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Transport Problems in a CTR**

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Preliminary Assessment of Corrosion Product

Transport Problems in a CTR

Corrosion products generated at one location in a flowing circuit typically are transported and deposited at other locations. This process has caused some problems in water reactors;^(1,2) potential corrosion product problems and associated solutions are being evaluated in Liquid Metal Fast Breeder Reactor (LMFBR) technology studies.^(3,4) In fusion reactor systems relying on lithium or molten salts for heat transfer, corrosion product transport considerations may have a significant bearing on materials selection and plant design. The four essential factors considered here are: corrosion product generation, transport, deposition and removal. Corrosion product generation in CTR's is amplified by the relatively large areas in contact with the primary coolant. The system parameters which apply to the Wisconsin Toroidal Fusion Reactor (UWMAK-1) appear in Table I. By comparison with the area cited in Table I, the area of the Fast Flux Test Facility (FFTF) primary circuit is $\sim 1 \times 10^3 \text{ m}^2$.⁽³⁾ The proposed construction material for the UWMAK-1 primary circuit is 316 stainless steel; the composition appears in Table II.

Accurate assessment of corrosion phenomena in lithium-cooled CTR's is compromised by the relatively small amount of pertinent data. The published data for corrosion of stainless steel in lithium are reviewed elsewhere.⁽⁵⁾ The UWMAK-1 lithium inlet and outlet temperatures are 300 and 500°C. Corresponding stainless steel corrosion rates are reported to be 0.01 and 1 mg/cm² mo based on short-term exposures to flowing lithium (15-85 cm/sec).⁽⁶⁾ These corrosion

rates, extended to an annual basis, indicate that approximately 2500 kg/y of corrosion product would be released to the primary circuit due to thermal corrosion.

Fast neutron sputtering from the lithium side of the first wall also appears to be a substantial materials transport mechanism, paralleling projected behavior for sodium systems.⁽⁷⁾ The first wall area in UWMAK-1 is about 10% of the primary circuit area. The estimated sputtering rate for stainless steel is 9×10^{-3} atoms/n.⁽⁸⁾ Using the calculated neutrons flux on the lithium side of the first wall (4.7×10^{14} n/cm²sec), the indicated material loss from the inside surface of the first wall due to sputtering is ~250kg/y.

While the accuracy of the calculated rates of corrosion product release is in question, the magnitude focusses on the importance of considering corrosion product generation and transport in future experiments and eventually in plant design and materials selection if the order of magnitude is correct.

The corrosion of stainless steel in lithium at 500-600°C does not release the individual constituents in the stoichiometry shown in Table II. Nickel is reported to be a principal element transferred; chromium, manganese, silicon, and carbon were detectable in the stainless steel corrosion product deposits.^(6,9) Selective leaching of nickel results in development of a ferrite phase on the corroding stainless steel surface. The corrosion rate reportedly is controlled by solid-phase diffusion through the ferrite layer in the temperature range of 510-610°C.^(6,9)

Corrosion data for other CTR candidate materials (alloys of Mo, Nb, and V) suggest that transport rates due to thermal corrosion

may be orders of magnitude lower than those calculated for stainless steel, even at higher operating temperatures projected for CTR's constructed from the refractory metals. The corrosion rates generally are reported as "nil" or "slight". Quantitative corrosion rate data for a Nb-1Zr alloy in flowing lithium at 1200°C⁽¹⁰⁾ indicate that the thermal corrosion product transport rate would be ~5 kg/y in a system having the area shown in Table 1. The principal species transferred were zirconium, nitrogen and carbon in the study cited. Estimated sputtering rates in the niobium system indicate that approximately 125 kg/y would be added to the lithium from sputtering, based on a sputtering ratio of $\sim 4 \times 10^{-3}$ atoms/n for niobium.⁽⁸⁾

Corrosion products will be carried to all parts of the primary circuit in solution and also possibly as particulates. Corrosion product deposition tends to be most severe in the cooler regions of liquid metal circuits.^(4,6) Potential problems due to corrosion product deposition include: fouling of heat transfer surfaces; plugging of heat exchanger tubes, valves and instrument sensor lines; fouling of tritium extraction surfaces; development of high radiation levels in reactor maintenance areas. The radioactivity content of 2500 kg of stoichiometric stainless steel corrosion product from UWMAK-1 is estimated to be 4×10^6 curies. Radiation levels in an FFTF heat transport system cell are estimated to be 1 to 15 Rad/hr,⁽³⁾ based on a stainless steel corrosion product inventory which appears to be approximately three orders of magnitude below the estimated CTR inventory, portending that relatively high radiation fields would develop near out-of-reactor regions of a stainless steel CTR circuit. Based on half life considerations, stainless steel is the least desirable

and vanadium appears to be the most desirable candidate material for rapid decay of activity in reactor maintenance areas.⁽¹⁰⁾

Stainless steel is the only CTR candidate material with a well-developed industry, opting for its consideration as a construction material in first-generation plants. If this incentive persists as the time to build the first plant approaches, a major effort will be needed to determine corrosion and corrosion product transport rates under prototypical CTR conditions. Extraction of corrosion products from the primary system almost certainly would be required if the estimated transport rate is accurate. Preliminary studies are underway to investigate corrosion product removal from LMFBR systems, either continuously⁽³⁾ or by dissolution during plant shutdowns.⁽⁴⁾ Similar studies probably will be necessary to identify optimum methods for corrosion product removal from lithium-cooled systems.

