Experimental Investigation on Aluminum Precipitates by Chemical Effects in ECCS Sump Fluids under Post-LOCA Conditions

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1. Introduction

A variety of materials present in a reactor building may dissolve or corrode when exposed to reactor coolant and spray water solutions in a post-LOCA (Loss of Coolant Accident) environment, forming oxide particulate corrosion products and precipitates through chemical reactions with other dissolved materials. These chemical products could produce a considerable head loss through the emergency core cooling system filter screen. However, it is very difficult to predict the effects of chemical products on the head loss because of the variety of the chemical reactions occurred in the solution after a LOCA. The present study has been performed to evaluate experimentally the amount of chemical precipitates due to aluminum released from the post-LOCA sump fluids and to compare the results of the present tests with the USNRC approved methodology of WCAP-16530-NP-A [1].

2. Methods and Results

The chemical precipitate generation tests have been performed for 30 days under the post-LOCA conditions of OPR-1000. Figure 1 shows the test apparatus that consists of reactor, agitator and reactor cooling coil in the reactor head, auxiliary recirculation loop for measuring pH and electrical conductivity, chemical reagent introduction module, and pressurization module which enable to keep the pressure in the reactor higher than saturation vapor pressure. To protect the pH and electrical conductivity sensors and prevent thermal shock, heat condenser and pre-heater were instrumented in auxiliary recirculation loop.

The plant-specific containment materials introduced in the reactor to simulate the post-LOCA condition were glass fibers, concrete blocks, aluminum specimens, and chemical reagent – boric acid, spray additives or buffering chemicals (sodium hydroxide, Tri-Sodium Phosphate (TSP), or others). The inside temperature of the reactor was controlled by heater and cooling coil to simulate the plant-specific temperature profile in the post-LOCA condition.

After 30 days, the reactors are opened and all reactants and products are collected. Table 1 shows the concentration and total amount of aluminum dissolved in reactor solution. It is considered that this amount is very small because almost aluminum dissolved in solution take part in the reaction to produce the precipitate.

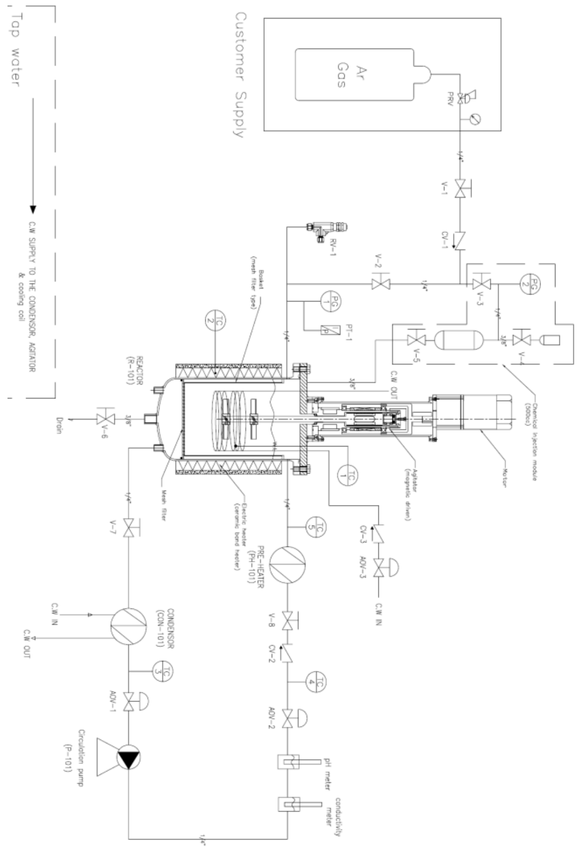

Fig. 1. P&ID of chemical precipitate generation apparatus.

Table 1. Concentration and total amount of aluminum dissolved in reactor solution (8.5L)

Reactor No.	Conc. of Al in reactor solution (ppm)	Amount of Al in reactor solution (mg)
1	0.78	6.62
2	0.98	8.33

Because the precipitates exists as a mixture with fibrous debris, all the fibrous debris and precipitates mixture scatted in reactor were dissolved in extremely strong acid (the mixture of aqua regia (nitro-hydrochloric acid) and Hydrofluoric Acid) to analyze the amount of each element. This strongly acidic solution is so acidic that this solution cannot be analyzed directly by ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectrometry). In this reason, this solution is treated for deacidification and dilution. Table 2 shows the concentration of aluminum in deacidified solution and total amount of aluminum in reactant-product mixuture.

