MASTER

**REMOVAL OF SODIUM FROM CORE SUBASSEMBLIES
WITH
WHITE OIL AND ULTRASONICS**

Z. R. Kanaan and C. R. Nash

March 1961

**ATOMIC POWER
DEVELOPMENT ASSOCIATES, INC.**

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SUMMARY

This report describes a method for removing sodium from fuel and blanket subassemblies that have been irradiated in the reactor of the Enrico Fermi Atomic Power Plant.

In the cleaning method described, the subassemblies are flushed with white oil aided by ultrasonic agitation. The sodium is carried away from the surfaces of the subassemblies by the oil.

Data gathered from experimental studies of the white-oil cleaning method are described; conceptual flow diagrams, materials balance sheets and equipment arrangements applicable to the Fermi plant are discussed; and sodium cleaning methods currently in use at various reactor installations and sodium manufacturers in the United States are summarized.

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I. INTRODUCTION

The Enrico Fermi Atomic Power Plant is powered by a 300-Mw_t, sodium-cooled fast breeder reactor. The core of the reactor is made up of 639 fuel and blanket subassemblies (Figure 1). These subassemblies consist of an outside wrapper or can, which is in the form of a stainless-steel tube, 2.646 inches square and 73-6/16 inches long. A support structure, 20-3/16 inches long by about 2 inches in diameter, is attached to the lower end of the wrapper, and a handling head is attached to the upper end. The fuel and blanket elements are contained within the wrapper. The pins that make up these elements are held in a tightly packed array by a "honeycomb birdcage" support structure. The sodium coolant flows upward through the subassemblies, and all 639 subassemblies are immersed in sodium during their residence in the reactor.

After the fuel and blanket subassemblies have attained the desired burn-up, they are removed from the reactor. The facilities for sodium removal and handling are designed to accommodate both fuel and blanket subassemblies. Since the fuel subassemblies have higher decay heat generation rates, contain a much greater quantity of fissionable material, and require greater shielding thickness than the blanket subassemblies, the design is dictated by the fuel subassembly characteristics. Thus references in this report to "subassemblies" will mean fuel subassemblies unless otherwise stated.

The design of the reactor was well along at the time work was started on the fuel cleaning and decay storage facility. The following conditions had already been established and were basic to the design of the fuel cleaning system:

1. The subassemblies would be transported in a gas-cooled, self-propelled, shielded cask car.
2. The subassemblies would be carried in the cask car in sodium-filled finned pots (Figure 2). The pots provide the extended surface required to permit transfer of decay heat from the spent subassembly to the argon gas coolant in the cask car. The cask car gripper mechanism is designed to latch only to the finned pots.
3. A cooling period of about six months would be required to permit the decay of active fission products in the spent fuel.
4. An underwater decay storage area would provide cooling and shielding and would simplify the preparation of the spent fuel for shipment to off-site reprocessing facilities.

Because sodium and water are violently incompatible, underwater storage of fuel subassemblies from a sodium-cooled reactor requires the removal of all but microscopic traces of sodium from the subassemblies. Since many users of sodium have expended a great deal of effort in developing methods of removing sodium from equipment without damaging the equipment, several of these methods were investigated. They are discussed in Section II of this report.

FIG. 1 MODELS OF CORE AND RADIAL BLANKET SUBASSEMBLIES

FIG. 2 FINNED POT

When sodium is used as the coolant in nuclear reactors, the problem of sodium removal is further complicated by the necessity to provide adequate shielding against the gamma activity of Na-22 and Na-24 and against the radioactivity of the component proper. When a spent core subassembly such as Fermi Core A is cleaned, adequate provisions must be made for removing the decay heat from the spent fuel. The techniques employed in sodium removal depend in part on the size, configuration, and complexity of the contaminated hardware. The magnitude of the decay heat removal problem depends upon the burnup permitted in, and the power level of, the reactor that uses the fuel, and upon the configuration and complexity of the unit from which the heat must be dissipated.

The hottest Fermi core subassembly emits 8 kw of heat at 6 a/o burnup after two weeks of decay (design basis for the Fuel and Repair Building). Positive cooling of the Fermi subassembly is mandatory at all times during the transfer. Should the positive cooling system fail, the subassembly will melt down in a few minutes if held in an ambient inert atmosphere. If a meltdown should occur, the cleaning chamber and related equipment would then have to be placed in special casks and shipped off-site for burial. Such a breakdown would be very costly.

The problems encountered in the removal of sodium from core subassemblies can be summarized as follows:

1. The explosive reaction of sodium and water.
2. The difficulty of cooling the subassemblies.
3. The necessity for shielding and remote handling of the subassemblies and radioactive sodium.

The problem of heat transfer and the search for a reliable heat sink for the subassemblies led to the development of the white-oil cleaning concept. Transferring subassemblies under oil is considered to be a good solution since the oil is inert to sodium. The oil is a good fluid for flushing sodium from the subassemblies, provides the required heat sink, and is an ideal fluid in which to operate the complex transfer machinery.

In the study discussed in this report, there was insufficient time to resolve one consequence of oil cleaning, the possibility that oil would find a way back to the reactor. The work done indicates that no traces of oil were left on test specimens after hot water-detergent washing with ultrasonic agitation. There is no feasibility question here, but tests should be run on prototype equipment to stimulate confidence in the method. Studies described later indicate that further refinement of the present concepts will assuredly lead to a suitable system for transferring spent fuel from a sodium-cooled reactor, utilizing white oil and ultrasonic agitation as the in-process cleaning method.

II. STATEMENT OF THE PROBLEM AND ALTERNATIVE METHODS

A. HANDLING OF IRRADIATED SUBASSEMBLIES

The major steps in removal of an irradiated subassembly from its operating position in the reactor vessel are

1. Removal into the reactor transfer rotor.
2. Removal from the transfer rotor into the cask car.
3. Transfer from the cask car into the fuel transfer tank in the Fuel and Repair Building.
4. Removal of sodium in the cleaning chamber.
5. Transfer of subassembly to the water decay pools.

B. PROBLEMS ASSOCIATED WITH HANDLING SUBASSEMBLIES

To design the required equipment for accomplishing the foregoing operations, the method of performing the steps had to be determined. The following basic properties and considerations were taken into account in arriving at an adequate design basis.

1. Radioactivity and Decay Heat Generation

After removal from the reactor, the subassemblies are highly radioactive, and decay of fission products in these elements results in release of considerable heat. Hence, shielding of the components and reliable heat removal schemes had to be devised to provide an adequate design during all the transfer steps.

Because of the high radioactivity of the components, the removal and transfer operations would be carried out remotely. This requirement dictates that the equipment be designed for the most reliable operation with provisions for remote replacement or repair.

