

CONF-730326--1

RECEIVED BY TIC MAR 29 1973

THE STATUS OF SODIUM CLEANING
PROCESSES IN THE LMFBR PROGRAM, USA*

by

6580000

G. R. Taylor
E. C. Bishop
M. H. Cooper

581 0000

Westinghouse Advanced Reactors Division

and

6580000

P. Perrone

581 0000

U. S. Atomic Energy Commission, RDT

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

*Work Funded Under AEC Contract AT(11-1)-3045, FFTF Pump Bearing Test

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

201

I. Introduction

The basic methods which have been used in sodium reactor programs to clean and requalify specimens and components that have been exposed to sodium are well known, although not well documented. Moreover, while these methods have been extensively applied to laboratory cleaning of test specimens or small, simple components, their use in cleaning complex reactor or test components and systems, as well as requalifying them for continued service, has been limited and sporadically unsuccessful. Documentation of the precise conditions of reactants, temperature, time, etc., has been almost nil, with the result that the definition of a reliable process and its embodiment into a specification or standard for a complex component is not possible at this time.

In view of the imminence of the need to clean and requalify large, intricate components in LMFBR testing programs, as well as actual reactor components, considerable engineering application work must be done to be prepared for these requirements. It is the purpose of this presentation to recount the results of several component and system cleaning cases, examine examples and causes of successes and failures, and identify the further application engineering they dictate should be carried out.

Table 1 gives a comparison of the advantages and disadvantages of the principal cleaning processes. Inability or slowness of either alcohol or vacuum distillation to remove sodium compounds, such as sodium oxide or sodium carbonate, is a significant advantage for the moist nitrogen process. Both the reactant cost, in the case of alcohol, and the engineering and equipment cost for vacuum distillation are more serious disadvantages than the formation of caustic solutions in the moist gas process. The catastrophic effects of caustic stress corrosion cracking can be avoided in the moist nitrogen process by careful temperature control. Sufficient experimental data are not available now to judge the superiority of any process in cleaning crevices; however, effective crevice cleaning has been reported for all three processes.

TABLE COMPARISON OF SODIUM CLEANING PROCESSES

<u>Process</u>	<u>Advantages</u>	<u>Disadvantages</u>
Moist Nitrogen	<ol style="list-style-type: none">1. Reaction rate readily controlled by moisture to nitrogen ratio2. Moisture diffuses into entire volume, eliminating potential unreacted areas because of gas trapping3. Reaction proceeds with both sodium and sodium oxide4. Reactants costs low5. Reactants non-toxic	<ol style="list-style-type: none">1. Formation of caustic solution which can lead to stress corrosion cracking if temperature exceeds safe limit ($\sim 250^{\circ}\text{F}$).2. Reaction with sodium in crevices limited by diffusion of moisture through crevice and absorption by caustic at the gas-liquid interface.3. Hydrogen is evolved.
Alcohol	<ol style="list-style-type: none">1. Reaction rate slow; can be controlled by water additions2. Formation of solutions of NaOH avoided3. Low temperatures easily maintained4. Reaction with sodium in crevices limited by diffusion of reaction products through crevice to the bulk alcohol	<ol style="list-style-type: none">1. Does not react with sodium oxide; hence must prevent oxidation of sodium during handling prior to cleaning.2. Alcohols flammable and toxic.3. High reactants costs may require distillation and recycle.4. Sodium may not be reacted in areas that form gas pockets.5. Alkaline organic compounds formed, which could cause stress corrosion cracking if not removed.

Process

Advantages

Disadvantages

Alcohol

6. Hydrogen is evolved.

Vacuum Distillation

1. Removes sodium without forming a caustic solution
2. Cleaning of crevices possible without leaving caustic residue
3. Can be performed in situ for some cases using trace heaters
4. Reactant costs are eliminated and waste disposal minimized
5. Hydrogen is not produced.

1. Non-volatile sodium compounds are not distilled.
 2. System must be capable of being heated uniformly at least to 800°F and being evacuated to 100 microns or less.
 3. In-leakage of air can oxidize sodium and prevent distillation.
 4. Scale up to large components complex and equipment is expensive.
-

to the component. Caustic stress corrosion cracking is avoided by this cleaning procedure because the temperature is low (i.e., steam temperature or below), caustic readily drains from component, and exposure time is short.

2. Pumps

Subassemblies of the three Enrico Fermi-Power Plant primary sodium pumps were successfully cleaned in 1964 after more than 7500 hours operation by uncontrolled atmosphere steam cleaning.⁽³⁾ Removal, disassembly, and cleaning of these pumps were required to modify internal check valves to correct a system hydraulic instability (water hammer). After withdrawal into an argon filled transport cask, the pump was allowed to cool to ambient temperature. Then the pump was slowly lifted from the transport cask into an air atmosphere and installed in a disassembly fixture. As the pump was disassembled, the subassemblies were taken outside for steam cleaning. After inspection, including dye penetrant testing of the Colmonoy bearings, the pump was reassembled with the modified check valve and re-installed in the plant. All three pumps were processed using this procedure. Since the uncontrolled atmosphere cleaning procedure was used for these pumps, there was no damage because of the factors discussed previously.

3. Heat exchangers

ARD⁽⁴⁾ successfully cleaned an experimental sodium heated steam generator using a modified uncontrolled atmosphere cleaning process. The steam generator, which consisted of three 1-1/2 inch diameter tubes, was cleaned outdoors by purging each tube successively with argon and dry steam. Although there were some small explosions and burning sodium ejected from the tubes, no damage attributed to cleaning was noted by visual and metallurgical examination of the sodium tubes. This cleaning operation was successful because of its short duration, low temperature, and unconfined volume for hydrogen reactions.

II. Component and System Cleaning Case Histories

A. Steam or Moist Inert Gas

As is well known, the hazard associated with "steam" cleaning austenitic stainless steels is the potential of stress corrosion cracking, either from chloride carryover in the steam or rinse water, or from the caustic formed in the sodium/water reaction. Chloride contamination can be controlled, but caustic is inherent in the process.

Of the four parameters affecting caustic stress corrosion cracking (CSCC)-caustic concentration, residual tensile stress, time, and temperature - only time and temperature are controllable during cleaning, since caustic over a wide concentration range and significant residual stresses are probably unavoidable. Figure 1 summarizes the data relating time and temperature to the onset of CSCC for austenitic stainless steels. Note that data for times less than two days is only semi-quantitative. Reference will be made to this figure in the ensuing description of several steam cleaning experiences.

The steam or moist inert gas method of sodium removal has probably had the widest application over the past 15-20 years with many successes, but some failures, covering a broad range of structures - large and small, simple and complex. Its use with fuel assemblies, such as SRE Core II⁽¹⁾ and EBR II⁽²⁾ are well known. Remaining applications may be grouped into several classes:

1. Uncontrolled Atmosphere Cleaning of Small Components

Uncontrolled atmosphere cleaning by flowing dry steam has been successfully used in cleaning small components by many liquid-metal workers. While small explosions, usually noted as bangs and pops during steaming, result from reaction of evolved hydrogen with air, damage to the components being cleaned are rare. Presumably, the components are not damaged because the hydrogen explosions occur in an unconfined volume, which is often external

Cleaning of the 10% Model of the S2G (Seawolf) Superheater at KAPL was not as successful.⁽⁵⁾ Severe cracking of the superheater tubing was observed during and after the cleaning operation. The cleaning procedure specified the use of superheated steam rather than water to reduce the explosion hazard. However, the use of superheated steam, presumably resulted in temperatures above the critical temperature as illustrated in Figure 1 for caustic stress corrosion cracking to occur at the exposure time of the system to the caustic.

4. Test loops

Steam or moist inert gas cleaning of a few test loops has been reported. Although a 4" sodium loop at KAPL⁽⁶⁾ reached temperatures as high as 1200°F during steam cleaning, no CSCC occurred, presumably because cleaning times were short and no aqueous phase was present at the extreme temperature. A Type 316 stainless steel loop of 75-100 gal. NaK capacity was drained and successfully cleaned with an argon/steam mixture in the CANEL project⁽⁷⁾. No loop preheat was employed, but temperatures were controlled to 200-300°F by gradually enriching the mixture, while circulating it through the loop for about one week. A water rinse and vacuum dryout at 100-200°F prepared the loop for insertion in ETR, where it operated successfully for 1000 hours. In this instance, although cleaning times were long, CSCC was probably avoided by controlling temperatures below 300°F.

