. The top mesh "wafer" was then pried out and placed in the bag. This wafer is shown in Figures 10 and 11. Both sides were completely free of oxides and had only a light coat of sodium. The wafer was very easily removed. It was compressed about 1 in. at the center and 2 in. around the outside from the original 6-in. uniform thickness.

The second wafer, after removal, had very little oxide, mainly a few small globules on the bottom side, and was compressed about the same amount as the first wafer. The second wafer was removed using the same screwdriver-pry technique as used to remove the first wafer (see Figures 12 and 13).

The third wafer presented much more resistance to removal due to an oxide buildup on one side. The oxide buildup can be seen in Figures 14 and 15 as a half-moon, covering about one-sixth of the surface area of the wafer. The wafer was also compressed in the same way as the first two.

The top of the fourth wafer was similar to the matching bottom side of the third wafer. The fourth wafer was very difficult to remove, and a special spatula with a flat cutting edge was used to pry it out. The wafer was compressed about 2 in. in the center and about 3-1/2 in. at the outer edge. The bottom of the wafer contained many heavy globules which covered about one-third of the area (see Figures 16 and 17).

The fifth wafer was extremely difficult to remove and it was nearly destroyed during removal. Figure 18 shows the top side of the fifth wafer. Note the very large oxide globules on the one side, and that the oxide in the mesh extends over three-quarters of the area. Figure 19 shows the bottom side of the fifth wafer, clearly showing 100% coating of oxide. A piece of 1/8-in. wire 8 in. long was removed from the side of the fifth wafer.

The sixth wafer was left in the mesh container because removal would have destroyed the oxide configuration.

The mesh sections were weighed. Table 2 gives the weights of the mesh sections. Since the sixth mesh section was left in the mesh container, the weight of the sixth section was obtained by weighing the remaining mesh container and then subtracting the weight of the metal as determined from the drawing.

Figure 8 Mesh Container Interior

Figure 9 Economizer Tube Sheet

Figure 10 First Mesh Wafer, Top View

Figure 11 First Mesh Wafer, Bottom View

Figure 12. Second Mesh Wafer, Top View

Figure 13. Second Mesh Wafer, Bottom View

Figure 14. Third Mesh Wafer, Top View

Figure 15. Third Mesh Wafer, Bottom View

Figure 16. Fourth Mesh Wafer Top View

Figure 17. Fourth Mesh Wafer, Bottom View

Table 2
WEIGHT OF MESH SECTION

Cold Trap No. 2

First wafer	6.8 lb
Second wafer	6.9 lb
Third wafer	7.2 lb
Fourth wafer	8.1 lb
Fifth wafer	10.0 lb
Sixth wafer	<u>38.2 lb</u>
Total	77.2 lb

Cold Trap No. 1

First wafer	6.8 lb
Second wafer	7.1 lb
Third wafer	7.25 lb
Fourth, fifth, and sixth wafers	<u>76.7 lb</u>
Total	97.85 lb

The top five mesh sections were placed in order of removal on top of each other to show the oxide distribution. Figures 20 through 23 were taken in four quadrants to show the oxide distribution better.

Figure 22 shows the oxide wedge on the right and the almost oxide-free portion of the mesh. Figure 23 shows the side opposite the oxide wedge.

Measurements were taken of the oxide buildup in the mesh section. These measurements are shown in Figure 24.

The measurements show less than an inch of mesh at the thinnest section. This measurement was verified by driving a 1-in. stainless steel sample tube through that section and measuring the thickness. Several other "cores" were taken near the outside of container in the thickest area. The cores were taken with a coring tool similar to the one used to core the Fermi cold trap. This coring tool worked very well, and a 4-in. core was taken for analysis. A stainless steel can 4 in. in diameter was stuffed full of the oxides from the inner part of the mesh section. The can contained 284 grams of sample.

After examination of the No. 2 cold trap, it was decided to disassemble the No. 1 cold trap to verify the cause of the premature plugging. The No. 1 cold trap was made ready for draining in the same manner as the No. 2 cold trap. The cold trap was drained, using the earlier established procedure. The drain line plugged on the first attempt, but a heat gun cleared the line and 287 lb of sodium drained into the barrel.

On May 17, 1971, cold trap No. 1 was cut apart inside the glove box. The finned tube section separated cleanly and appeared inside very similar to No. 2 cold trap (see Figure 25). The finned tube section contained 10 lb of sodium and sodium oxide, as determined by weighing before and after cleaning.