2. Presence of Radioactive Sodium on the Components

The presence of radioactive sodium on the subassemblies presented the following problems:

- a. A method for safely removing or reacting all of the sodium from the subassemblies before exposing them to water had to be conceived. This was necessary to (1) prevent damage to the elements, (2) prevent a violent sodium-water reaction, and (3) provide adequate containment and removal of radioactive sodium and possibly other fission products during the process. The sodium adhering to the subassemblies contains the two radioactive isotopes, Na-24 (half-life 15 hours) and Na-22 (half-life 2.6 years).

- b. Adequate facilities for the handling and disposal of liquid and gaseous waste materials had to be provided.

3. Avoiding Contamination of Reactor Coolant

It was necessary to provide adequate storage capacity for spent and new subassemblies to assure a smoothly integrated handling system for performing the necessary fuel replacement operations at the required rates and as simply as possible. Adequate precautions had to be provided to prevent the buildup of sodium oxide, oil, dirt, etc., which might be returned to the reactor on new subassemblies.

4. Criticality Considerations

Adequate precautions had to be taken to assure that the accumulation of a critical mass could not occur under any conceivable conditions.

C. STUDIES OF METHODS OF REMOVING SODIUM

1. Methods Investigated or Developed by APDA

Six preliminary process concepts for removing the sodium adhering to the subassemblies were investigated. These concepts were

- a. Reaction with Steam - Experimentation proved the feasibility of the concept.⁽¹⁾ This method was chosen for Fermi reactor use.
- b. Fused Salt - Mercury - Concept was technically infeasible and thus was omitted from further consideration.
- c. Dow Melting Alloy - Experiments showed that the concept was technically infeasible; thus the concept was not studied further.⁽²⁾
- d. Mercury - Lead - No experiments were performed. Concept was dropped because of the toxicity of mercury and lead.
- e. Mineral Oil - Experiments on small-scale models were successful.⁽¹⁾ Other details are incorporated in Section III.
- f. Vacuum Distillation - Experiments were successful.⁽¹⁹⁾ This type of sodium removal is applicable to components that do not require cooling.

2. Methods Investigated at Other Sites

a. General Processes Investigated

The processes investigated at other sites can be classified as follows:

(1) Reaction with Water

This reaction is given by the equation

The heat and free energies of reaction are

$$\Delta H^{\circ}_{298} = -33.67 \text{ K cal} \text{ and } \Delta F^{\circ}_{298} = -35.34 \text{ K cal},$$

respectively. (20)

If the contact interfaces of sodium and water are large, the reaction becomes violent. In an effort to control the rate of reaction, the water can be finely dispersed or its rate of introduction can be reduced and controlled.

(2) Reaction with Steam

The reaction progresses in accordance with Equation 1. The heat and free energies of the reaction are -45.7 and -37.4 K cal, respectively. (20) The reaction thus progresses much more slowly if steam is used instead of water. Water condensation should be prevented until nearly all the sodium has been reacted.

(3) Reaction with CO₂, CO and N₂

The reaction with certain combustion gases which consists of a mixture of CO₂, CO and N₂ results in sodium being converted to sodium carbonate and sodium nitride. The solid Na₂CO₃ must be removed after the reaction. An adaptation of this method is the "humid gas technique" (4) in which moist gas composed of approximately 15% CO₂ and 85% N₂ is used as a reacting agent. A difficulty with this technique is that the initial reaction between sodium and superheated steam can form a protective film of NaOH on the sodium which, if broken later, may permit a sodium-water reaction.

(4) Reaction with Alcohol

The reaction of sodium with alcohols is similar to, but less rapid than, the reaction of sodium with water. The reactivity of sodium with alcohol decreases in order from primary to tertiary, and the greater the number of carbon atoms the less rapid the reaction. The general reaction which takes place is

The reaction between metallic sodium and many alcohols of higher molecular weight are quite slow at room temperature. The large heat of reaction, removal of gelatinous reaction products, and the fire hazards involved tend to restrict the use of this method. The alcohol reaction products are soluble in water.

(5) Flushing with Mineral Oil

Mineral oil is inert to sodium. The oil is heated to above the melting point of sodium (208 F), and is used to flush residual

sodium from components. Increased sodium removal rates can be obtained by use of ultrasonics agitation. Removal of the residual oil film, subsequent to oil flushing, can be performed by steam.

(6) Reaction with Mixed Organics

Mixtures of acetone in benzene and tetraline in benzene have been reacted with sodium.⁽⁴⁾ The acetone and tetraline are the active agents while the benzene is an inert carrier. The organic end products which are formed are soluble in water.

(7) Reaction with Moist N₂

Sodium is partially removed mechanically by nitrogen circulated at high velocities. Then steam is gradually introduced into the circulating nitrogen to react with the residual sodium under controlled conditions.⁽⁴⁾

(8) Reaction with Ammonia

The liquid ammonia extraction method has been used with good results. The system has to be closed and the ammonia kept under pressure; or a low-temperature system must be used. NH₄Cl is added to dissolve any oxides that are present.⁽⁴⁾

b. Methods Used at Other Sites for Removing Sodium from Fuel Elements

(1) EBR-II

The proposed method for use at the EBR-II facilities is briefly described as follows:⁽³⁾

Subassemblies are removed from the sodium pool into a cask car. In the cask car the elements are cooled by argon gas, which is blown down through the subassemblies. The gas flow is expected to remove most of the sodium by drainage and evaporation. The cask car transports the subassemblies from the reactor containment building to a reprocessing building. When in the processing building, the fuel subassemblies are flooded by water so that any remaining sodium may be reacted before the subassemblies are dried and disassembled.

(2) SRE

Irradiated fuel elements are inserted in 3-inch-diameter by 24-foot-long vessels that extend below the operating floor in the reactor building.⁽⁴⁾ The sodium is removed in these vessels. Provisions are made for inert gas blanketing, pulling a vacuum, and introducing water. The steps used in sodium removal from SRE subassemblies are:

- (a) Subassemblies placed in cleaning vessel.
- (b) Vacuum pulled on cleaning vessel.
- (c) Vessel filled with helium.
- (d) Vent opened.
- (e) Vessel filled slowly with water, drained and step repeated.
- (f) Vacuum pulled on vessel to dry the chamber and subassembly.

Problems with fuel element ruptures and problems in obtaining rapid-response pressure-measuring instruments capable of measuring the pressure transients were encountered at SRE.