A recent attempt to steam clean a sodium test facility, the Pump Bearing Test Facility (PBTf) at the Liquid Metal Engineering Center, resulted in extensive caustic stress corrosion cracking of the loop piping. A P&I diagram of the sodium system, modified for steam cleaning, is shown in Figure 2. The bulk of the piping was 2" and 6" diameter AISI type 304 stainless steel, which had been gravity drained prior to cleaning. However, significant quantities of sodium remained in non-drainable areas, such

as blind spots, weirs created by valves (which were removed prior to cleaning), etc. Loop piping was preheated, nominally to 250°F, prior to passing a steam/nitrogen mixture, also preheated to 250°F, through the piping. Piping preheat and superheated steam were utilized to increase reaction rates and, mistakenly, to attempt the formation of anhydrous caustic, which would not cause CSCC.

Although it was intended to clean the piping in sections, the loop was actually cleaned as a system, and the steam/nitrogen mixture and sodium reaction products were present in the system for 10-12 days. Moreover, problems with system preheat temperature control and the heat generated by sodium water reactions resulted in actual system temperatures of 300-400°F in some regions for several days, and locally higher temperatures for similar periods.

The results of this exposure are shown in Figures 3 and 4, which illustrate the branching type of cracking typical of transgranular stress corrosion. All cracks were associated with welds, but were not located in the weld metal areas. They were located in heat affected zones, presumably locations of high residual stress. It is instructive to note that cracks occurred on the inside diameter of 2" diameter x 0.154" wall piping opposite O.D. thermocouple tack welds, even though the fusion zone extended only 10-25% into the wall from the O.D. The absence of cracks in the weld areas of the stainless steel tank used to mix the steam and nitrogen, which was exposed to similar time - temperature cycles, ruled out the possibility of chloride stress corrosion from the chlorides present in the boiler feed water. The valves and the drain tank of the loop, which were separately steam cleaned at temperatures of approximately 250°F for times ranging from a few hours to slightly more than one day, revealed no cracking. Much of the piping I.D. had a heavy, dark oxide coating, often observed by others on stainless after exposure to caustic at high temperatures.

Obviously, failures occurred because areas of the loop piping, containing residual stresses from welding, were in contact with caustic solutions for days at temperatures considerably above the curve shown in Figure 1. Actually, analysis of the data indicates that cracking occurred only in areas that were in excess of $\sim 300^{\circ}\text{F}$. The attempt to maintain anhydrous caustic failed because, once formed, it will pick up moisture from even superheated steam and form an aqueous solution.

What are the lessons to be learned from these cases and what are their implications for future cleaning of larger, more complex components and systems? While it certainly cannot be denied that a more precise definition of the time-temperature boundary for the initiation of CSCC, especially at short times, is required, the failures that have occurred cannot be attributed primarily to the imprecision of this data. Rather, this experience demonstrates the need to concentrate cleaning effort on the engineering problems of applying the known technology of this process to complex structures and systems.

Unfortunately, although the application to many components has been successful, little documentation exists to form a basis of preparing a standard or even positive guidelines covering the method. Moreover, the experience of PBTF demonstrates that the lack of a clearly delineated set of limits led to inadequate control of cleaning parameters. Once the process had started, on-the-spot decisions were made to permit deviations, simply because no strict limits were set. The entire process was not thoroughly planned so that the mandatory controls to avoid CSCC were identified and rigidly maintained. The point should be made that in cleaning reactor components or systems, a similar result could occur again unless more attention is paid to doing the engineering application work required to truly adopt the process to such components. The principal tasks involved in this effort, such as mock-up or prototype cleaning, demonstrating requalification, disassembly to verify cleaning and integrity, etc., are discussed later in this paper.

B. Alcohol

Alcohol has been utilized for cleaning large components because of its slow and controllable reaction rate and lower risk of damage. Despite its higher cost and potential fire hazard, alcohol has been successfully used in cleaning large reactor components, such as pumps and a steam generator. Careful attention to inert gas blanketing was utilized in these cases to minimize the fire hazard. Components to be cleaned by alcohol should be protected from air contamination, since sodium oxide, hydroxide, and carbonate are non-reactive with alcohol and are relatively insoluble.

Following the failure of the sodium steam generators at the Enrico Fermi Power Plant in 1962, the steam generator tube bundle was removed by withdrawal into a nitrogen filled shipping container.⁽⁸⁾ The container was transferred to an outdoor cleaning facility equipped with a 50 ton crane, nitrogen supply, railroad tank car with ethyl alcohol, and required piping. All vents were fitted with flame arrestors and all components were grounded. The tubes which had failed were plugged and alcohol pumped into the remaining tubes at 20 gpm. Absence of hydrogen in the nitrogen purge indicated that sodium had not penetrated any of the unplugged tubes.

The shell side was cleaned by pumping alcohol into the shipping container at 10 gpm and sparging with nitrogen at 5 to 10 SCFM. Filling was interrupted periodically to monitor temperatures and pressures. During filling, the pressure increased about 3 psi and the hydrogen concentration in the vent line varied from 20 to 65%. The maximum local temperature observed was about 100°F. The tube bundle was then soaked in alcohol for a total of about 60 hours, with a partial drain and refill after 12 hours to attempt to augment internal mixing. Then the alcohol was drained and the tubes dried with nitrogen.

The cleaned tube bundle showed a small white deposit, identified as sodium carbonate, above the sodium operating level. The sections

of the tubes immersed in sodium were covered with a fine gray powder, reported to be Croloy metal particles resulting from sodium reduction of the oxide film initially present on the tubes.

An EBR-II primary sodium pump was removed and cleaned after more than 32,000 hours of service because of shaft binding arising from oxidized sodium deposits.⁽⁹⁾ The pump was withdrawn into an argon filled caisson, allowed to cool, and the surface of the adherent sodium oxidized by slow introduction of air. Then the pump was partially disassembled and the parts transported to an outside metal-covered, concrete cleaning pad. Pump subassemblies were placed in argon filled tanks specifically designed for each unit. Ethyl alcohol was remotely pumped into each tank until the tanks were filled. Water was slowly added to the alcohol until a 50% mixture was obtained. When the sodium reaction was complete, the alcohol was drained and the subassembly washed with hot water. Subsequently, the pump assemblies were decontaminated with Turco No. 4521 and rinsed. Modifications to the pump to alleviate the sodium deposition on the shaft were accomplished and the pump returned to service. At the time of the referenced report, the pump had been operated satisfactorily for more than 1500 hours.

Thus, two complex reactor components have been successfully cleaned with alcohol, and one of them, the EBR-II pump, returned to service. Well planned procedures and inert gas protection during cleaning contributed to the satisfactory results achieved in these two cases. The decision of the EBR-II staff to oxidize the sodium surface is rather curious, in that sodium oxide inhibits the reaction with alcohol. Presumably, the water added to the alcohol reacted with this sodium oxide.

Both EBR-II pumps had been removed and cleaned in 1963 about six months after start-up because of binding problems. Hence, at least two cleaning cycles on one pump and a single cleaning on the other has had no noticeable effect upon their performance.

C. Vacuum distillation

Vacuum distillation has been successfully employed on both a laboratory scale and on small components or systems to remove residual sodium. Emperically, its application to larger systems appears attractive, i.e., temperatures are no higher than those required for system operation and may be lower, pressures do not require elaborate pumping systems, and times may not be excessive. However, even experience on a small scale and analysis of the extrapolation to larger systems reveals that the engineering to permit reliable use on large complex components is inadequate.

At the W Advanced Reactors Division vacuum distillation has been employed for cleaning a wide variety of components and systems, with varying success:

1. A 37-pin, grid type dummy fuel assembly used in a sodium fretting test was very successfully cleaned at $\sim 1000^{\circ}\text{F}$ for 316 hours at pressures of 20-200 microns. Even areas of fuel pin-grid intersection and threaded end fittings (Figure 5) were completely cleaned, with no trace of a residual "smudge" often found after vacuum distillation.
2. In contrast, repeated cleaning of a sodium wear test rig at $\sim 800^{\circ}\text{F}$ and 1-5 microns for 72 hours on each occasion has resulted in the gradual accumulation of a crust on certain areas, such as bellows. Since the rig operates with a considerable cover gas volume, it is probable that this accumulation is due to frost formation, containing oxide formed from oxygen and water vapor impurities in the cover gas. Removal of this residue is possible only by reaction to form a soluble reactant, such as flushing with water.
3. Attempted vacuum distillation of a complex control rod sodium test system (Figure 6) was only partially successful due to

a variety of causes:

1. Frost or oxide formation in cover gas areas
2. Limitations on heating certain components above 400°F
3. Intricate, long passages requiring long diffusion times
4. Inability to determine the completion of the distillation process.