Figure 18. Fifth Mesh Wafer, Top View

Figure 19. Fifth Mesh Wafer, Bottom View

Figure 20. Mesh Wafers, Right Side View

Figure 21. Mesh Wafers, Front View

Figure 22. Mesh Wafers, Left Side View

Figure 23. Mesh Wafers, Back View

Figure 24. Mesh Section Measurements for No. 2 Cold Trap

Figure 25. Finned Tube Section Interior

The mesh section was much harder to separate from the economizer section because the center tube was plugged with the mesh. The mesh wafer was made by rolling the 6-in.-wide stainless steel into a large wafer. The center of the wafer had been forced about 4 in. up into the economizer center tube. It came out in one piece, and no tears or cuts could be seen to indicate that any mesh was missing. The outside of the mesh section did not have any "vee" formations as were found on No. 2 cold trap (see Figure 26). The mesh was compressed into No. 1 as it was in No. 2 (shown in Figure 27). See also Figures 28 and 29, showing the inside of the mesh section.

The mesh section was dismantled by removing the wafers. The first (or top) wafer was removed easily. It had been compressed to the point where it had 1/2-in. dimples where the mesh was against the economizer tubes. No cuts indicating loss of mesh were noted. The second and third wafers also were removed easily and showed very little oxide. The fourth wafer showed some 1/4-in.-diameter globules of oxide, mostly around the edges.

The fifth wafer was extremely difficult to remove. In the process of removing the fifth wafer, a small, easily extinguished, sodium fire occurred. The fifth wafer was cut into two pieces, and the mesh section was blanketed with inert gas and allowed to cool to prevent reflash. The half of the fifth wafer cut away was inserted in a large bucket and allowed to cool. The wafer was difficult to remove because the sixth wafer had been pressed into the fifth wafer. The edges of both wafers were cemented to the sides of the mesh section by oxides, and the insides were forced up another 2 to 3 in. The mesh section and mesh wafers were weighed; the results are listed in Table 2.

The cold traps were cleaned by reacting the sodium and oxides, and flushing with water. All pieces were then removed to a storage area.

Chemical analysis of the oxide samples showed a large amount of carbon, probably due to sample contamination between collection analyses. The results of the chemical analysis are shown in Table 3. There was a larger than expected percentage of copper present, probably from trace amounts of copper in the stainless steel materials of the sodium systems.

Table 3
CHEMICAL ANALYSIS OF OXIDE

Sodium oxide sample, removed from inside mesh container
Number 2 cold trap, was tested for metals using an x-ray
emission spectrograph.

Element	ppm
Cu	200
Fe	50
Cr	20
Ud	2
Mg, Mn	4
Ag	≅ 1
Ni	≅ 6
B, Ba, Pb	< 20
Sm, Ti, Mo	< 20
Al	< 20
C ⁻	240 (Reflects carbonate)
C (element)	130

Figure 26. Mesh Container

Figure 27. Mesh Section Measurements for No. 1 Cold Trap

Figure 28. Mesh Section Interior

Figure 29. Mesh Section Interior

4. COLD-TRAP ANALYSIS

4.1 CONJECTURE

This part of the document is called "Conjecture" because we are expressing our ideas as to how and why the cold traps prematurely plugged. We offer these ideas in this section not as absolute facts, but "conjecture"—to invite further questioning and study into the problems of cold-trap design and operation. We would like to point out several factors that affected the cold-trap plugging, and tell how and why they came into effect. There are six areas of interest for speculation:

- The compression of the mesh inside the mesh section
 - The buildup of oxide on the lower third of the outside of the mesh section
 - The "vee" formations on the inside of the finned tube section
 - The downcomer area between the finned tube section and the mesh container
 - The "vee" formations on the outside of Number 2 cold-trap mesh container
 - The nonuniformity of nitrogen cooling flow.
- a. The compression of mesh occurred very early in cold-trap life. Problems with flow stability were also evident then, as stated in Section 2. With the reactor vessel head removed, the high O₂ content of the refueling cell introduced a continual source of O₂ into the sodium. The O₂ was removed in the form of sodium oxide in the cold trap. The early principles of operation of the cold trap required a cold-trap temperature 25 degrees below plugging temperature. The oxide, then, probably precipitated out before it arrived at the mesh. The lower part of the mesh section was then coated with oxide. As the oxide coating built up, so did the differential pressure across the oxide, and the mesh started to move. The early flow problems—flow decreasing after 30 to 40 hours of operations—were initially resolved by increasing pump voltage, which increased pump head and flow rate. It can be seen on the flow recorder charts that the difference in temperature between plugging temperature and cold-trap temperature around 50°F caused very rapid flow decrease. We feel this flow decrease was due to premature precipitation and a "plating" out of oxides on the lower mesh. This plating out thus was the cause of the differential pressure and was the driving force to collapse the mesh. Calculations show that some plugging was necessary to collapse the mesh, and also that at maximum pump output, the mesh will crush with over five tons of force on it.