(3) SLG

The SLG is a land-based prototype of the Sea Wolf submarine. After the subassemblies are removed from the reactor, time is allowed to permit the molten sodium to drain by gravity. A cask car transfers the fuel elements through an air lock into the Fuel Element Services Building. Here the fuel elements are placed in the rod-cleaning and leak-check station. Inert gas and steam are blown through the elements for five minutes. The elements are then flushed with a mixture of helium and water and water-soaked. Each of these steps continues for a period of five minutes. Drying of the elements by their decay heat in a helium atmosphere completes the process.⁽²¹⁾

c. Sodium Removal from Other Components

(1) EBR-II Prototype Pumps

Argonne National Laboratory has removed residual sodium from these pumps by reaction with superheated steam and/or saturated steam, and finally by water soaking.⁽⁴⁾ The reaction with superheated steam was continued until the reaction velocity subsided. Saturated steam exposure was continued until no evidence of reaction was visible. Unexpectedly, sodium was found in out-of-the way places such as areas below bolt holes. When reaction with steam could not be performed because of the possibility of damage from pressure resulting from insufficient venting of reaction gases, the components of the pumps were disassembled.

Personnel at ANL used long extension pipes (lances) to enable them to steam the components from a safe distance. The process was performed in a cleaning hood.

Generally, if one must choose either a steam- or oil-cleaning method, steam may be used if sufficient pressure relief openings are available or if no large pockets of sodium are present. Otherwise, an oil-cleaning method should be used.⁽⁴⁾

(2) SRE Pumps

In the early stages of the SRE project, Atomics International (AI) personnel inserted a pump to be cleaned in a steel tank and bolted the pump flange to the tank so that clearance was available between the pump casing and the tank.⁽⁴⁾ A steam line was connected to a manifold between the tank wall and the pump housing, and steam was used to react the sodium on the pump. When the pumps were cleaned by this method, violent reactions occurred, possibly because of condensation of water in the lines.

(3) Heat Exchanger

AI has used the steam cleaning method on heat exchangers.⁽⁴⁾ The heat exchanger is heated to prevent condensation of the steam during cleaning.

(4) Cold Traps

ANL has removed sodium from cold traps from the SIR system by the following procedure:

- (a) Sodium is drained from trap.
- (b) Hot (225 F) mineral oil is pumped through trap with a low-flow high-head gear pump at 50 gpm, 50 psig.
- (c) A mixed organic wash is circulated through the trap. Mixtures of acetone in benzene and tetraline in benzene were the most satisfactory.
- (d) Water is pumped through trap to remove residual organic wash.
- (e) Trap is steamed and then dried.

In developing this method, ANL found that cleaning by an alcohol-sodium reaction was unsatisfactory because of the violence of the reaction. The temperatures required for the use of acetates are too high. They also found that when rapid reaction rates are desired, reactions produced through the use of the methyl, ethyl, and higher ketones were too slow.

(5) Small Components

ANL personnel clean bellows-sealed valves by first draining as much residual sodium as possible and then washing the component in ethyl alcohol or an acetone-alcohol mixture. If the sodium is oxidized, the sodium oxide can be removed by steaming. AI⁽⁴⁾ has suggested that in cleaning valve bellows the component be flushed with oil, butyl alcohol, and then water.

d. Sodium Removal Methods Used at
Sodium Manufacturing Plants

(1) U.S. Industrial Chemical Company

USI removes the bulk of the exposed sodium mechanically prior to cleaning.

Large, rugged pieces of machinery are sprayed with, or soaked in, hot water.⁽⁶⁾ USI claims that the sodium-water reaction is less violent when water is at about 212 F than in cold water.

USI personnel also use steam lances for cleaning their sodium containers 5 feet in diameter and 8 feet in length, with about 200 lbs. of residual sodium.⁽⁶⁾

USI has had good results when using methyl cello-solve alcohol (120 F flash point) to react with small amounts of sodium.⁽⁶⁾

USI tested the reaction of sodium with 60 to 75% NaOH at 180 F and found that the reaction proceeds quite rapidly but is controllable provided that no localized dilute (less than 60%) NaOH exists.⁽⁷⁾

(2) Ethyl Corporation

Ethyl Corporation removes sodium from some components by steam cleaning.⁽⁸⁾

Also Ethyl Corporation has achieved satisfactory and safe results when removing sodium with 80% butanol alcohol + 20% water.

(3) E. I. duPont deNemours & Company, Inc.

duPont uses the steam cleaning method.

III. REMOVAL OF SODIUM WITH WHITE OIL

A. GENERAL

In considering the problem of removing sodium from subassemblies, APDA developed two subassembly transfer-cleaning concepts, one of which was chosen for this study. The other was not developed further because it required extensive design work for which time was not available.

Liquid white oil in an argon atmosphere is used in both concepts to flush sodium particles from the surfaces of the subassemblies. The oil, which does not react chemically with the sodium, is maintained at a temperature higher than the melting point of sodium (208 F). The viscosity of the oil is 7.0 centipoise at this temperature.

B. SUBASSEMBLY TRANSFER-CLEANING PROCEDURES

Of the two concepts described below, the first was selected for this study.

1. Concept Number 1 - Oil Pool Receiving Station

The steps that a subassembly passes through from reactor to water pool are as follows:

- a. Spent subassembly is placed in the finned pot in the reactor vessel transfer rotor. Subassembly is left to decay in the transfer rotor for about two weeks.
- b. Spent subassembly and pot are transferred to cask car.
- c. Cask car transfers spent subassembly (still in finned pot) to an oil pool (Figure 3) that has argon as its cover gas. The oil pool, which functions as a receiving station and a heat sink, is designed to handle 35 subassemblies every two weeks.
- d. The finned pot and subassembly are lowered from the cask car by a gripper and hoist. To prevent contamination of the gripper with oil, the finned pot receiver is at an elevation which keeps the gripper and latching flange above the oil level at all times.

In order to maintain a clean argon cover gas in the cask car, the inert gas flows from the cask car down to the pool and not vice versa.

- e. The finned pot and subassembly are then completely submerged under oil in an argon atmosphere.
- f. The heat from the subassembly is given off to the oil. The oil pool temperature is maintained at 220 to 250 F.

FIG. 3 OIL TRANSFER SCHEME

- g. The subassembly is separated from the finned pot (still under oil) and placed in the cleaning chamber which is full of oil.
- h. The finned pot is emptied of its molten sodium content and then transferred to the pot cleaning chamber.
- i. The subassembly in the cleaning chamber is first purged with 250 F (approx.) oil (Figure 4). The oil carries most of the sodium off the subassembly⁽¹⁾ and is discharged to the oil pool. After the oil purging phase is complete, the cleaning chamber is isolated from the oil pool and the oil flow is positively stopped in the cleaning chamber.