It was eventually cleaned using Dowanol; however, modifications are being made to permit heating of the entire system to 800°F and the use of gas sweeping to obtain more complete distillation during the next cleaning cycle.

These and other similarly reported experiences presage the problems of applying vacuum distillation to larger, more complex components:

1. Since oxides or other compounds of sodium are almost certain to be found to some degree, especially in components exposed to a cover gas, incomplete removal of sodium will result.
2. Residual compounds left after vacuum distillation must be reacted away, probably with water or alcohol rinses.
3. Since the advantages of vacuum distillation are enhanced by performing it in situ (minimize oxidation, utilize trace heating, isolate with existing valves, etc.) the need to follow with a rinse presents special problems in isolation from the remainder of the system. Vacuum distillation does however simplify subsequent removal of the component from the system for further cleaning.
4. Complex components which have long, intricate passages create long diffusion times, unless gas sweeping is used to accelerate vapor removal. Little experience exists with such techniques, which also increase the probability of oxidizing the remaining sodium.
5. With intricate components it is difficult to determine the end point of the distillation process. Disassembly

and examination is likely, of course, to oxidize remaining sodium.

6. All parts within an enclosed area to be vacuum distilled must be capable of being heated to at least 800°F.
7. Heating of large, complex structures with trace heating in the absence of sodium can result in thermal stresses, unless the heating is specifically designed for this purpose.
8. If the containment vessel for vacuum distillation is a part of the reactor system (pump tank, etc.) it must be designed for vacuum loads to temperatures of at least 800°F.
9. Sodium valves may not provide adequate isolation for vacuum distillation and subsequent water rinsing.

III. Implications for Reactor Component and System Cleaning

A. Components

The experiences cited here, as well as those of others, serve to point up the problems which can be anticipated when attempting to apply these cleaning methods to larger, more complex reactor components, especially those from primary systems, which will exhibit radioactivity levels considerably in excess of any encountered to date. It would appear that many of these problems of engineering application of the known technology of cleaning have not been adequately addressed in component design, delineation of actual process steps; and cleaning facility design. Some of the more significant areas are discussed below:

1. Disassembly

Both the successful EBR-II and the Enrico Fermi pump cleaning operations were accomplished with partial disassembly. This disassembly simplified the cleaning operations and permitted inspection of critical surfaces. The demonstration by examination that cleaning had not damaged the pump contributed greatly to the acceptance of the pump for reuse by the reactor operators.

The capability to disassemble a component during or after cleaning is therefore clearly a desirable design objective. Alternatively, if design for disassembly is deemed impractical, mock-up cleaning programs must demonstrate unequivocally the capability of the process to clean and maintain the structural integrity of critical surfaces in identical configurations. In designing for disassembly, the fact that primary system components will be radioactive from transported corrosion and fission products must of course be considered in specifying procedures.

2. Isolation

Isolation can consist of removal of the component from the system or isolation of the component in situ in the system. The former is preferable, however, it may be impractical for valves, pump and IHX tanks, as well as certain vessel internals.

Existing valves may not represent satisfactory means for isolation. In general, sodium valves have a certain amount of leakage and are not consistent with the isolation requirement. In this event provision for capping off or inserting a temporary block must be considered in the original system design. In other words, the design must consider the alternatives available for isolation of each component and either provide that isolation or identify a method for attaining it in the event cleaning is necessary.

3. Drainability

Although drainability is generally identified as a design criterion for sodium components, most complex components are not designed for complete drainability of sodium as illustrated by the PBTF loop, and cleaning processes must be mated with the component to identify drainability requirements. It may be necessary to provide for methods of rotating components during cleaning to present new surfaces to cleaning agents and provide for draining others. Such handling provisions must be made before operation of primary system components, since activity levels may not permit it later.

4. Temperature Monitoring and Control

Since temperature control is vital to most cleaning methods, identification of the cleaning process prior to design is highly desirable in order to incorporate the proper capability

in the original design. Strategic location of thermocouples to monitor the progress of the cleaning process at critical areas should be a design requirement. Heating or cooling to maintain the desired temperature must also be provided in the original design. Trace heating for sodium fill may not be adequate because of capacity, control, or uniformity. In the absence of sodium, the uniformity of heating is important to avoid excessive thermal stresses. Where cooling is required, analysis should verify that adequate heat removal capacity is available during the cleaning process.

5. Design for Vacuum Distillation

In addition to heating requirements, if vacuum distillation is to be used for cleaning a component and its own containment is to serve as the distillation vessel, it must be mechanically designed to withstand a vacuum at 800°F minimum. Attention should be paid in the design to the location of evacuation system attachments and the possible need to introduce a sweeping gas.

6. Requalification

Until recently little attention has been focused on setting criteria for requalification and establishing the methods for meeting those criteria. Requalification of most components cleaned to date has consisted primarily of visual examination and a few instances of return to service without failure for a limited period. Restoration of surfaces to their original state in most cases cannot be considered a viable criterion of requalification, because sodium service and cleaning methods do alter surfaces. However, specific criteria for acceptability could be established for surfaces, crevices, and certain configurations based on feature tests and the application of selected non-destructive examination methods. In this connection, the cleaning and destructive examination of mock-ups or prototypes of major components or their critical features, as discussed later, is of major importance.

8. Systems

The requirements described above for components are fully applicable to systems, whether test or reactor. However, systems present certain additional problems, discussed briefly in the following sections. It should also be noted that certain complex components should be considered, for the purposes of cleaning, as similar to systems, for which then the following sections may also be applicable.

1. Disassembly, Isolation and Draining

The experience in cleaning PBTF has demonstrated the desirability of breaking down and isolating parts of systems into manageable components. For this purpose, consideration should be given to placing tees or crosses in strategic locations as a means of providing access for plugging and cleaning sections of loop piping. Coupled with true design for drainability, these provisions could guarantee that reaction products would not be in contact with loop piping and components for long periods of time.

2. Temperature and Vacuum

Use of existing trace heating systems for temperature control and monitoring should be a design requirement, particularly if vacuum distillation is contemplated. However, grouping of heaters per control system may not be satisfactory if uniform heating and adequate monitoring cannot be provided.

3. Operation

Operating procedures should be geared to minimizing cleaning problems. For example, draining a system following an oil spill may produce a coating of oil over the entire system, instead of localizing it. Control of subsequent operating temperatures following an oil spill could affect disposition and/or decomposition of the oil following a spill.

In any event, operating procedures should recognize that removal of sodium to remove contamination should be avoided, if at all possible. Alternate methods, such as decomposition and trapping, should be planned prior to operation and be incorporated in operating and maintenance procedures.

Examples of successful disposition of oil spills by this means are SRE⁽¹⁰⁾ and FERMI⁽¹¹⁾.

C. General

Basically, there is an industry-wide need for a set of clear, unambiguous standards for moist gas, alcohol, and vacuum cleaning, which, if adhered to, would assure safe, reliable cleaning of components or systems. Before a final standard can be written, however, additional work is required.