Table 2. Concentration of aluminum in deacidified solution and total amount of aluminum in reactant-product mixture

Reactor No.	Amount of deacidified solution (L)	Conc. of Al in deacidified solution (ppm)	Amount of Al in mixture (mg)
1	0.72	140	100
2	0.56	213	119

The concentration and the amounts of each element in fiber glass put into the reactor before the 30 days test (4.95 g of fiber glass) is summarized in Table 3.

Table 3. Concentration and amount of each element which composes the fiber glass

Element	P	Ca	Al	Na
Conc. (ppm)	18.0	6.76×10^4	1.28×10^4	8.83×10^5
Amount in 4.95 g (mg)	0.09	3.34×10^2	63.0	4.35×10^2

After collecting all solution and reactant-product mixtures in reactor, there can be some residue so that it makes an error in analyzing the amount of each element. In this reason, 0.5 L of strong acid (1 M of hydrochloric acid) is used to clean up the reactor after the 30 days test and collected this cleaning solution to analyze by ICP-AES. The result of ICP-AES analysis for reactor cleaning solution is summarized in Table 4.

Table 4. Concentration and total amount of aluminum dissolved in cleaning solution (0.5L)

Reactor No.	Conc. of Al in reactor solution (ppm)	Amount of Al in cleaning solution (mg)
1	0.16	0.08
2	0.60	0.30

Using the data of Tables 1 ~ 4, the overall amount of aluminum released can be calculated by following;

$$\begin{bmatrix}\text{Overall amount}\\ \text{of Al released}\end{bmatrix} = \begin{bmatrix}\text{Amount of Al}\\ \text{in reactor solution}\end{bmatrix} + \begin{bmatrix}\text{Amount of Al}\\ \text{in cleaning solution}\end{bmatrix} + \begin{bmatrix}\text{Amount of Al}\\ \text{in reacant product}\\ \text{mixture}\end{bmatrix} - \begin{bmatrix}\text{Amount of Al}\\ \text{which compose}\\ \text{the fiber glass}\end{bmatrix} \quad (1)$$

Table 5 shows the total amount of aluminum released in reactor calculated using Eq.(1) and the converted amount to the actual plant specific condition that is compared to the total amount of aluminum released calculated by WCAP-16530-NP-A [1]. Table 6 shows the comparison of the amount of AlOOH and $NaAlSi_3O_8$ obtained by the present test and WCAP-16530-NP-A. The amount of aluminum released from sump fluids is estimated as 20.3 kg in the present tests that is 34.6% compared to 58.7 kg of WCAP-16530-NP model. The total amount of aluminum precipitates is estimated as 197 kg compared to 492.1 kg of the WCAP model.

The total head loss of the ECCS strainer is originated mainly from these aluminum precipitates. In some plants, there is no space in the containment floor for such a large strainer to accommodate chemical debris of the WCAP model. In this case, the present method to determine the amount of aluminum precipitate will be applicable to reduce overly conservative results of WCAP-16530-NP-A model.

Table 5. Overall amount of aluminum released in reactor and comparison with the result of WCAP-16530-NP-A

Rx No.	Overall amount of Al released in reactor (mg)	Converted actual amount of Al released in plant (kg)	Total amount of Al released as the result of WCAP-16530-NP-A (kg)
1	44.0	16.4	58.66
2	64.5	24.1	

Table 6. Comparison of Al precipitates generation with the result of WCAP-16530-NP-A

Precipitate		Result of WCAP-16530-NP-A	Result of the present test
Al released (kg)		58.7	20.3
Al Precipitate (kg)	AlOOH	23.1	197
	$NaAlSi_3O_8$	469.0	0.0

3. Conclusions

The total amount of aluminum released from post-LOCA recirculation sump fluids has been evaluated by ICP-AES analysis to determine the amount of AlOOH and $NaAlSi_3O_8$ which induce very adverse effect on the head loss across the ECCS sump strainer. From the comparison on the amount of aluminum released in the solutions of ECCS sump fluids, it is identified that the USRNC approved methodology of WCAP-16530-NP-A is very conservative in the prediction of aluminum precipitates. The present method is recommended as an alternative method to reduce overly conservative results of the USNRC approved methodology of WCAP-16530-NP-A.

REFERENCES

[1] WCAP-16530-NP-A, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191, PWROG, March 2008.