Demineralized water is then admitted from the bottom of the chamber to displace the oil. Both the oil and water overflow into a waste effluent tank. This step is followed by a controlled flushing of the subassembly with demineralized water. The final cleaning phase is to wash the subassembly with non-ionic detergent followed by a demineralized water rinse. Ultrasonic agitation may be required to help remove all oil traces.

- j. The subassembly is then transferred to the water decay pool.
- k. The cleaning chamber is completely dried, filled with oil and thus made ready for cleaning of the next subassembly.
- l. The finned pot in the pot cleaning chamber is purged by hot oil. This oil is discharged to the oil pool. Then the cleaning chamber is drained of all oil (back to the oil pool). Demineralized water and detergent flushing follows. Ultrasonic agitation may be required to help remove all oil traces before the pot is returned to the reactor. Oil traces have been completely removed from a finned pot test specimen⁽⁹⁾ during ultrasonic cleaning tests described later under Item E-2.

After the oil traces have been removed, the finned pot is dried and is then ready for reloading.

2. Concept Number 2 - Oil Pool Receiving Station with Intermediate Sodium Column

This concept is similar to the aforementioned concept except that the finned pot does not touch the oil during subassembly-finned pot separation (Figure 5). An intermediate sodium column with oil floating on top of it provides for such a transfer. Since the finned pot is still full of sodium it requires no cleaning and could take new subassemblies to the reactor. This concept was abandoned because of difficulties involved in achieving a workable transfer scheme in the time available for this study.

NOTES—

1. PROCESS PIPING SIZE RANGE: 1" DIA.-2" DIA.
2. PUMP HP. RANGE: $\frac{1}{2}$ HP.-2 HP.
3. R. L. I.: RADIOACTIVITY LEVEL INDICATOR.

FIG. 4 SODIUM REMOVAL BY WHITE OIL-CONCEPTUAL
PROCESS FLOW SHEET

C. WASTE DISPOSAL AREA (FIGURE 4)

The waste system is divided into the following three phases:

1. Sodium Removal and Purification of Oil Pool

- a. A centrifuge is used to separate the sodium and oil. The centrifuged oil is then passed through a sand filter in order to remove any possible polymers and then is returned to the oil pool. It is estimated that a bank of four stand-by centrifuges would last the lifetime of the reactor without the need for radioactive equipment maintenance.
- b. The centrifuged sodium sludge (97% sodium, 3% oil; particle size 10 to 100 microns)⁽¹⁰⁾ is discharged to a sodium reacting tank. The sodium is reacted slowly with 55 to 60% NaOH present in the tank. The by-product of 60 to 70% NaOH effluent is shipped off-site for disposal. About 3400 gallons of total waste would be shipped each year. (Refer to Section IV-A, Paragraph 5(d).
- c. The sodium sludge coming from the centrifuge might possibly be separated from the oil and purified to reactor-grade sodium instead of being reacted with NaOH. Experimentation is required to verify this possibility.

2. Waste Effluent from Subassembly and Finned Pot Cleaning Chambers

- a. The cleaning chambers discharge their waste effluent into a NaOH holdup tank. The effluent is left in the holdup tank for two weeks to allow the Na-24 to decay.
- b. The effluent is then pumped through an ion-exchanger which removes the sodium-ions and thus decontaminates the water.⁽¹¹⁾ The deionized water is discharged to the lake after being monitored for radiation. The exhausted resin is shipped off-site for disposal.

3. Waste Gases

Waste gases are pumped through absolute filters to the central waste system of the plant for decay and or disposal.

D. EXPERIMENTS

1. Sodium Removal by Ultrasonics and Hydrocarbon Flushing (APDA Test Memo No. 3, not attached)

a. Purpose

The purpose of this experiment was to determine the following:

- (1) Compatibility of sodium and oil.
- (2) Effectiveness of oil flushing in removing sodium from metal surfaces.
- (3) Effectiveness of ultrasonic agitation in removing sodium from metal surfaces.

b. Procedure

- (1) Two types of test specimens were tested (Figures 6 and 7), one simulating the core part of the subassembly and the other simulating the nozzle part of the subassembly (Figure 1). The experiments were conducted at the APDA Sibley Quarry Laboratory in a test rig as shown in Figures 8 and 9.
- (2) Test specimens were heated in sodium at 750 F until metal surfaces were wetted with sodium.
- (3) Test specimens were purged for about 15 minutes with hot oil in some experiments.
- (4) Test specimens were purged for about 10 minutes with hot oil and then were subjected to ultrasonic agitation in other experiments.
- (5) Test specimens were examined for post-cleaning residual sodium at Detroit Edison Laboratory.⁽¹²⁾

c. Results Compiled from Twenty (20) Test Runs

- (1) No sodium-oil reaction.
- (2) Test specimens after oil flushing were clean enough to put into water with no violent reaction of sodium and water. None of the test specimens were damaged in any of the twenty cleaning tests that were run.
- (3) The oil flushed away most of the sodium from the test specimen. The residual sodium-water reaction was controllable and non-damaging throughout the tests.
- (4) The oil formed a coating on the residual sodium particulates. This oil film helped to inhibit the sodium-water reaction.⁽¹⁾

FIG. 6 SODIUM REMOVAL BY ULTRASONIC AND HYDROCARBON FLUSHING-
TEST SPECIMENS

DUMMY CORE

DUMMY NOZZLE

FIG. 7 TEST SPECIMENS-SODIUM CLEANING TESTS

FIG. 8 TEST EQUIPMENT FOR SODIUM REMOVAL BY ULTRASONIC AND HYDROCARBON FLUSHING

FIG. 9 DIAGRAM OF TEST EQUIPMENT USED IN
SODIUM REMOVAL BY ULTRASONIC AND
HYDROCARBON FLUSHING

- (5) Ultrasonic agitation helped remove more sodium than oil flushing alone. Without ultrasonic agitation, cleaning efficiency was 64%, but with ultrasonic agitation, the cleaning efficiency was 94%.⁽¹⁾

The following data taken from Detroit Edison Engineering Laboratory and Research Department Report No. 58-D-96 (July 18, 1958), shows how the cleaning efficiency figures were derived.

Test Specimen (Dummy Nozzle, Figures 6 and 7)

before cleaning had

1.6823 grams of sodium left on its surfaces.

with oil flushing had

0.6007 grams of sodium left on its surfaces.

with oil flushing and ultrasonics agitation had

0.0686 grams of sodium left on its surfaces.