Force on Unplugged Stainless Steel Mesh at 20-gpm Flow

The pressure drop through the mesh can be estimated from the following empirical equation:*

$$\Delta P = \frac{150 G_o L \mu (1 - \epsilon)^2}{D_p^2 \rho \epsilon^3} + \frac{1.75 L G_o^2 (1 - \epsilon)}{D_p \rho \epsilon^3},$$

*Rohsenow, W. M., and Choi, H. Y., "Heat, Mass and Momentum Transfer," Prentice-Hall, Inc., New Jersey (1961), page 81.

where

$$G_o = \text{mass flow rate/cross-sectional area} = 9,177 \text{ lb}_m/2.4 \text{ ft}^2\text{-h,}$$

$$\epsilon = \text{void fraction} = 0.97,$$

$$L = \text{length of mesh section} = 3 \text{ ft,}$$

$$\mu = \text{viscosity} = 1.5 \text{ lb}_m/\text{h-ft,}$$

$$D_p = \text{diameter of wire} = 0.006 \text{ in.} = 5 \times 10^{-4} \text{ ft, and}$$

$$\rho = 57.5 \text{ lb}_m/\text{ft}^3.$$

The calculated pressure drop through the length of mesh container is 0.10 psi. This agrees well with the calculated value of 0.15 psi for the pressure drop, based on the force per unit volume experienced by the mesh. From these two calculations, it seems obvious that the mesh did not collapse until at least some plugging had taken place.

Force on Plugged Stainless Steel Mesh

In the case where the stainless steel mesh is completely plugged and there is no flow through the cold trap or any of its associated piping, the mesh bears the full force of the static pump head of 46 psi. The total force on the mesh section in this condition is given by

$$F = P A = p \frac{\pi}{4} D^2 = 46 \times \pi \times \frac{(17.625)^2}{4} = 11.23 \times 10^3 \text{ lb}_f.$$

So, at design pump static pressure for full pump voltage, a force somewhat greater than five tons was acting to compress the mesh.

The fact that the mesh was crushed early in life is also supported by

1. The abundance of O_2 in the Na systems early in the operating history
2. The early flow problems
3. The small amount of oxide past the first mesh wafer
4. The presence of large amounts of oxide on the inside of the mesh container.

In explanation of Items 3 and 4: If the crushing had occurred late in life, more oxide buildup would have been present in the upper mesh sections. Also, the inside of the mesh container would have been clean, or the mesh stuck to the inside wall lower down. The small amount of oxide that was in the upper five mesh wafers can be attributed to later breakthrough of the crust.

- b. The buildup of oxide on the outside of the lower third of the mesh section is consistent with the fact that the cold traps were operated 25°F below the plugging temperature. The sodium temperature drop in the downcomer area is about 100°F . The downcomer area can be treated as a counter-flow heat exchanger, with nitrogen as the coolant. In counter-flow heat exchangers, the temperature change is about 75% of the total change, at roughly two-thirds of the length of the exchanger. Thus, at the point two-thirds down the

mesh section, the oxide-laden sodium would be at plugging temperature, and the oxide would start to precipitate out on the metal surfaces. The oxide precipitate becomes more abundant as the temperature is lowered, and as it moves to the bottom of the mesh container. Other factors in the distribution on the lower third are the "eddys" formed by the precipitate particle which gives more sites for precipitation, and the "roughness" of the surface which tends to break up any boundary layers.

- c. The "vee" formations on the inside of the finned tube section were formed in the same way as those discussed in b. above. The main difference is due to the added heat from heaters on the outside of the finned tube section. At the heater locations, there is no oxide precipitation. The tips of the "vees" start at the same elevation as the buildup on the outside of the mesh section, and are located exactly between the heater locations. This would correspond to the cold spot in a temperature distribution combining heat gains from heaters and heat losses due to nitrogen cooling.
- d. The downcomer area—the sodium volume between the finned tube section and the mesh container—is of interest due to the possibility of blockage at the lowest part of the channel. The oxide buildup on the inside of the finned tube section was about 1 in. thick, as described in Item c. This buildup was in the shape of a triangle on No. 2 cold trap, and a rectangle on No. 1 cold trap. The buildup on the mesh section was about 1/2 in. and was uniformly distributed. Models were formulated to investigate the flows in this region and are shown in Figure 30.

