

Fig. 9 Stress corrosion specimen stripped down with sodium on the thread

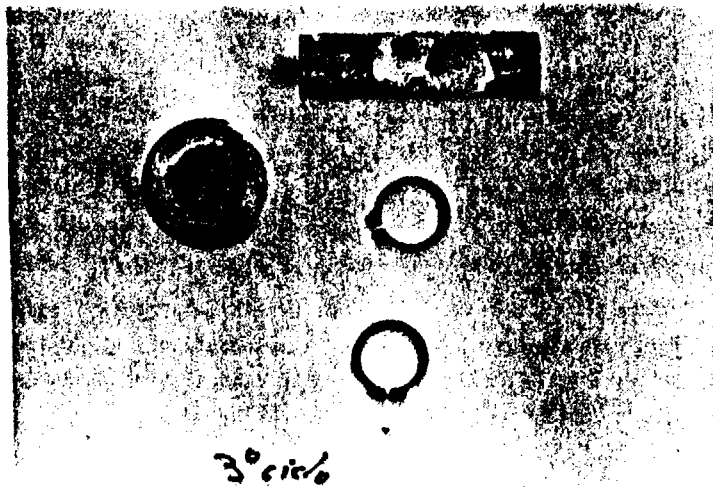


Fig.10 Rolling coupling showing sodium remains

SUMMARY OF SODIUM REMOVAL AND DECONTAMINATION PROGRAMS IN THE USA

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The goals of the United States Department of Energy sodium removal and decontamination programs are 1) to identify plant requirements and develop safe effective processes for sodium removal, both for experimental facilities and for reactor components, 2) to develop effective decontamination processes for removing deposited radioactivity, 3) to establish and put into use a set of workable criteria for requalification and return to service of components after sodium removal and decontamination, 4) to design, build and operate facilities in which to perform the sodium removal and decontamination operations. This paper gives a summary of progress toward each of these goals; details will be presented in other papers at this meeting.

Three basic processes for sodium removal have been investigated extensively: the use of water vapor in an inert carrier gas, the use of an alcohol-type reagent, and evaporation. The process development work on the first two processes has been essentially completed. The evaporative process is still under development, but preliminary parameters have been established.

The water vapor-nitrogen (WVN) process uses a mixture of nitrogen and water vapor in concentrations as high as 15%, at temperatures of 71° to 88°C, followed by rinsing in demineralized water and drying in nitrogen or vacuum. The reaction rate of residual sodium with the water vapor-nitrogen mixture is controlled by measuring the hydrogen concentration of the effluent gas, and increasing or decreasing the water vapor concentration accordingly.



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Reaction of sodium in crevices and other inaccessible locations was increased by increasing system pressure to aid gas penetration of restricted areas, followed by depressurization to allow removal of the hydrogen. The WVN process has been demonstrated on both large reactor and experimental components.

In the water vapor-argon process, adopted specifically for the removal of sodium from the EBR-II and FFTF fuel assemblies, argon gas is bubbled through water and then blown through the assemblies to be cleaned. The resultant water vapor concentration is typically 0.5% to 4%. Following reaction of sodium and water vapor to form sodium hydroxide, the surfaces are rinsed with water. The argon and water are at room temperature to provide removal of up to seven kilowatts of decay heat from the fuel assemblies. Minor variations of this procedure have been made to accommodate special requirements of experimental fuel assemblies.

The alcohol process uses hot, denatured ethanol to react the residual sodium forming hydrogen and sodium ethylate. The cleaning operation is performed in a closed vessel. The reaction rate can be regulated by controlling the temperature of the alcohol. Completion of the reaction is determined by the termination of the hydrogen evolution which is measured by monitoring the effluent gas.

A variation of the alcohol process uses acidified, denatured ethanol where the composition of the alcohol process fluid has been adjusted by the addition of 1.5 volume percent of acetic acid. This acidic ethanol solution has the advantage of remaining acidic during the cleaning process, neutralizing the basicity and thus eliminates any caustic which may be formed. The acid addition has the disadvantage of lowering the solution solubility for sodium ethylate.

The evaporative process, as it is evolving, employs temperatures in the range of 260°C to 340°C and vacuum of 10^{-5} to 10^{-6} torr. (1.3×10^{-3} to 1.3×10^{-4} Pa) for the removal of sodium. Under these conditions, it has been demonstrated that sodium is rapidly removed from deep, tight crevices by a gas expulsion phenomenon. Because of this expulsion of the sodium from the crevices, followed by evaporation from the exposed surfaces, the sodium removal rates for the evaporative process are more rapid than one would calculate from gas diffusion theory.

For breeder reactor primary system components, a need also exists to have a decontamination process for the removal of deposited corrosion products, chiefly ^{54}Mn and ^{60}Co , and fission products such as ^{137}Cs and $^{95}\text{Nb-Zr}$. Studies have shown that substantial fractions of all species except ^{137}Cs are firmly bonded to or diffused into the deposition surface. Often the radioactivity is incorporated in deposits that have physical and chemical characteristics quite different from the underlying austenitic stainless steel.

Work is progressing on the development of a decontamination process. An initial selection led to a concentration of effort on an acid process. It was hoped that a reagent could be found which would uniformly etch away a thin surface layer of the base metal containing the diffused radioactivity without any damage to the base metal structure. This ideal situation is not completely realized in practice. However, a process based on a water solution of 2.5 percent glycolic - 2.5 percent citric acid, is being developed. At process temperatures between 70°C and 90°C, this solution will remove the contamination to the necessary degree and produce less damage to the base structure than any other acid reagent investigated. The reaction rates vary widely depending on material chemistry and past operating history, and are extremely sensitive to dissolved oxygen. A preliminary process condition has been defined for more extensive evaluation under system conditions.