2. Removal of Oil Film from Dummy Finned Pot

a. Purpose

The purpose of this experiment was to determine the amount of residual oil after ultrasonic cleaning of the dummy finned pot.

b. Procedure

- (1) A sectional model simulating the finned pot was tested at Pioneer Central Division, Bendix Corporation, Davenport, Iowa.⁽⁹⁾
- (2) The model was quenched in Kaydol white oil that had tracer isotopes.
- (3) The model was ultrasonically cleaned and then placed under a scintillation counter and examined for residual radioactive oil.

c. Results

- (1) Amount of oil left on model prior to cleaning - 20.7 gm
- (2) Amount of oil left on model after 2 minutes of ultrasonic cleaning in water detergent - 4.8 gm
- (3) Amount of oil left on model after 6 minutes of ultrasonic cleaning in water detergent - 0.0 gm

3. Oil Reclaiming by Centrifuging of Sodium-Oil Suspension and by Sand Filtering

a. Purpose

The three-fold purpose of this experiment was as follows:

- (1) To return oil (which had been used for cleaning) to its original physical condition.
- (2) To check the centrifuged sodium-oil sludge for the amount of residual oil.
- (3) To determine the decolorizing efficiency of sand filters.

b. Procedure

- (1) A sodium in oil suspension sample was centrifuged (by a Sharples Laboratory centrifuge).
- (2) The centrifuged oil was passed through a sand filter.
- (3) The sodium sludge was analyzed for particulate sizes.

c. Results (Reference: APDA Test Report No. 3)

- (1) The oil sample tested through a sand filter attained its original color and properties.
- (2) The percentages of sodium and oil in the sludge were about 97% sodium and 3% oil.
- (3) The test showed that oil reclaiming could be done on a continuous process basis.
- (4) Sodium particle size distribution was found to be the following: (10)

80%	2.5 microns
5%	40 to 80 microns
5%	100 microns and over
10%	10 microns and less

4. White Oil Radiation Stability

a. Purpose

The purpose of this experiment was to test the Standard Oil detergent Alkymer Bottoms Heavy under radiation and check for polymerization and other property changes incurred by the gamma radiation.

b. Procedure

Decolorized and non-decolorized oil were tested to an accumulated dosage of 1.0×10^9 rads in the Argonne high level gamma irradiation facility.

(Note that Fermi I core subassembly maximum surface dose rate is 6×10^7 roentgens/hr at an operating power of 430 Mw and two weeks decay time).

c. Results

- (1) Both oil samples gave almost identical results.
- (2) Viscosity of oil at 210 F increased from 5.96 centistokes to 9.19 centistokes when subjected to 1.0×10^9 rads.
- (3) Flash point of oil changed from 340 F to 89 F after an irradiation dose of 1.0×10^9 rads.
- (4) There was no observed precipitate, i.e., tar and sludge, whatsoever. (16)(17)
- (5) NPA color for the (non-decolorized) oil dropped from 2-1/2 to 1 because of irradiation.

d. Later Developments

Standard Oil Company (Indiana) has developed a new fluid, the viscosity of which changes a little less than that of detergent Alkylmer Bottoms Heavy on irradiation to 1.0×10^9 rads. This fluid has the unique property that its flash point increases, rather than decreases, on exposure to 10^9 rads.

E. UNRESOLVED PROBLEMS

1. Full-scale tests have not been conducted on subassembly and finned pot. Presumably no trouble would result if one assumes that the results of the small-scale tests would hold true for full-scale tests.
2. If sodium could be reclaimed from the oil pool, then the amount of waste to be shipped off-site would decrease considerably. So far, centrifuging can separate sodium from oil but cannot completely free the oil film from the sodium. An additional step such as decanting and solvent extraction might reclaim all the sodium.
3. More work is required for developing a better transfer scheme than the ones already developed.
4. The possibility of using an oil decay pool should be explored. This concept would eliminate the water phase and leave only the sodium-oil phase. An oil purification and make-up system would be essential to remove heavy oil polymers.

F. CONCLUSION

It is considered that removal of sodium from spent subassemblies can be done safely with white oil. The oil provides a constant under-liquid cooling of the subassembly at all times during transfer and thus safeguards the subassembly against meltdown. Although the oil also provides a transparent shield cover over the subassembly, a submersible telescope would help provide the operator the vision he needs for cleaning, inspecting, disassembling, and transferring the subassemblies.

There is no cause for concern over the oil polymerizing, because of gamma radiation, and possibly plugging the subassembly, provided an adequate oil purification, circulation, and make-up system is incorporated.

This conclusion is based on the following sources of information:

1. Standard Oil experimentation results which showed no tars or precipitates at 1×10^9 rads total irradiation dosage. This dose is equivalent to placing a Fermi I subassembly in an oil pool for about 20 hours with no forced or natural circulation of oil in the subassembly proper. Under these conditions there will be no precipitates to plug the subassembly.

In practice the subassembly will have thermal circulation, and there will be ample time for oil purification.

2. OMRE (Organic Moderated Reactor Experiment) operating experience⁽¹⁸⁾ indicates that a reliable purification system for the oil is possible and that the maintenance of the OMRE recirculating piping system was very simple because of the low activity of the oil.

Direct steam cleaning of the subassembly subjects it to regional high temperatures (approximately 1200 F),⁽¹⁾ and possible stress corrosion,⁽¹³⁾ but the oil cleaning does not have such adverse effects on the cleaned component. Also, most of the equipment and piping material for the oil cleaning concept is constructed of mild steel as compared to the use of 304 stainless steel for the steam cleaning concept.

As previously stated, it is considered that the problem of preventing return of oil to the primary sodium system is one which can be solved at reasonable cost with the application of more design effort than was possible in this investigation.

IV. APPENDIXES

A. WHITE OIL CONCEPT - CALCULATIONS AND SPECIFICATIONS

B. WHITE OIL CONCEPT - COST ESTIMATE

C. LIST OF REFERENCES

TITLE: SODIUM REMOVAL BY OIL -
CONCEPTUAL CALCULATIONS AND SPECIFICATIONS

REFERENCE: Flow Sheet, 6XN-2430

CONTENTS: Item 1 - Calculations and Miscellaneous Specifications
Item 2 - Contaminated Sodium Bi-Weekly Distribution
Item 3 - Materials Balance - Subassembly and Finned
Pot Cleaning Chambers
Item 4 - Materials Balance - Oil Receiving Pool
Item 5 - Total Waste Per Year

REMARKS: 1. These calculations and specifications are based
on processing 35 subassemblies every two weeks.
2. For all pump head calculations, the following is
assumed:

