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Control of Oxygen, Hydrogen, and Tritium in Sodium Systems
at Experimental Breeder Reactor II

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ABSTRACT

The source rates and steady-state concentrations have been measured for oxygen, hydrogen, and tritium impurities in EBR-II sodium systems. An analytical approach is used to determine the effectiveness of the cold traps for removing oxygen, hydrogen, and tritium. The cold-trap effectiveness data accumulated to date for removal of oxygen, hydrogen, and tritium indicate that EBR-II cold traps are highly effective in controlling these impurities to very low concentrations in the sodium systems.

Introduction

Oxygen and hydrogen are major nonmetallic impurities found in the primary and secondary systems at the Experimental Breeder Reactor II (EBR-II). Tritium is a major radionuclide contaminate in the primary and secondary systems. All three of these impurities, if allowed to reach excessive levels in the sodium, could become potential hazards to the operation of EBR-II: oxygen and hydrogen for their effects on corrosion and sodium-flow blockage; and tritium for its potential biological dangers if released to the environment.

Oxygen, hydrogen, and tritium are controlled to low levels by continuous cold-trapping of the primary and secondary sodium systems. The effectiveness of the cold traps in removing these impurities can be determined quantitatively by measuring concentrations, source rates, and removal rates of the impurities.¹ Cold-trap effectiveness data accumulated throughout the history of EBR-II support the conclusion that EBR-II cold traps are very effective in controlling oxygen, hydrogen, and tritium levels.

Source-rate Data

Impurity source rates are determined by measuring the increasing concentration of impurities in sodium when the cold trap is isolated from the system. Table I summarizes this data for oxygen, hydrogen, and tritium.

The source of oxygen and hydrogen into the primary sodium is principally from residual moisture on fuel-handling equipment. Significant source rates are observed only during periods of fuel handling, when subassemblies are inserted into or removed from the primary tank. For this reason, oxygen and hydrogen source rates into the primary sodium are best reported on a "per fuel handling" basis. Additional oxygen ingress has been attributed to intermittent air inleakage into the primary cover-gas space.

TABLE I

Oxygen, Hydrogen, and Tritium Source Rates at EBR-II
(Reactor at Full Power)

<u>Impurity</u>	<u>Source Rates (average values)</u>	
	<u>Primary Sodium</u>	<u>Secondary Sodium</u>
Oxygen	7 g/fuel handling	0.3 g/d
Hydrogen	0.5 g/fuel handling	0.5 g/d ^b
Tritium	14 GBq/d ^a	0.9 GBq/d

^aA becquerl (Bq) is a disintegration per second (SI unit)

^bIn terms of hydrogen flux through the steam generator, this value is 1.1×10^{-12} g/cm²-s

Tritium is produced in the primary system principally by ternary fission in the fuel and subsequent diffusion of the tritium through the fuel cladding into the sodium. Tritium may also be formed by neutron activation of boron carbide control rods present in the reactor core.

The small, but measurable, oxygen source rate into secondary sodium is most likely due to oxygen contamination in the cover gas. Hydrogen diffuses into the secondary sodium from water-side corrosion of the steam-generator tubes. Tritium enters the secondary sodium from the primary sodium via diffusion through the intermediate heat exchanger.

Steady-State Impurity Levels

The oxygen, hydrogen, and tritium impurities are controlled to near their solubility limits by continuous cold trapping of the sodium. Table II lists the steady-state impurity levels normally measured when the reactor is at full power. The much lower steady-state levels of oxygen and tritium in secondary sodium (Table II) are attributed to their much lower source-rates (Table I) as compared to that in the primary sodium. The solubility concentrations of oxygen and hydrogen in sodium at the operating temperature of the cold traps (120°C) are 0.7 ppm oxygen and 55 ppb hydrogen respectively.

Cold-Trap Effectiveness

The rate of removal of any impurity depends on impurity source rate, sodium inventory, cold-trap flow rate, and cold-trap effectiveness, according to the equation described in reference 1.

