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# Study on the Purification Half-life in an Open-pool Research Reactor

Jungwoon Choi*, Seong-Hoon Kim, Dae-Young Chi, and Cheol Park
KAERI, Research Reactor System Design Div., #111, 989 St., Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: ex-jwchoi@kaeri.re.kr*

## 1. Introduction

For the design and construction of an open-pool type research reactor in the Kijang-gun, a basic design of the reactor itself and the main fluid systems relevant to the reactor have been proceeding at the Korea Atomic Energy Research Institute. The main fluid systems are composed of a primary cooling system (PCS), a primary purification system (PPS), a pool water management system (PWMS), a hot water layer system (HWLS), and a safety residual heat removal system (SRHRS). Unlike a nuclear power plant, the KIJANG Research Reactor (KJRR) is constructed and operated for multi-purpose utilizations: mainly radio-isotope production for medical treatment, irradiated silicon ingot production for the semiconductor industry, and irradiation facility operation for other objectives. For these multiple purposes, the reactor should be designed as an open-pool type, and the pool water should be managed within the allowable water chemistry limits to minimize the corrosion of the nuclear fuel cladding and systems through the operation of purification systems. Since the purification half-life is one of the dominant factors to design the sizing of the ion exchanger, it is of importance to determine the appropriate value not only to satisfy the water chemistry requirements but also to optimize the dimension of the ion exchanger. In this study, the purification half-life is discussed to design the optimized ion exchanger for the KJRR.

## 2. Results and Discussion

The KJRR has three sections of the pool: the reactor pool, the service pool, and the spent fuel storage pool. The reactor pool and the coolant in the PCS are purified by the PPS, and the service pool and the spent fuel storage pool are purified by the PWMS.

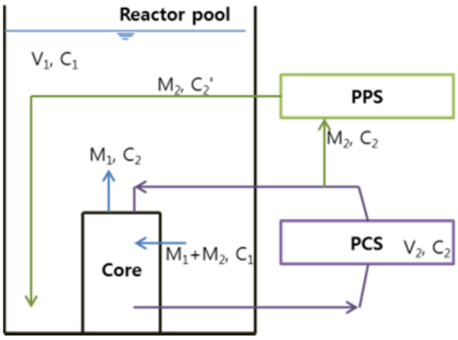

Fig. 1 Flow pattern in the reactor pool

As shown in Fig.1, the primary coolant flows from the bottom of the core and goes to the components of the primary cooling system to remove the heat delivered from the core, and then flows back to the top of the core. Before flowing back to the core, a small portion of the primary coolant flows into the primary purification system to purify the radioactive ionic impurities and then flows out to the bottom of the reactor pool.

Because of the arrangement of the ambient structure, some of the returned PCS flow to the core, $M_1$, leaks out to the pool. A portion of pool water, $M_1+M_2$, flows through the holes of the upper guide structure at the top of the core to maintain the PCS flow rate constant.

As the general approach of the research reactor design, the purification half-life is 6 hours in the reactor pool with the inventory of the PCS since the major contamination source is impurities in the PCS flow through the core. In the KJRR case, the PCS flow is circulated in the quasi-closed loop and the all bypass flow from the PCS is flowing into the PPS for the purification. If the purification half-life is considered as 6 hours for the reactor pool, the flow rate of the PPS is too conservative to optimize and design compactly the ion exchanger under the consideration of the total purification volume, i.e., 240 $m^3$ of the reactor pool and 89 $m^3$ of the PCS coolant. It is necessary to have different purification half-life to apply in the reactor pool and PCS inventory, 20 hours and 3 hours respectively, in order to optimize not only the PPS flow rate but also the dimension of the ion exchanger. [1] For the decision of the PPS flow rate, this approach should be confirmed under the aspect of the water chemistry requirement.

The ion exchanger is generally designed with the purification flow rate, operation period per batch, control conductivity, and the recommended operation conditions supplied by the ion exchange resin manufacture. Under the same conditions of the design consideration except the flow rate, the ion exchange resin volume is highly dependent on the purification flow rate because of the recommended operation conditions as shown in Eq.1.

$$\text{purification flow rate} = \frac{total\ inventory}{purification\ half\ life \times ln2} \qquad \text{(Eq.1)}$$

As explained above, the purification flow rate is determined with the purification half-life and the control volume for purification. According to the value of purification half-life, the PPS ion exchanger sizing can be different as presented in Table I. If the ion exchange resin per batch is charging less, the following can be less: generated spent resin volume, operation cost for fresh resin filling, solid radwaste management cost, installation area, and lead shielding thickness. Therefore, the optimization of the ion exchanger is of importance in terms of the construction and operation costs.