Total equivalent length = 300 ft length

Static head "Z" = 20 ft of liquid

1. CALCULATIONS AND MISCELLANEOUS SPECIFICATIONSa. General Specifications

(Refer to Flow Sheet, 6XN-2430)

$$(1) \text{ Subassembly open area} = 3.19 \text{ sq. in.}$$

$$\text{Flow} = 50 \text{ gpm}$$

$$\text{Subassembly cleaning chamber} = 6 \text{ in. diameter (28.9 sq. in.)}$$

$$\text{Open chamber area} = 28.9 - (2.646)^2 = 21.9 \text{ sq. in.}$$

$$\text{Velocity around subassembly} =$$

$$\frac{50 \times 144}{7.48 \times 60 \times (21.9)} = \frac{16.05}{21.9} = 0.74 \text{ ft/sec}$$

$$\text{Velocity through subassembly} = \frac{16.05}{3.19} = 5.0 \text{ ft/sec}$$

$$(2) \text{ Oil viscosity} = 3.9 \text{ centipoise @ 250 F}^{(14)}$$

$$(3) \text{ Pressure drop through subassembly @ 50 gpm flow:}$$

$$\text{Velocity in core section} = 5 \text{ ft/sec or } 1.8 \times 10^4 \text{ ft/hr}$$

$$NR_e = \frac{1.80 \times 0.01312 \times 0.89 \times 62.4 \times 10^6}{3.9 \times 242} = 1400$$

$$\text{Based on } NR_e = 1400 \text{ then } \frac{\Delta h}{Q^2} = 1420^{(15)}$$

$$\Delta p = \frac{p \Delta h}{144} = p \times 1420 \times Q^2 = \frac{(0.89 \times 62.4) (1420) (5^2 \times 3.9^2)}{144} = 10 \text{ psi}$$

$$= 21 \text{ ft of oil}$$

$$(4) \text{ Temperature rise in oil (due to 50 gpm oil flow through subassembly):}$$

$$Q = 8 \times 3413 = 0.55 \times (50 \times 60 \times 7.43) \times T$$

$$T = \frac{27,300}{12,250} = 2.23 \text{ F/hr}$$

$$(5) \text{ Cooling load for receiving and separation station:}$$

Assume 35 subassemblies in oil station each giving 8 kw of heat;

$$\text{then heat load} = 35 \times 8 \times 3413 = 955,000 \text{ Btu/hr}$$

b. Assumed Operational Head on
Pressure Wash Oil Pump - Pump No. 1

Pump capacity = 50 gpm (of oil)
 Oil temperature = 250 F (operational)
 Pressure drop through subassembly = 21 ft approx (See Item 1(a)-3)
 h_f per 100 ft = (From Cameron Handbook) for 2-in. pipe
 and viscosity of 35 S.S.U.
 h_f = 5.4 ft/100 ft
 h_f = $\frac{300}{100} \times 5.4 = 16.2$ ft

Therefore, total pump head = $21.0 + 16.2 + 20 = 57.2$ ft of oil

Therefore, total pump head (incl. 20 per cent S.F.) = $(37.2 \times 1.2) + 20 =$
 $44.7 + 20 = \underline{64.7}$ ft

Pressure wash pump data = 50 gpm, temp. 350 F maximum
 64.7 ft total head
 2 hp motor

c. Subassembly - Finned Pot Separation
Under Oil - Oil Reclaiming Data

Assume oil pool to be = 30 ft x 10 ft x 20 ft (deep) x 7.48 =

45,000 gallons of oil @ 250 F.

$4\frac{1}{3}$ gallons of sodium per finned pot and subassembly or $4\frac{1}{3} \times 18 =$

78 gallons of sodium per weekly reactor unloading.

Or, 4060 gallons of sodium per year.

Assume oil reclaiming is accomplished by centrifuging.

Based on a 20 gpm centrifuge, e.g., No. 16 "Vaporite - Super-Centrifuge"
 manufactured by Sharples Corp.

Centrifuge data: 1200 G.P.H.

hp = 2 hp

Then, total oil reclaiming time = $\frac{45,000}{1200} = 37\frac{1}{2}$ hours

Available time is about 7 days.

d. Receiving and Separation Station -
Cooling Requirements

Assume 35 core subassemblies in oil pool. Also assume that the tolerable temperature rise of oil = 300 F, i.e., final oil temp = 250 + 300 = 550 F (which is below the boiling point of oil, 600 F)

$$Q = \text{lb of oil} \times C_p \times \Delta T$$

$$X \text{ hr} \times (35 \times 8 \times 3413 \text{ Btu/hr}) = 45,000 \times 7.43 \times 0.55 \times 300$$

$$X \text{ hr} = \frac{45,000 \times 7.43 \times 0.55 \times 300}{35 \times 8 \times 3413} = 58 \text{ hr to raise oil pool temperature by 300 F}$$

Based on (1) hr of time required to clean one subassembly and transfer it to decay pool.

Total time required for 35 subassemblies to move through oil pool = 35 hr.

Thus, no cooling is required for the oil pool since it is assumed that this heat will be dissipated in 2 weeks before the new batch of subassemblies is admitted to the pool.

After cleaning 18 subassemblies in 18 hr, temperature rise in oil pool = 100 F.

e. Reclaimed Oil Pump Data - Pump No. 2

Oil temperature = 350 F max.

Pump capacity = 20 gpm

For 2-in. pipe and 20 gpm flow, $h_f = 1.5 \text{ ft}/100 \text{ ft}$

Assume pressure drop through sand filter = 30 ft

$$\text{Then total pump head} = \left(\frac{300}{100} \times 1.5 \right) + 20 + 30 = 54.5 \text{ ft}$$

Add 20 per cent safety factor, then total pump head =

$$1.2 (4.5 + 30) + 20 = 41.5 + 20 = \underline{61.5 \text{ ft}}$$

Pump No. 2 Data = 20 gpm of oil @ 350 F maximum

61.5 ft total head

1 hp motor

- f. General Note: The 2-in. diameter pipe size on the circulating line is oversized. This is done to avoid any sodium plugging in case pipe heaters are off.

2. CONTAMINATED SODIUM BI-WEEKLY DISTRIBUTION

a. The following assumptions are made:

- 1) 4-1/3 gallons of sodium in one finned pot and one subassembly
(4-1/3 gallons = 31.3 lb sodium)
- 2) 0.5 lb sodium adhering to subassembly.
0.5 lb sodium adhering to finned pot.
- 3) Upon oil flushing, 64 per cent of the adhering sodium is removed from pot and subassembly. This figure was arrived at from small-scale experimentation of the simulated dummy nozzle part of the core.