The basic thermodynamic and chemical data on the materials and reactions involved in moist gas or alcohol cleaning are available or can be estimated with satisfactory accuracy. What is needed is (1) data on the rates of the various reaction processes particularly on the rate of water vapor or liquid and alcohol reaction with sodium in crevices and with sodium in bulk. This is needed to specify conditions which will avoid runaway reactions in the latter case, and which will assure complete reaction in the former; (2) a better definition of general corrosion rates and of the CSCC environmental bounds in aqueous alkali solutions. While absolutely safe operating conditions can be specified now, they may be too restrictive or difficult to maintain with absolute certainty; accordingly, an effort should be made to broaden the acceptable time-temperature conditions, if necessary by the development of a modified process as, for example, the simultaneous use of an acidic oxide gas (CO₂ or NO₂) in concert with steam to decrease the pH of the reaction products as the cleaning process progresses; (3) once tentative standards are established, their validity must be demonstrated by satisfactory application to the

TABLE 2

CONTROLLING PARAMETERS OF LARGE SODIUM COMPONENTS
(Sheet 1 of 2)

Component	How Handled	Maximum Weight(1)	Length	Height	Diameter	Cleaning Method
1. Medium Capacity Sodium Pump Internal Assembly	Vertical	90 (113)tons ⁽²⁾	N/A ⁽³⁾	40 ft ⁽⁴⁾	< 13 ft	In cleaning vessel
2. Medium Capacity Sodium Pump Outer Case	Vertical	65 (82) tons	N/A	40 ft	13 ft	Out of cleaning vessel
3.a) FFTF Sodium Pump Internal Assembly	Vertical	64 [74]	N/A	40 ft ⁽⁴⁾	< 6 ft	In cleaning vessel
3.b) Pump Lift Fixture	N/A	1.25 [1.4] tons	N/A	N/A	N/A	N/A
4. FFTF Sodium Pump Outer Case	Vertical	40 (50) tons	N/A	34 ft	7 ft	Out of cleaning vessel
5. AI Modular Steam Generator	Horizontal & Vertical	14 tons	72 ft	N/A	2-3 ft	Out of cleaning vessel
6. FFTF Intermediate Heat Exchanger (complete)	Horizontal	68 (85) tons	35 ft	N/A	7 ft	See Note (7).
7. FFTF Intermediate Heat Exchanger (Tube bundle only)	Horizontal & Vertical	42 (53) tons	< 35 ft	N/A	< 7 ft	In cleaning vessel
8.a) FFTF Maintenance Cask (inc. hoist module)	Horizontal & Vertical	90 [104] ⁽⁵⁾	N/A	59'-9"	10 ft ⁽⁶⁾	Requirement for cleaning not established
8.b) Cask Vertical Lift Fixture	N/A	2.8 [3.2] tons	N/A	N/A	N/A	N/A
9. FFTF Dump Heat Exchanger	N/A	60 (75) tons	35 ft	10 ft	16 ft wide	Out of Cleaning Vessel

cleaning of a series of complex prototypic systems and components; (4) an answer to the question of whether or not even the best sodium cleaning process which involves a thorough water rinse as the final step does not detract from the acceptability of the component for subsequent long term use in sodium. The plant system components themselves must give the ultimate answer, but the calculated risk can be considerably lessened by continuing out-of-reactor studies.

D. Cleaning Facility Designs

Two major cleaning facilities are planned as part of the U.S. LMFBR program; the Component Handling and Cleaning Facility (CHCF) to be located at the Liquid Metal Engineering Center (LMEC), and the Alkali Metal Cleaning Facility (AMCF), to be located at the Hanford Engineering Development Laboratory (HEDL).

Both facilities in concept will use moist nitrogen as the reference cleaning method but will retain sufficient flexibility for later additions of alcohol or vacuum cleaning of large components if necessary.

Component Handling and Cleaning Facility⁽¹²⁾

The size of the components to be handled and cleaned at CHCF is illustrated by Table 2. This facility is to be housed in a structure (galvanized steel siding) 60 feet wide by 80 feet deep by 67 feet high. Considerable flexibility in handling and disassembly is to be available; for example, the facility must have the capability of removing tube bundles from heat exchangers or steam generators in either the horizontal or vertical position; it must be capable of rotating all components from a vertical to horizontal position or vice versa both indoors and outdoors.

The building will, in addition to an internal bridge crane, either be equipped with a roof mounted stiffleg derrick of about 100 ton

Future Applications

In order to focus clearly on the problems to be solved in liquid metal component cleaning in the future, preliminary sodium cleaning procedures for the FFTF IHX tube bundle and the primary pump will be outlined for discussion.

A. FFTF IHX Tube Bundle

The size (81 inches O.D. by 32 ft. overall) of the IHX tube bundle can be appreciated from Figure 7. Some idea of its complexity can also be seen, but the myriad of crevices, semi-stagnant areas, and flat surfaces which may drain poorly can be appreciated only after careful review of detailed drawings. The impossibility of a complete post-cleaning inspection is obvious, necessitating complete confidence in the efficacy of the cleaning procedure used.

A complete description of the proposed cleaning operation is beyond the scope of the paper; however, a procedure in outline might be as follows (the reactor or system is assumed shutdown and cooled to 400°F or less).

The primary sodium is drained by opening a valve in a 2" line off the primary outlet line after isolating the affected loop by closing isolation valves. The secondary loop is similarly drained, but this does not drain the secondary side of the IHX. To remove sodium from the secondary side, a complex procedure, some steps using remote tooling, and others using temporary radiation shielding, leads to the introduction of a dip pipe through the secondary inlet downcomer to the bottom of the tube bundle. The sodium is then removed from the secondary side by gas pressurizing the outlet side. Clearly a several pound heel of sodium may remain after this operation.

After this operation, the dip pipe is removed, and in largely remote operations, pipe spool pieces are removed from the secondary inlet

capacity or have access to a mobile crane of like capacity. Cleaning facilities will include a large vessel, 13 feet in diameter by 48 feet high and an intermediate vessel 8 feet in diameter and 16 feet high.

Alkali Metal Cleaning Facility⁽¹³⁾

The Alkali Metal Cleaning Facility will provide for the removal of nonradioactive residual sodium from large components and equipment parts that have been exposed to a sodium environment during nonradioactive LMFBR experimental activities.

The facility will be located in the existing High Temperature Sodium Facility (HTSF), will consist of a vertical cylindrical cleaning vessel, auxiliary equipment for the cleaning process, waste effluent disposal systems, demineralized water system, and necessary monitoring and control equipment for operation of the cleaning process.

The vessel will be sized to accommodate large components, with the In-Vessel Handling Machine (IVHM) and the Instrument Tree (IT) controlling design. The vessel will have the capability of adding spray nozzles and headers as required to insure sodium removal from complex component configurations. Immersion to the sodium wetted portion of the shield plug of the IVHM and IT will be possible. The vessel will be suitable for service to 15 psig and 275°F. Sufficient flexibility will be incorporated in process control instrumentation and components to assure adaptability to the standard moist gas cleaning process which is to be developed and the system will be modular to facilitate subsequent removal to FFTF.

It is to be emphasized that the CHCF and AMCF are in the conceptual stage; as a result of the PBTF failure, the processes and methods to be employed are to be reevaluated to ensure the avoidance of caustic stress corrosion cracking.

TABLE 2

CONTROLLING PARAMETERS OF LARGE SODIUM COMPONENTS
(Sheet 2 of 2)

Component	How Handled	Maximum Weight ⁽¹⁾	Length	Height	Diameter	Cleaning Method
10. FFTF Hot Leg Isolation Valve	Horizontal	9,356 lb	96 in.	8'9" ⁽⁸⁾	54 in.	In cleaning vessel
11. FFTF Cold Leg Isolation Valve	Horizontal	6,800 lb	78 in.	7'6" ⁽⁸⁾	40 in.	In cleaning vessel
12. FFTF Cold Leg Check Valve	Horizontal	1,340 lb	58 in.	N/A	32 in.	In cleaning vessel
13. SPTF Venturi Flowmeter	N/A	1,500 lb	8 ft	N/A	18 in.	In cleaning vessel
14. SPTF Valves:						
a. 12 in. Isolation	N/A	900 lb	32 in.	100 in.	26 in. depth	In cleaning vessel
b. 18 in. Control	N/A	2,200 lb	38 in.	80 in.	40 in. depth	In cleaning vessel

NOTES:

- (1) Figures in this column, unless otherwise noted, do not include weights of lifting or handling equipment or steel shot shielding where applicable. () represents actual weight plus a 25% contingency, [] represents actual weight plus a 15% contingency.
- (2) The handling equipment for the Medium Capacity Sodium Pump is estimated to weigh 12 tons (10% of pump internal assembly weight including contingency allowance).
- (3) N/A = not applicable.
- (4) This dimension includes the shaft projection above the mounting plate and bearing housing.
- (5) Maximum CHCF design load is 182.6 tons which consists of components Nos. 3 and 8. The 182.6 tons includes a 15% contingency.
- (6) The cask valve is < 11 ft square.
- (7) If the IHX is to be cleaned while fully assembled, the out-of-vessel method will be used.
- (8) This is the height dimension to the top of the operator/freeze seal mechanism.

and outlet lines, the secondary system is sealed, the shear blocks removed, the omega seal cut in two places, the maintenance cask sealed over the IHX, the IHX tube bundle pulled up into the cask, a dummy tube sheet seal installed on the secondary system, and the maintenance cask with the supported tube bundle contained in an inert atmosphere is ultimately transferred to a railroad car for transport to the sodium cleaning facility. (If the operation is necessary before a maintenance cask is available, isolation will be obtained by plastic bagging using techniques available or to be developed at LMEC for the IVHM.) Here, the tube bundle will be transferred to an inerted cleaning vessel, which, could most conveniently be the spare prototype IHX shell. The shell would be permanently installed with a 5-10,000 gpm low head pump, storage tank, and installed piping and available piping sections making it possible to pipe the IHX primary and secondary sides in series as illustrated in Figure 8. This arrangement is required to assure sufficient circulation of fluids in the final cleaning stages to complete reaction in crevice areas and to accelerate final cleanup of the rinse water by ion-exchange.