Table I: PPS Ion Exchanger Design

|  | 6 hours for all control volume | 3 hours for PCS<br>20 hours for Rx. pool |
|---|---|---|
| Flow rate | 10.5 kg | 8.0 kg |
| Bed height | 115cm | 115 cm |
| Bed ID | 105cm | 91 cm |
| Resin volume | 1000 liter | 750 liter |

The governing equations follow under the basis of the flow pattern as shown in Fig.1.

$$\rho_1 V_1 \frac{dC_1}{dt} = M_2 C_2' + M_1 C_2 - (M_1 + M_2) C_1 \qquad \text{(Eq.2)}$$

$$\rho_2 V_2 \frac{dC_2}{dt} = (M_1 + M_2) C_1 - (M_1 + M_2) C_2 \qquad \text{(Eq.3)}$$

Here, ρ is a pool water density, M is the flow rate, C is the conductivity, V is the purification volume, and t is the elapsed time. For simplicity of the equation, the decontamination factor (DF) is considered as 1.0, that is, all impurities in the PPS flow, $M_2$, are removed after passing through the ion exchanger. Accordingly, Eq.2 becomes simplified as in Eq.4.

$$\rho_1 V_1 \frac{dC_1}{dt} = M_1 C_2 - (M_1 + M_2) C_1 \qquad \text{(Eq.4)}$$

From Eq. (3) and Eq. (4), the exponential functions of $C_1$ and $C_2$ can be drawn with the initial conductivities of the reactor pool and PCS coolant.

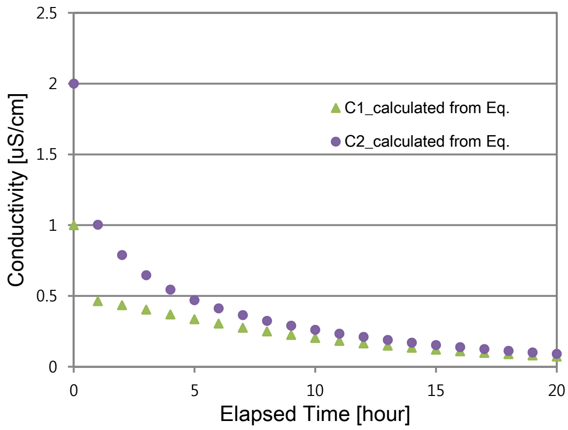

Fig. 2 Conductivity trend in the reactor pool and PCS coolant (initial conductivity ratio between pool and PCS = 1:2)

To confirm the validity of the adjusted purification half-life in the JRTR, it is necessary to define the initial conductivity of the reactor pool and the PCS coolant. The flow pattern in the pool of the HANARO research reactor is not exactly the same as that in the KJRR because not all of bypass flow from the PCS loop is purified through the PPS, and then goes out at the bottom of the reactor pool. Also, the purification flow ratio of the PPS flow rate over the PCS flow rate in the HANARO is less than that in the KJRR. Based on these, the initial conductivity ratio of the PCS coolant over the reactor pool in HANARO is expected to be higher than that in the KJRR. When the initial conductivity ratio, referenced in the operation data of the HANARO, is applied on the exponential functions of $C_1$ and $C_2$, the conductivity trend can be as shown in Figs.2 and 3.

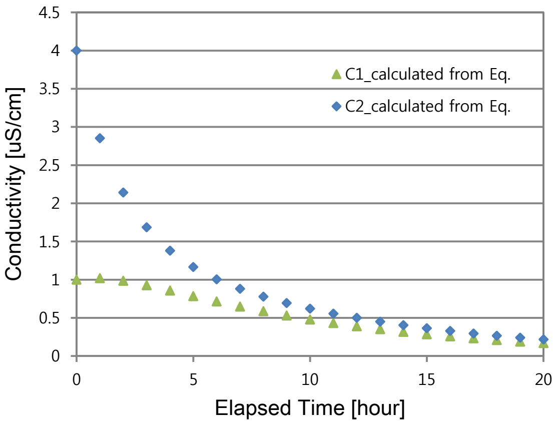

Fig. 3 Conductivity trend in the reactor pool and PCS coolant (initial conductivity ratio between pool and PCS = 1:4)

The conductivity in the reactor pool is reduced less than one half of the initial conductivity during the first purification half-life and is reduced to one half in the second and third purification half-life. The elapsed time to satisfy the purification half-life decreases to as low as the initial conductivity ratio between the reactor pool and the PCS coolant. That is, the purification efficiency of the PCS coolant is dependent on the initial ratio of the conductivity.

In terms of the water chemistry requirement for the reactor operation, the reactor pool water conductivity is the one of major parameters that should be kept less than the allowable limit. From these results, the adjusted purification half-life for the reactor pool is reasonable to design the ion exchanger for the PPS.

## 3. Conclusions

To optimize the design of the ion exchanger in the PPS, the adjusted purification half-life is adopted to manage in the water chemistry of the reactor pool. From this analysis, the adjusted purification half-life is verified to be reasonable in the application of purification of the reactor pool. Moreover, the conductivity in the reactor pool is confirmed to be managed within the allowable operation limit.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] KM-333-DD-P001, "Design Manual for KMRR Primary Purification System: Part B.", Rev.1.