Thus residual sodium on pot or subassembly =

$$0.36 \times 0.5 = 0.18 \text{ lb sodium}$$

- 4) Subassemblies and finned pots are given a final water detergent wash under ultrasonic agitation which removes the residual sodium and oil.
- 5) Washed and dried finned pots are free of oil before they are returned to the reactor.

b. Sodium Bi-Weekly Distribution

- 1) From subassembly cleaning chamber =

$$0.18 \text{ lb sodium} \times 35 = 6.3 \text{ lb sodium per two weeks.}$$

- 2) From finned pot cleaning chamber =

$$6.3 \text{ lb sodium per two weeks.}$$

- 3) From oil pool =

$$(31.3 \times 35) - (2 \times 6.3) = 1100 - 12.6 = 1087.4 \text{ lb sodium}$$

$$\text{Or, } 151.6 \text{ gallons/2 weeks.}$$

3. MATERIALS BALANCE - SUBASSEMBLY AND FINNED POT CLEANING CHAMBERS

a. General

- 1) Subassembly in finned pot is delivered to the (250 F) oil pool. The subassembly is separated from the finned pot under oil. Most of the sodium is drained into the pool. The subassembly and finned pot are then transferred to their cleaning units. It is then the intent to wash off residual oil and sodium from pot and subassembly with hot water and detergent.

- 2) Item 3(d)-2 which follows, considers alcohol as the alternate cleaning fluid for subassembly and finned pot chambers, while Item 3(f) considers hot water.

Alcohol to be used only if hot water-residual sodium reaction is harmful to pots and subassemblies. Most probably alcohol is not required in this design.

An experiment is required to show whether a finned pot or subassembly could be safely washed with hot water (after the finned pot or subassembly has been placed in hot (250 F) oil and allowed to drain most of its sodium in the oil by gravity settling and oil flushing prior to reacting.

Ultrasonic agitation could be provided to help drain most of the sodium from the finned pot before introducing hot water and detergent.

b. Alcohol - Butanol $\text{CH}_3(\text{CH}_2)\text{CH}_2\text{OH}$

Physical Properties

Molecular weight	= 74.12
Boiling point @ 760 m.m. Hg	= 117.7 C
Weight per U.S. gal @ 68 F	= 6.756 lb
Flash point	= 114 F
Solubility in water @ 77 F % by volume	= 8.9%
Solubility in white oil	= Infinitely soluble

c. Sodium Alcohol Reaction

d. Materials Balance - Sodium Alcohol Reaction

- 1) Total bi-weekly sodium to be reacted in pot and subassembly cleaning chambers =

$$6.3 + 6.3 = 12.6 \text{ lb Na per 2 weeks}$$

- 2) 3.21 lb of alcohol per one lb of Na is required to form about 4.21 lb of Na alcoholate Butoxide.

Therefore, alcoholate per year = $12.6 \times 26 \times 4.21 = 1380 \text{ lb/year}$

$$\text{Or, } = \frac{1380}{6.756} = 204 \text{ gallons/year}$$

Based on 75% alcohol reclaiming efficiency, wasted alcoholate per year =

$$\frac{204}{.75} = 272 \text{ gallons/year}$$

3) Standard cubic feet (SCF) of H_2 per year:

Evolved hydrogen per year (from both chambers) =

$$12.6 \times 26 \times 0.043 = 14.1 \text{ lb/year}$$

$$\text{Or, } 189 \times 14.1 = (2670 \text{ SCF/year})$$

1335 SCF/year from each chamber

e. Wasted Oil Per Year (From Both Chambers)

1) From finned pot cleaning chamber:

Oil is drained prior to detergent and water wash. Thus the oil lost is what is left after drainage. This could be assumed to be 2 x the amount of sodium adhering to the pot prior to water washing =

$$2 \times 0.5 = 1 \text{ lb/finned pot.}$$

$$35 \times 26 = 910 \text{ lb oil/year}$$

$$\text{Or, } = \frac{910}{6.6} = 138 \text{ gallons per year}$$

2) From subassembly cleaning chamber:

Oil is centrifuged and separated from the water prior to detergent admission. Assume centrifuging is 95% efficient and also assume that 6 gallons of oil is removed from cleaning chamber per washing =

$$\text{Then oil lost per year} = 6 \times 35 \times 26 \times \frac{5}{100} = 272 \text{ gallons/year}$$

3) From both chambers:

$$\text{Oil lost/year} = 138 + 272 = \underline{\underline{410 \text{ gallons/year}}}$$

f. Materials Balance - Subassembly and Finned Pot Cleaning Chambers = (Per Flow Sheet)

- 1) As shown in Item 4-a, 12.6 lb sodium per two weeks (or 328 lb/year) is the amount of sodium to be reacted in both cleaning chambers and carried by the hot water effluent.

$$12.6 \text{ lb} \times \frac{40}{23} \times 26 = 570 \text{ lb NaOH/year}$$

- 2) Assume that the effluent NaOH is carried to an ion-exchanger for decontamination, then the amount of resin required per year =

$$570 \div (3.75 \text{ lb NaOH per cu ft of cation resin})^{(11)} =$$

$$\underline{\underline{155 \text{ cu ft of resin per year.}}}$$

This 155 cu ft/year of resin is true provided the effluent water is demineralized and the detergent used is non-ionic detergent such as triton X-100.⁽¹¹⁾

g. Waste from Both Cleaning Chambers

- 1) Oil = 410 gallons/year (Item No. 4-c).
- 2) Ion-ex resin = 155 cu ft x 1.05 (5% swelling) x 7.48 = 1220 gallons/year.
- 3) Total waste per year from both cleaning chambers = 1220 + 410 = 1630 gallons/year.

4. MATERIALS BALANCE - OIL RECEIVING POOLa. General

Sodium from the oil pool might be handled by either of the following procedures:

- 1) Separate the sodium from the oil by centrifuging or filtering. Then reclaim the pure sodium by solvent extraction. The final oil-free sodium goes back to the reactor. More experimentation is required to prove the feasibility of this system.
- 2) Separate the sodium from the oil by centrifuging or filtering. Then react the sodium sludge (97% Na, 3% oil) in 55% NaOH to form (60 to 70%) NaOH. The (60 to 70%) NaOH is then pumped to the waste holdup tank to be shipped off-site.

System 2 has been chosen for the material balance calculation that follows.

b. (55 to 70%) NaOH Tank -
Materials Balance Into Tank

1087.4 lb Na per two weeks.

151.6 gallons of sodium per two weeks travels from the oil pool to the sodium reaction tank (Item No. II-2-c).

Or, $151.6 \times 26 = \underline{3925 \text{ gallons of sodium/year}}$

Assuming the sodium-oil ratio after centrifuging or filtering = 97% Na, 3% oil,

97% = 151.6 gallons of Na per two weeks.