If alcohol cleaning is used, the entire circulating system including the IHX bundle is maintained under an inert atmosphere, and Dowanol or other slow acting alcohol is slowly fed-into the system. Gas venting and alcohol addition are adjusted as required to maintain safe conditions. When the system is full, circulation is started and maintained until reaction is complete, water being added if desired or mandated to speed up or complete the reactions. When reaction is complete, the alcohol solution is dumped to recovery or disposal system, and the system is flushed with pure water, ultimately using circulation through a demineralizer system to establish required purity for the draining and drying operation. If radioactive decontamination is required, it will precede the final purification step. Presumably after these operations, leak detection and tube plugging operations can be carried out by essentially contact procedures. Also, removal of the bundle from the tank and visual inspection can be undertaken.

In carrying out these operations, all of the principles and guidelines discussed previously and yet to be established will of course be applied.

B. FFTF Pump

The FFTF primary pump assembly, shown in Figure 9, is about 40 feet high from the primary sodium outlet to the coupling spool. On removal from the tank, the maximum diameter (at the upper flange) is about 7-2/3 feet. As with the IHX, the figure illustrates size and gives some idea of the complexity of the component. The lower 12 feet of the removed assembly can be detached by unbolting, leaving the exposed impeller with the upper portion.

Removal of the pump from the tank and transfer to the cleaning and maintenance area in the maintenance cask or bagging requires a series of operations closely paralleling those used for the IHX tube bundle. One of the design requirements of this pump is that draining the primary loop should drain the pump, which has sodium up to within a few inches of the temperature radiation baffles during operation. The criterion of drainability requires the inclusion of many slots and small by-pass flow paths which are otherwise unnecessary or undesirable; accordingly, draining may be slow and perhaps incomplete. It is nevertheless proposed that the first step in cleaning the pump be the use of moist inert gas. To do this will require a tank about 38 feet high and 8 feet in diameter flanged to accept the pump flange. Use of a prototype or spare pump tank, paralleling the approach used with the IHX is not recommended since it would not result in significant flow in the upper portions of the assembly.

A final decision has not yet been reached on at what stage in the cleaning procedure the inlet-outlet-diffuser section should be removed from the upper portion of the pump. Based on the assumption that the pump will be radioactive, the feeling at

References:

1. NAA-SI-388
2. EBR-2 Fuel Cleaning H FEF/S - Procedure FCF-OM-281.4, Revised April 1971, "Standard Subassembly Transfer and Sodium Cleaning Operation."
3. T. P. Roso, "Primary Sodium System Pumps in the Enrico Fermi Atomic Power Plant," APDA-309 (Atomic Power Development Associates, Inc.), June 1969.
4. G. R. Taylor, ARD, personal communication.
5. J. L. Van Ullen and R. D. Wylie, "Metallurgical Problems of Liquid Metal Heat Exchangers," Unnumbered Report, Knolls Atomic Power Laboratory, January 14, 1957.
6. KAPL-M-WWK-4, "Cleaning of 4-inch Sodium Loop at Alplans Base by Two Methods, Alcohol and Steam, May 14, 1954.
7. R. Cochran, personal communication.
8. R. H. Anderson, J. A. Ford, P. S. Lindsey, "Design, Fabrication, and Preliminary Operation of the Steam Generators for the Enrico Fermi Atomic Power Plant, APDA-307 (Atomic Power Development Associates, Inc.), August 1968.
9. B. C. Cerutti, G. R. Deegan, J. D. Nulton, W. H. Perry, and R. E. Seever, "Removal and Repair of EBR-II Primary Sodium Pump No. 1," ANL-7835 (Argonne National Laboratory), May 1972.
10. "SRE Operates Again with Core 2..." Nucleonics, Vol. 20, No. 1, January 1962.
11. W. L. Chase, E. C. Kovacic, et al, APDA Technical Memo No. 35, "Carbon in the Primary Sodium System of the Enrico Fermi Atomic Power Plant," August 1, 1963.

present is that the cleaning should be carried through to a full water rinse in the inerted tank, before any disassembly, and hence, even in the non-radioactive condition the same techniques should be used. After this, the pump can be removed for disassembly in air, using semi-remote tooling and/or localized shielding. Once the lower assembly and impeller are removed, the radioactivity of the upper portion will probably be low enough to permit essentially contact inspection and maintenance operations, including further cleaning if necessary. The lower assembly and impeller can then be radioactively decontaminated in intermediate or small-sized vessels if required.

Clearly, for both the IHX tube bundle and the pump assembly, the specification of time-temperature-concentration conditions and the establishment of decision points in the procedures awaits the output of the development programs.

Similarly, detailed design of some aspects of the necessary cleaning facilities must await development results, although there can be little doubt that a large, versatile facility will be required at HEDL as part of the FFTF complex.

References (cont'd.)

12. HN 8112.1, Conceptual System Design Description, CHCF, Volume 1, August 1971.
13. Project WCP-704, System Design Description for the Alkali Metal Cleaning Facility, December 1972.