In summary, Table IV-C-8 compares corrosion product transport effects for two materials, 316 SS and Nb-1Zr. Literature values for thermal corrosion of stainless steel at 300-500°C indicate substantially higher rates than the rates for Nb-1Zr at 1200°C. Therefore, corrosion product transport for stainless steel appears to present substantial problems to CTR operation from corrosion product deposition and radioactivity transport. Corrosion product removal during plant operation, during shutdowns, or both almost certainly would be required.

A system designed at Princeton consists of a molten salt blanket and a helium coolant. In this concept, transport of large amounts of corrosion product to the primary heat exchanger could be avoided, but substantial problems may occur from transport to the tritium extraction system. However, the distribution of radioactivity would be more localized and heat exchanger fouling would be avoided, suggesting that the concept also may be attractive for a lithium system where corrosion product transport presents problems.

Thermal corrosion of Nb-1Zr appears to be sufficiently low, even at 1200°C to offer essentially no problem from deposition or radioactivity distribution. However, sputtering imposes additional considerations. In the case of stainless steel, sputtering adds an increment to an already-serious problem. In the case of Nb-1Zr, sputtering becomes the major source of circulating material, portending that it may impose the need for corrective measures in a system which otherwise might operate without cleanup.

Table I

Wisconsin Toroidal Fusion Reactor Parameters

Plant Rating	5000 MWth
Major Radius	13 m
Minor Radius	5.5 m
Primary Circuit Area in Contact with Lithium	$6 \times 10^4 \text{ m}^2$
Lithium in Primary Circuit	$8 \times 10^5 \text{ kg}$
Lithium Flow Rate, Maximum in Heat Removal Cells	5 cm/sec
Neutron Flux (E,0-14 MeV), Lithium Side of 1st Wall	$4.7 \times 10^{14} \text{ n/cm}^2 \text{ sec}$

Table II

Stainless Steel Composition Specifications

<u>316 Stainless Steel</u> <u>Weight Percent</u>	<u>Element</u>
Balance	Fe
16/18	Cr
10/14	Ni
2.0/3.0	Mo
2.0 max.	Mn
1.0 max	Si
0.080 max.	C
0.045 max.	P
0.030 max.	S

Table III

Comparison of Corrosion Product Transport in Lithium Primary Coolant

	<u>Source of Product</u>	
	<u>Thermal Corrosion</u>	<u>Sputtering</u> ^{a.}
316 Stainless Steel	2500 kg/y ^{b.}	250 kg/y
Nb-1Zr	5 kg/y ^{c.}	125 kg/y

- a. Based on sputtering from first wall, which is approximately 10 percent of the total primary system area.
- b. Based on thermal corrosion rates in the range of 300-500°C.
- c. Based on thermal corrosion rates at 1200°C, for the same system area used for stainless steel.

REFERENCES

1. G. J. Walke, R. W. Sinderman, C. E. Axtell, "The Effects of Failed Fuel on the Operation of a Commercial BWR Plant", Trans. Am. Nucl. Soc. 13, 165 (1970).
2. D. H. Charlesworth, "Water Reactor Plant Contamination and Decontamination Requirements-A Survey", Proceed. of Am. Power Conf. 33, 749 (1971).
3. T. J. Kabele, W. F. Brehm and D. R. Marr, "Activated Corrosion Product Radiation Levels in FFTF", Trans. Am. Nucl. Soc. 16, 108 (1973). See also HEDL-TME-72-71 (1972).
4. S. Weaver and E. Berkey, "Radioactive Decontamination Studies of LMFBR Coolant Systems:", Trans. Am. Nucl. Soc. 16, 109 (1973).
5. A. B. Johnson, Jr. and W. F. Vogelsang, Corrsion and Corrosion Product Transport in Lithium-Cooled Stainless Steel Fusion Reactor Circuits University of Wisconsin Fusion Design Memo FDM-54, July 1973.
6. W. N. Gill, R. P. Vanek, R. V. Jelinek and C. S. Grove, Jr., "Mass Transfer in Liquid - Lithium Systems", AIChE Journal, 6, 139 (1960).
7. J. N. Anno and J. A. Walowit, "Analysis of Corrosion of Stainless Steel in a Sodium and High Radiation Environment", incl. Tech. 10 67 (1971).
8. R. G. Brown, "The Effects of Sputtering and Blistering on the UWCTR First Wall", UW FDM-60, May, 1973.
9. H. W. Levenworth and D. P. Gregory, "Mass Transfer of Type 316 Stainless Steel by Liquid Lithium", Corrosion, 18, 43t (1962).
10. M. V. Davis, Selected Properties of Materials with Application to CTR Design, Argonne National Laboratory, ANL/CTR-72-01, p.143 (1972).
11. R. W. Boom, G. L. Kulcinski, C. W. Maynard, and W. F. Vogelsang, "Engineering Feasibility of a Fusion Reactor", University of Wisconsin Fusion Design Memo 43, May, 1973.