3% oil = $\frac{3}{97} \times 151.6 = \underline{4.4 \text{ gallons of oil per two weeks.}}$

Or, 115 gallons oil per year

c. (55 to 70%) NaOH Tank -
Materials Balance From Tank

1) Waste 60% NaOH per year (assumed):

Total 60% NaOH waste =

$$1087.4 \times 26 \times 2.94 = 83,400 \text{ lb of 60\% NaOH per year.}$$

$$\frac{83,400}{8.33 \times 1.63} = \underline{6250 \text{ gallons of 60\% NaOH per year.}}$$

2) Standard cu ft of hydrogen per year:

$$\text{Evolved H}_2 \text{ per year} = (1087.4 \times 26) \times 0.043 = 1215 \text{ lb of H}_2 \text{ per year.}$$

$$189 \times 1215 = \underline{230,000 \text{ standard cu ft of H}_2 \text{ per year.}}$$

3) Wasted oil per year:

$$4.4 \text{ (gallons of oil per week)} \times 26 = \underline{115 \text{ gallons oil per year.}}$$

4) Total waste per year from (55 to 70%) NaOH tank:

$$6250 \text{ (60\% NaOH)} + 115 \text{ (oil)} = \underline{6365 \text{ gallons of waste per year}}$$

5. TOTAL WASTE PER YEAR

a. From subassembly and finned pot cleaning chambers =

1630 gallons/year.

b. From (55 to 70%) NaOH tank =

6365 gallons/year.

c. Total waste =

$$1630 + 6365 = \underline{7995 \text{ gallons/year}}$$

Or, 8000 gallons/year to ship off-site (160 drums)

d. Based on 15 subassemblies/2 weeks:

Total waste =

$$8000 \times \frac{15}{35} = \underline{3400 \text{ gallons/year (approx.)}}$$

WHITE OIL CONCEPT - COST ESTIMATE1. GENERAL NOTES

- a. Cost estimates are based on flow sheet 6XN-2430, except the design criterion is 15 subassemblies/2 weeks instead of 35 subassemblies/2 weeks.
- b. The flow sheet 6XN-2430 is designed with all necessary engineering stand-by and safety features to cope with possible cleaning facility process failures, and the cost estimates reflect this.

2. OIL CLEANING OF CORE SUBASSEMBLY
ABSOLUTE MINIMUM REQUIRED - COST ESTIMATEa. Process Major Equipment Cost

1) Pumps and Tanks:

2 - 1 hp all iron rotary pumps, 20 gpm, 75 psig, 250 to 350 F	\$ 870
2 - 2 hp all iron rotary pumps, 50 gpm, 75 psig, 250 to 350 F	1,100
4 - 3/4 hp 304 S.S. centrifugal pumps, 2 gpm, 32 ft head	1,840
5 - 2 hp 304 S.S. centrifugal pumps, 50 gpm, 70 ft head	3,625
1 - 4000 gallon mild steel tank, "Oil Supply Tank"	3,300
5 - 500 gallon mild steel tank,	4,600
1 - 1500 gallon 304 S.S. tank, (55 to 70%) NaOH tank	4,500
1 - 4000 gallon 304 S.S. tank, (1/2 to 1%) NaOH tank	9,200
1 - 7500 gallon 304 S.S. tank, "Water Holdup Tank"	13,400
1 - 10,000 gallon 304 S.S. tank, "Waste Holdup Tank"	16,000
TOTAL PUMPS & TANKS	\$58,435

2) Centrifuges:	
(2) units, no stand-by	\$ 8,300
3) Ion-ex:	
(2) ion-ex units (each = 32.3 cu ft mixed bed)	8,400
4) H ₂ and Gas System:	
(Similar to steam cleaning)	7,100
5) Heating and Cooling of Oil:	
(Similar to steam cleaning)	2,600
6) Receiving Station:	
45,000 gallon mild steel tank	12,100

PROCESS MAJOR EQUIPMENT COST	<u>\$96,935</u>

b. Process: Installation, Piping, Elect., Supports, Etc.

= 3.25 x 96,935	\$315,000

c. Transfer Equipment and Installation

(Incl. ultrasonic cleaning for finned pot)	\$105,000

d. Shielding

For 7 ft 0 in. shielding - total cu ft of concrete =
 (20 ft x 20 ft x 7 ft) + (20 ft x 20 ft x 7 ft) =
 5600 cu ft

For 3 ft 0 in. shielding - total cu ft of concrete =
 (3 ft x 25 ft x 20 ft) + (3 ft x 25 ft x 25 ft) =
 3375 cu ft

$(5600 \times \frac{200}{27}) + (3375 \times \frac{100}{27})$	= 41,500 + 12,500	\$ 54,000

TOTAL FACILITY COST	<u>\$570,935</u>

(Or Approximately)	<u><u>\$571,000</u></u>

3. OIL CLEANING OF CORE SUBASSEMBLY
ENGINEERING MARGIN SAFETY - COST ESTIMATE

a. Process Major Equipment Cost

1) Pumps and Tanks:

3 - 1 hp all iron rotary pumps, 20 gpm, 75 psig, 250 to 350 F	\$ 1,300
2 - 2 hp all iron rotary pumps, 50 gpm, 75 psig, 250 to 350 F	1,100
7 - 3/4 hp 304 S.S. centrifugal pumps, 2 gpm, 32 ft head	3,220
9 - 2 hp 304 S.S. centrifugal pumps, 50 gpm, 70 ft head	5,175
1 - 4000 gallon mild steel tank, "Oil Supply Tank"	3,300
5 - 500 gallon mild steel tank,	4,600
1 - 1500 gallon 304 S.S. tank (55 to 70%) NaOH tank	4,500.
1 - 4000 gallon 304 S.S. tank, (1/2 to 1%) NaOH tank	9,200
1 - 7500 gallon 304 S.S. tank, "Water Holdup Tank"	13,400
1 - 10,000 gallon 304 S.S. tank, "Waste Holdup Tank"	16,000
TOTAL PUMPS & TANKS	\$61,795

2) Centrifuges:

(6) units (4) stand-by \$24,900

3) Ion-ex:

(3) ion-ex units (each = 32.3 cu ft mixed bed) \$12,600

4) H₂ and Gas System:

(Similar to steam cleaning) \$ 7,100

5) Heating and Cooling of Oil:

(Similar to steam cleaning) \$ 2,600

6) Receiving Station:

45,000 gallon mild steel tank	\$12,100
PROCESS MAJOR EQUIPMENT COST	\$121,095
b. <u>Process: Installation, Piping, Elect., Supports, Etc.</u>	
= 3.25 x 121,095	\$393,000
c. <u>Transfer Equipment and Installation</u>	
(Incl. ultrasonic cleaning for finned pots)	\$135,000
d. <u>Shielding</u>	
Refer to minimum required cost estimate	\$ 54,000
TOTAL FACILITY COST	\$703,095
(Or Approximately)	<u>\$703,000</u>

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