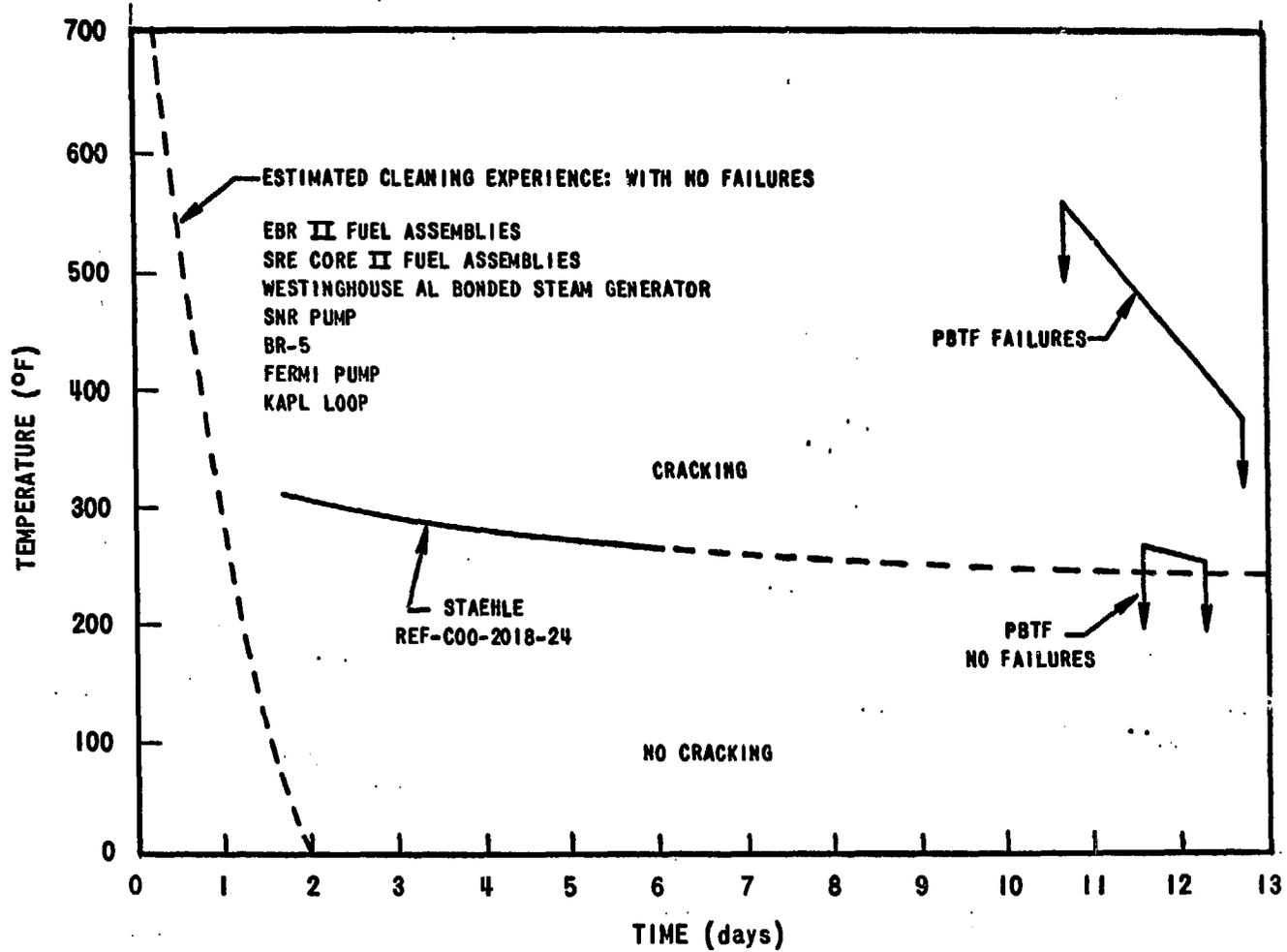


Figure 1. Reported Caustic Stress Corrosion Behavior in 300 Series Stainless Steels

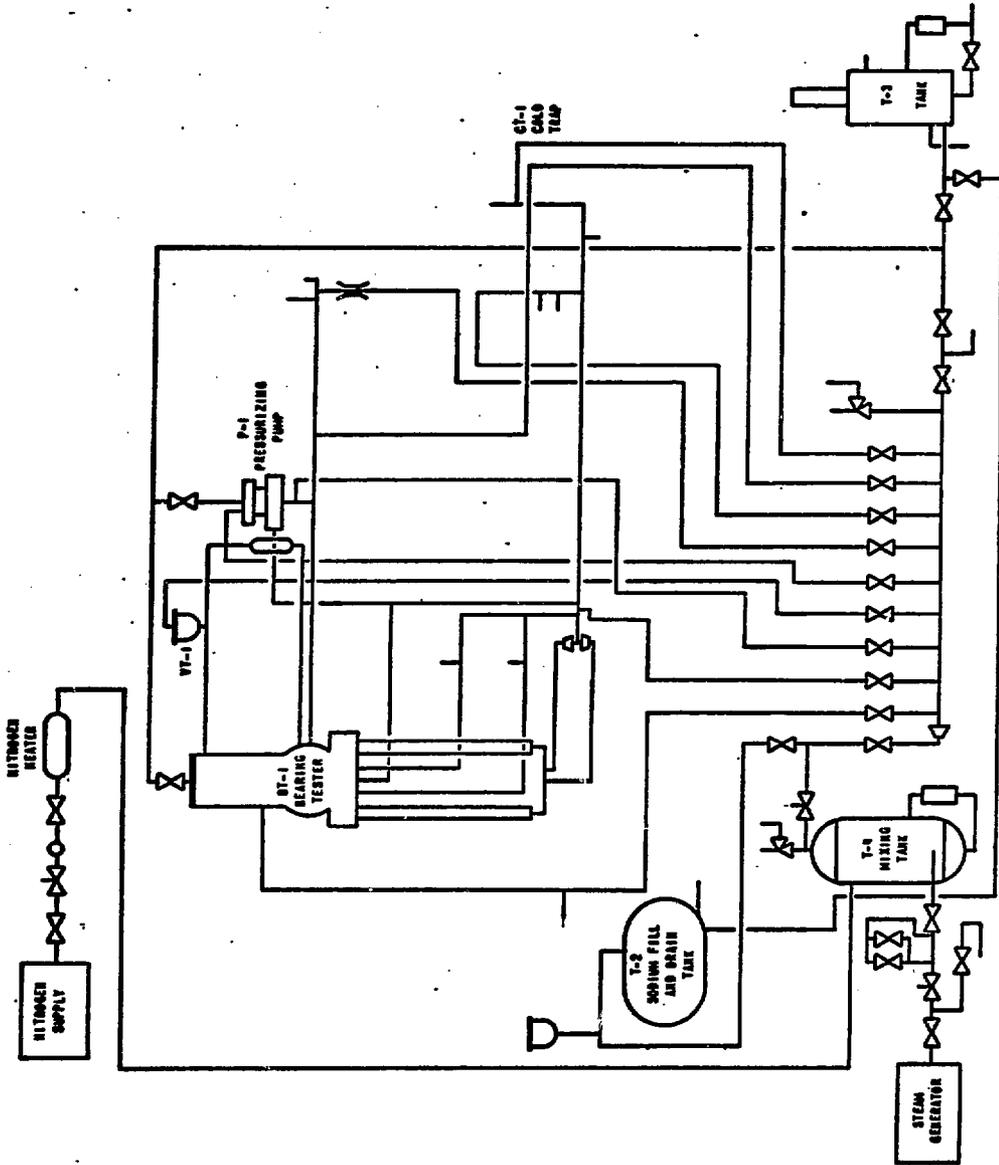


Figure 2. P&I Diagram of PBTF Modified for Steam Cleaning

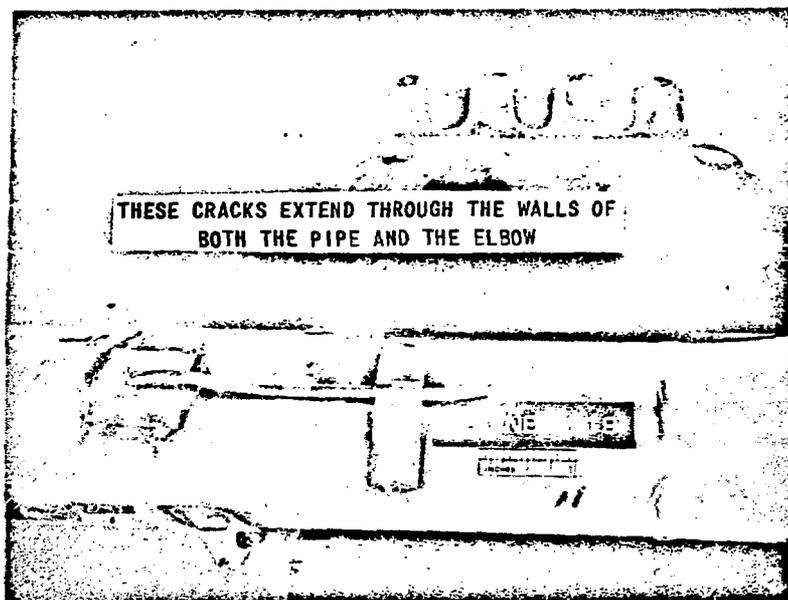


Figure 3. Results of Dye Penetrant Examination Showing Cracks Associated With Tack Welds and a Butt Weld on PBTf Piping