The criteria for requalification of components subjected to both the sodium removal and decontamination processes are currently being developed. For decontamination processes, at the present, a maximum of 25 μm metal removal and 51 μm intergranular penetration or pitting is specified.

All sodium removal processes are reasonably effective at their present state of development; however, further refinement would be desirable to minimize process time and reduce the volume of radioactive waste solutions.

A number of sodium removal facilities have been designed and constructed or are under construction in the U. S. Table 1 is a partial list of these facilities, the process for which they are designed, and some of the items that have been processed in each. The Sodium Removal Development Apparatus (SRDA) facility at HEDL and the Sodium Alcohol Process Facility (Na/APF) at AI are being modified to be used in the decontamination process evaluation.

One limitation that has been encountered with the use of both the WVN and the alcohol processes is the failure to remove sodium from tight-fitting crevices. Current test results indicate that the evaporative process may perform this type cleaning operation more satisfactorily than either chemical process.

In the cleaning of the FFTF In-Vessel Handling Machine in the Alkali Metal Cleaning Facility (AMCF) with the WVN Process, some unreacted sodium remained in a cavity into which the water vapor did not penetrate. This sodium reacted with water during the rinse cycle producing a localized pressure surge. Revision of the operating procedure to use longer vapor phase processing during the gas phase reaction will minimize such problems. Multiple cleaning operations on a model of the IVHM have demonstrated this.

The FFTF Dump Heat Exchanger which was cleaned in the Component Handling and Cleaning Facility (CHCF) had horizontal tubes which were partially blocked with solid sodium plugs. The alcohol in these tubes stagnated and became saturated with sodium. To complete the cleaning operation, it was necessary to mechanically rock the tube bundle to force fresh alcohol into the tubes.

Subsequent development tests have shown that, although the maximum reaction rate of the sodium/alcohol occurs just below the normal boiling point of alcohol, with a pressurized system the sodium-alcohol reaction is stable well above the melting point of sodium. With this information, future operations of this type could be performed at temperatures high enough to melt out the sodium plugs.

To date in the United States, process parameters have been determined for two sodium removal processes - Water Vapor in an inert gas carrier, and Ethanol Alcohol - and these have been demonstrated at a number of different sites. Process selection depends on the particular application. Laboratory development work has been performed on the evaporative process, but no large system demonstrations have been performed.

Process development work is progressing on an acidic reagent decontamination process, but final selection of the process parameters and demonstration of the process remains to be done. The requalification methods and criteria have yet to be approved and reduced to practice.

TABLE I
SODIUM REMOVAL FACILITIES IN U. S.

Operator	Facility	Approx. Dia.	Size Ft. (meters) Height	Process	Typical Items Processed
Westinghouse Hanford Engineering Development Laboratory (HEDL)	Sodium Removal Development Apparatus (SRDA)	2-1/2 (0.76)	12 (3.6)	Water Vapor-Nitrogen	Process Development, Intermediate Heat Exchanger Tube Mockup, Small Valves, Cold Trap Heat Exchanger, Pump Mockup
	Sodium Removal Development Apparatus Number II (SRDA-II)	2 (0.6)	12 (3.6)	Alcohol	IVHM Mockup
	Alkali Metal Cleaning Facility (AMCF)	9 (2.7)	40 (12)	Water Vapor-Nitrogen	FFTF In-Vessel Handling (IVHM)
Westinghouse Advanced Reactor Division (WARD)	In situ	1/3 (0.1)	50 (15)	Alcohol	Steam Generator Mockup
	Sodium Cleaning Facility (NaCF)	2-1/2 (0.76) 2 (0.6) 1/2 (0.15)	7 (2.1) 16 (4.9) 22 (6.7)	Water Vapor-Argon	16" (0.4m) Pipe Elbow, CLIMA Piston Ring Test, Jet Heat Transfer Test Assembly, FFTF Control Rod Mechanism
	Sodium Removal Facility (Temporary)	3 (0.91)	20 (6.1)	Downanol PM (Propylene glycol-methyl ether)	Pump Bearing Test Assembly
Atoms International	Sodium/Alcohol Process Facility (Na/APF)	3-1/2 (1.1)	9 (2.7)	Alcohol	Process Development, IHX Tube Bundle Mockup, IVHM Mockup Valves, EM Pumps, Mechanical Pumps, Cold Trap
	Radioactive Sodium Removal Facility	3 (0.91)	7 (2.1)	Alcohol	SRE Auxiliary Pump, Valves, Hot Traps, Pipe
Operator	Facility	Approx. Dia.	Size Ft. (meters) Height	Process	Typical Items Processed
Atoms International (continued)	SRE Components In situ	12 (3.7)	27 (8.2)	Alcohol	SRE Core Vessel, Cold Traps, Economizer, Primary Heat Exchanger, Primary Pump
Atoms International Liquid Metal Engineering Center	Component Handling and Cleaning Facility	9-1/2 (2.9)	39 (11.8)	Alcohol	FFTF Pump and Dump Heat Exchanger
	In Situ	1-1/2 (0.46)	68 (21)	Downanol-PM and Alcohol	A1-Modular Steam Generator
General Electric Sunnysale	Sodium Cleaning Facility (SCF)	1-1/2 (0.40)	24 (7.3)	Alcohol	Under Construction
Argonne National Laboratory (ANL)	Sodium Components	3-1/2 (1.1)	5 (1.5)	Alcohol	Under construction
	Maintenance Shop	7 (2.1)	22 (6.7)		
	Inter Building Cask System	1/3 (0.091)	8 (2.4)	Water Vapor-Argon	EBR-II Fuel Subassemblies