The cold trap effectiveness is defined as the ratio of the quantity of impurity removed per pass to the quantity that could theoretically be removed, and is expressed in percent.

By comparing actual data with theoretical curves, cold-trap effectiveness for removal of oxygen, hydrogen, and tritium from sodium was estimated. The periods studied were those following an increase in impurity levels (i.e.,

TABLE II

Steady-State Impurity Levels

<u>Impurity</u>	<u>Steady-State Impurity Level at 62.5 MW_t</u>	
	<u>Primary Sodium</u>	<u>Secondary Sodium</u>
Oxygen	1.2 ppm	0.7 ppm
Hydrogen	80 ppb	100 ppb
Tritium	3 kBq/g	0.3 kBq/g

following an outage of a cold trap, or a change in the operating temperature of a cold trap); where the subsequent clean-up of the impurity could be analyzed. Figure 1 illustrates the actual and theoretical results of one such study, shown graphically as a plot of "fraction of impurity remaining" versus "time." The actual data falls very close to the theoretical 90% cold-trap-effectiveness curve.

Table III summarizes the results of effectiveness studies performed on EBR-II cold traps. The data are organized according to the age of the cold trap, where age is defined as the number of years of cold-trap operation.

From Table III we conclude:

- (1) For a trap of a given age, oxygen is removed less effectively than hydrogen (or tritium). This is to be expected since crystallization is dependent on diffusivity of the particle, which in turn depends on the particle volume.²⁻⁵
- (2) Hydrogen and tritium are trapped with similar effectiveness, suggesting that Na^3H is removed via coprecipitation with NaH .⁶
- (3) A comparison of cold-trap effectiveness versus time indicates that trap effectiveness passes through a maximum as the trap ages. Initially, the trap's effectiveness increases as impurity crystals accumulate, providing more surface area for further crystallization. The effectiveness reaches its maximum early in the trap's lifetime. Then, the effectiveness gradually lessens as the trap becomes choked with precipitates.

TABLE III

Cold Trap Effectiveness Data

<u>Cold Trap</u>	Age of Cold Trap, <u>yrs. of Operation</u>	<u>Cold Trap Effectiveness, % Impurity Removed per Pass</u>		
		<u>Oxygen</u>	<u>Hydrogen</u>	<u>Tritium</u>
Primary	0.1	45	70	45
	0.3	50	90	--
	0.7	80	95	85
	7.0	30	75	--
Secondary	0.2	10	70	60
	0.7	20	90	50
	1.8	40	85	80
	4.7	--	50	--
	5.5	--	25	--

Recent data on oxygen, hydrogen, and tritium levels in primary and secondary sodium are shown in Figures 2 and 3, together with concurrent data showing impurity source rates (measured during periods of reactor full power) cold-trap effectiveness, and reactor power level. The impurity concentrations in both primary and secondary sodium were measured by on-line oxygen,⁷ hydrogen,⁸ and tritium⁹ meters. For the periods covered, the primary cold trap had been in use approximately 8 months, and the secondary cold trap approximately 1.8 years. Note that, in Figure 3, effectiveness was determined once during reactor full power (when impurity source rates are greatest) and again with the reactor shut down (when source rates are minimal). Effectiveness data do not differ significantly between the two periods.

Conclusions

Oxygen, hydrogen, and tritium impurities in EBR-II sodium are well controlled to near their solubility limits by continuous cold-trapping. The cold trap effectiveness is strongly dependent upon the type of impurity being removed, cold-trap operating parameters, and the age of the trap. The EBR-II cold traps can operate up to 5-7 years and still exhibit effective removal of oxygen, hydrogen, and tritium.

FOOTNOTES

^a The solubility concentrations are based on equations found in RDT Standard F-3-40T, Appndix N (January 1976):

Oxygen: $\log C \text{ (ppm)} = 7.006 - 2820/T(^{\circ}\text{K})$

Hydrogen: $\log C \text{ (ppm)} = 6.067 - 2880/T(^{\circ}\text{K})$

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