Figure 4. Typical Transgranular ID Cracks in 2 in. Pipe From PBTf
Mag 100X

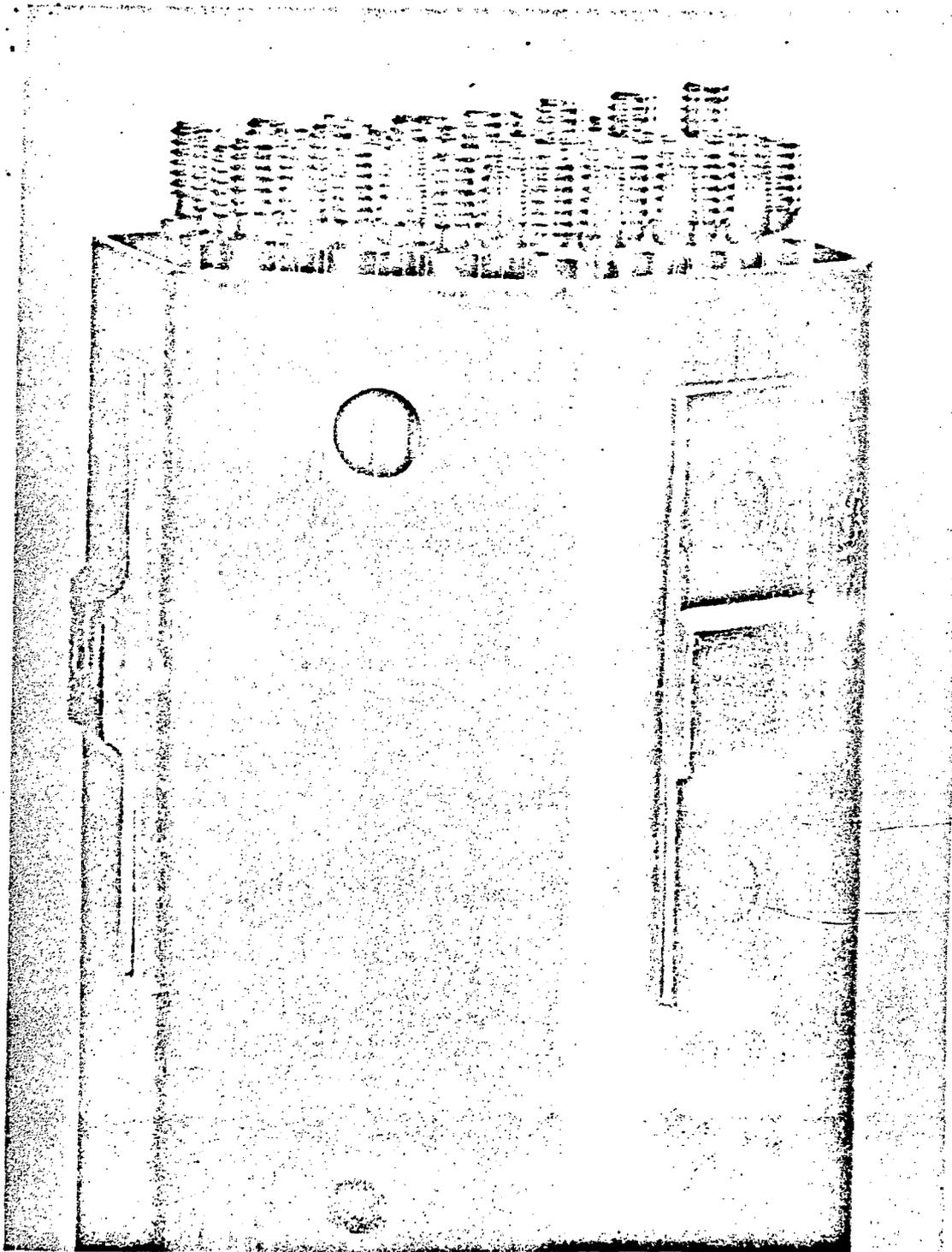


Figure 5. Top of SAFT Fuel Pin Bundle Showing Cleanliness After Vacuum Distillation Cleaning

5609-6

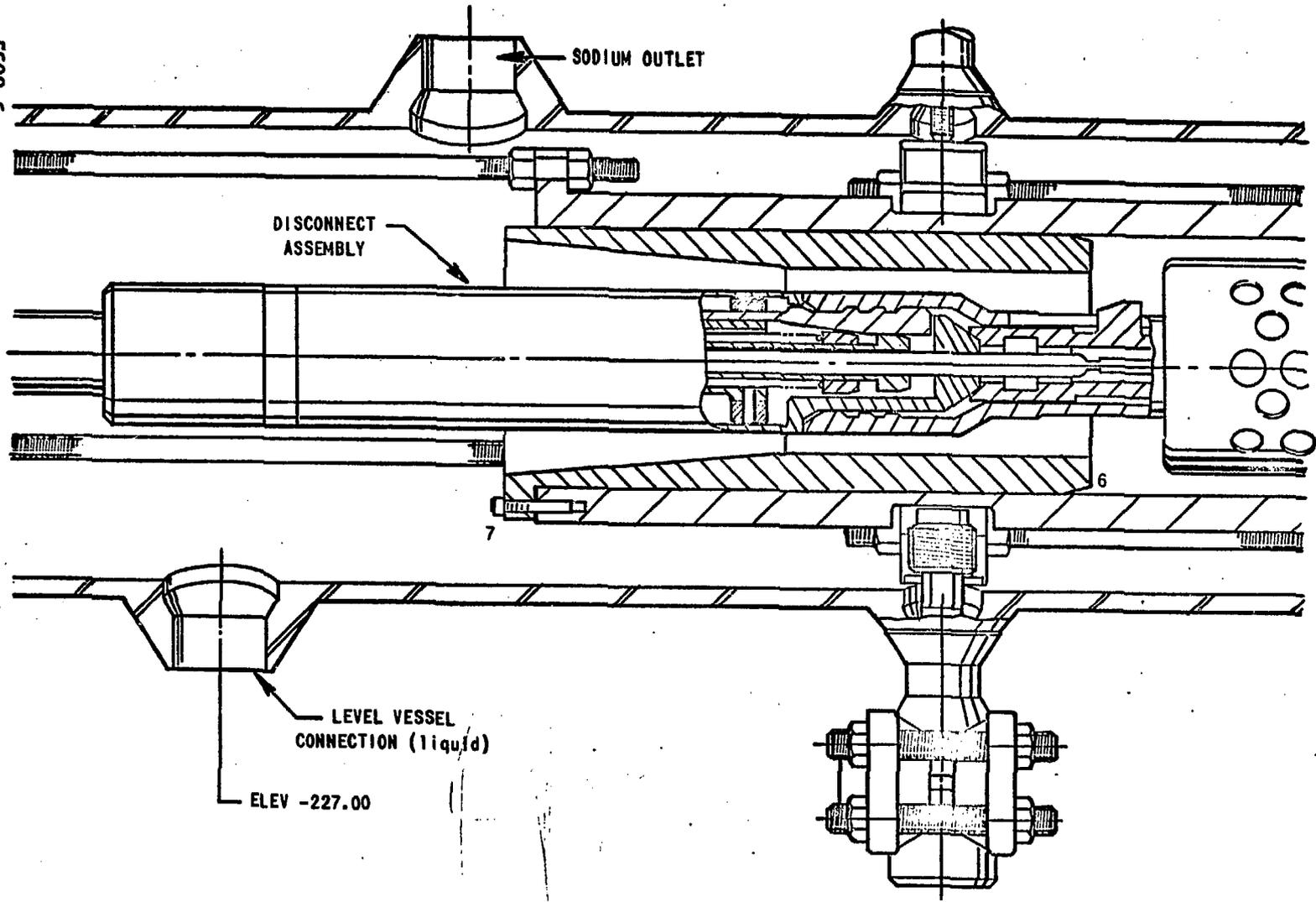


Figure 6. Part of Control Rod Assembly Illustrating Complex Configuration for Cleaning