It is assumed that the growth on the finned tube section was of a rectangular distribution, as shown in No. 1 cold trap, and was "later in life" than in No. 2 cold trap. This is based upon the amount of oxide contained in No. 1 cold trap being larger than No. 2 cold trap, as shown in Table 2. The growth pattern would then be in a direction outward from the finned tube section wall, with the cooler area between the heaters the most likely spot of deposition. As shown in Figure 30, the area in the downcomer decreased, and the outward growth patterns could have possibly bridged the gap. It is difficult to say when, or if, a condition of the maximum oxide growth in the channel can exist. A plugging meter can block off flow and the rate of plugging will increase as the velocity increases.

- e. The "vee" formations on the outside of No. 2 cold-trap mesh container, as shown in Figures 4 and 5, are also very interesting. There are two points that affect the theory: they occurred only on No. 2 cold trap, and they occurred on the upper half of the mesh section. As stated in Item b., the temperature distribution for the reverse flow heat exchanger can explain the lower deposit. The "vee" formations started about 8 in. from the top of the mesh container and were about 8 in. long. They covered only one-half of the circumference of the mesh container, and corresponded roughly with the heater locations on the finned tube section.

It is also noted that the bottom of the "vee" formation corresponds to the approximate location of the compressed mesh position. Our explanation is that the mesh was compressed early in life to the approximate position of the lower part of the "vee." As the cold trap operation continued, cracks developed between the mesh and the mesh container near the "vee" formation positions. These cracks can be seen in the oxide distribution in the figures showing the mesh wafers. Also, the difficulty in removing the wafers from the mesh section because of the oxide buildup at this point indicates that breakthrough occurred. The breakthrough would destroy the normal reverse flow heat exchanger temperature distribution, and a new distribution would be set up. The oxide on the lower third would tend to insulate the two flows, but the breakthrough of sodium on the inside would cause a lowering of the temperature at the outside. This lowering of the temperature on the outside would be enough to put the sodium below plugging temperature where it would precipitate out.

- f. The last topic to be covered is the nonuniformity of nitrogen flow. As can be seen in Figure 8, there is a nonuniform oxide buildup on the mesh section walls. The large buildups on the left and right sides occur at the same position as would correspond to the nitrogen inlet position and outlet position. The nitrogen enters the bottom and takes the path of least resistance, under the dome and up the opposite side, where it

Figure 30. Downcomer Area Analysis

leaves the cooling can. This nonuniform distribution can also be seen on the inside of the finned tube section. This nonuniformity is mentioned because the cold trap had "cooler" spots in it, and the location of the "control" thermocouple corresponded to a "warm" spot. This means that the 25 degrees below-plugging temperature control could have resulted in a larger temperature drop below plugging temperature than measured.

4.2 CONCLUSIONS

- a. The SEFOR operating procedure for the cold traps evolved from 10-gpm flow at 25°F temperature difference between plugging temperature and cold-trap control temperature to 20-gpm flow at no initial temperature difference. This change in operating procedure has reduced flow anomalies in the cold trap and reduced the large temperature differences that were seen in the original cold traps. The plugging temperature should never exceed the cold trap temperature, and this should eliminate precipitation in the downcomer area. The experience gained on these cold traps has produced a workable and successful operating procedure for the replacement cold traps, as they have shown no flow problems to date.
- b. The procedures used for the SEFOR cold-trap inspection were successful in that they
 - Allowed visual observation of the oxide formation, since the formation remained virtually intact after draining.
 - Eliminated the requirement for many samples to determine the oxide content and distribution.
 - Made repair of disassembled cold traps feasible by cutting only into the previous weld areas.
 - Allowed for greater safety while handling sodium and sodium oxide by providing an inert atmosphere during all disassembly phases.
- c. The compression of the mesh wafers can be attributed to the formation of a layer of oxide on the lower mesh wafer. This oxide layer then caused a differential pressure and the resultant movement upward into the mesh section. The cause of the oxide layer can be attributed partially to the way the cold trap was operated. The cold trap was run at a sodium temperature, as detected by the thermocouple at the inlet to the mesh section, of 25 degrees below the plugging temperature. Due to the uncertainties of measuring this plugging temperature and the length of time between plugging runs, this limit was often exceeded, causing the oxides to precipitate out before reaching the lower mesh section. The absence of sodium oxide in the upper five mesh section supports the theory of premature precipitation, as does the occurrence of flow problems when the temperature difference exceeded 25°F.
- d. The results of the radiography were re-evaluated after the physical inspection of the cold traps. The films show the layering and compression of the mesh, and also show the area of dense sodium oxide on the lower layer of mesh. Radiography could be utilized to inspect cold traps as installed in the system.
- e. The cold traps inspected were not radioactive. The procedures used would lend themselves readily to disassembly radioactive cold traps after a sufficient time for decay. The main problem would be the area of levels giving personnel a whole body exposure. The contamination would be contained within the glove box.

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