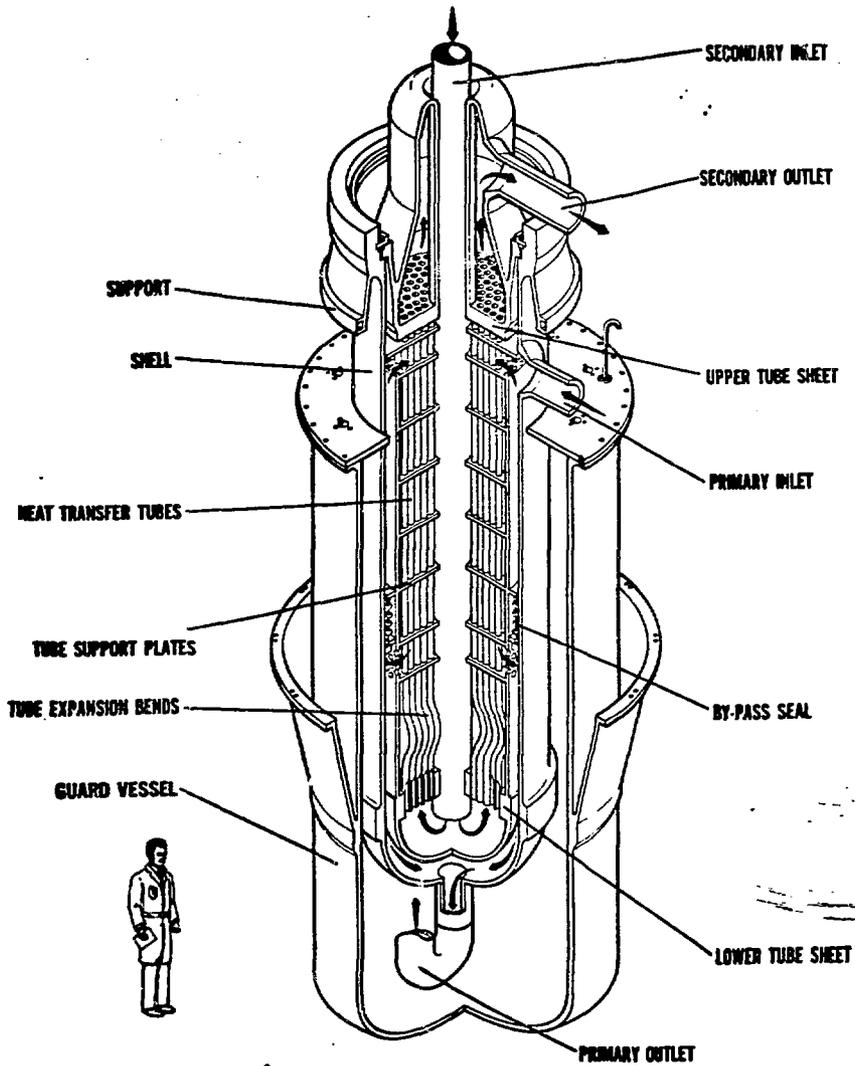
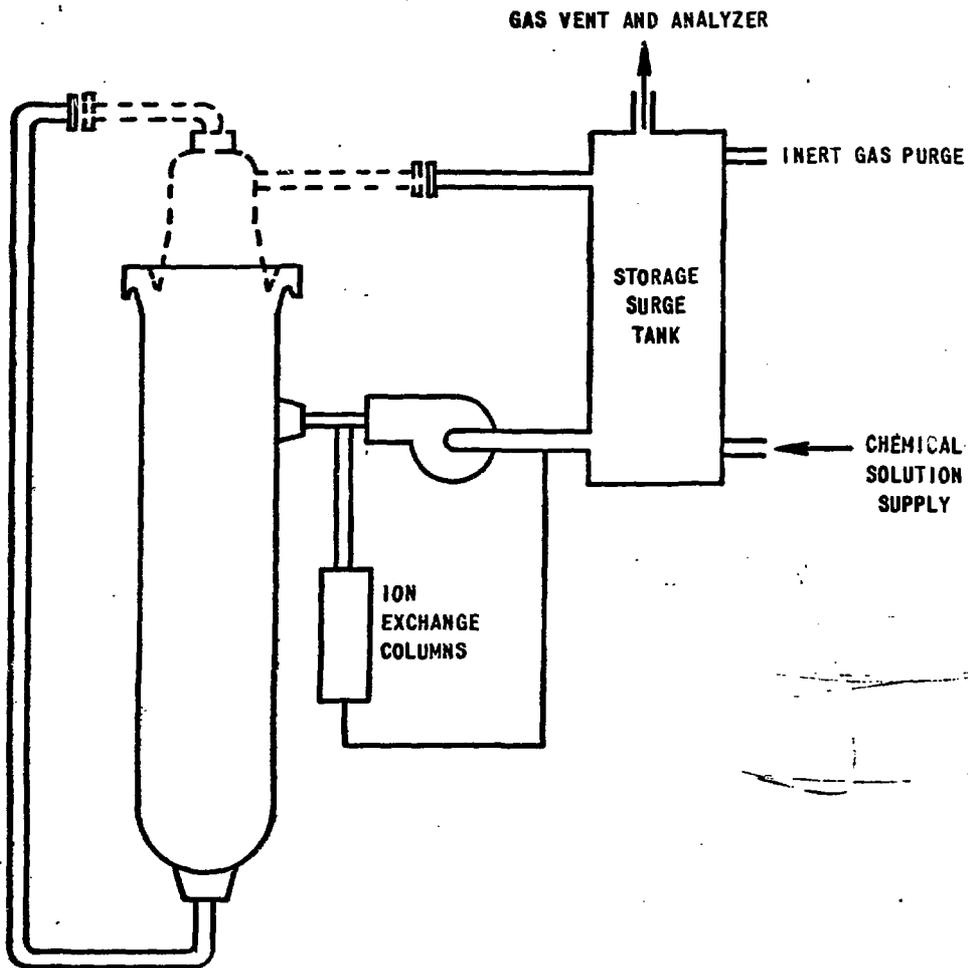


Figure 7. Intermediate Heat Exchanger and Guard Vessel



SOLID LINES ARE PERMANENT
CLEANING FACILITY LINES

DOTTED LINES ARE INSTALLED
FOR IHX TUBE BUNDLE CLEANING

Figure 8. Schematic of FTFF Tube Bundle Installed for Alcohol Cleaning

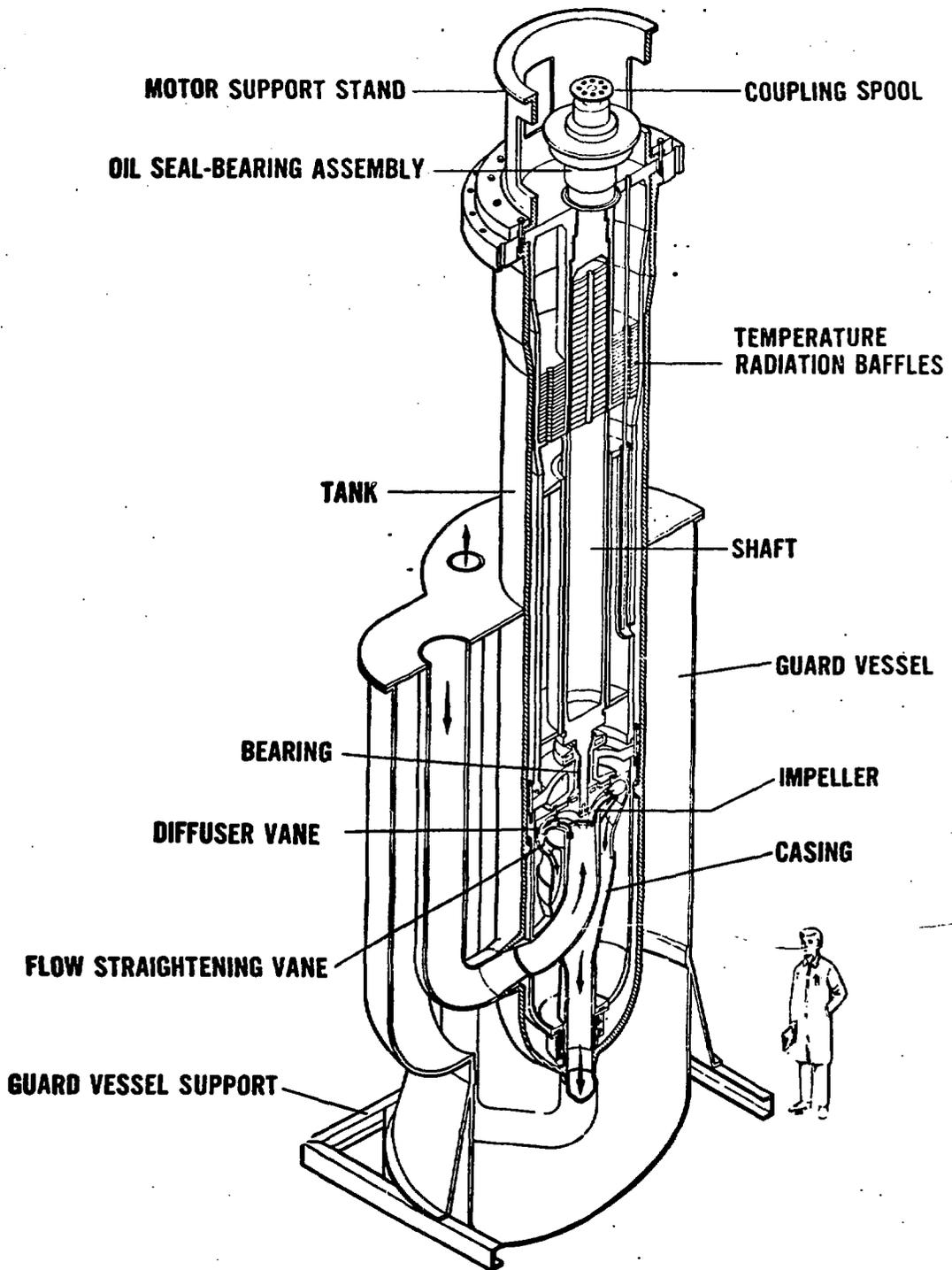


Figure 9. Primary Pump With Guard Vessel