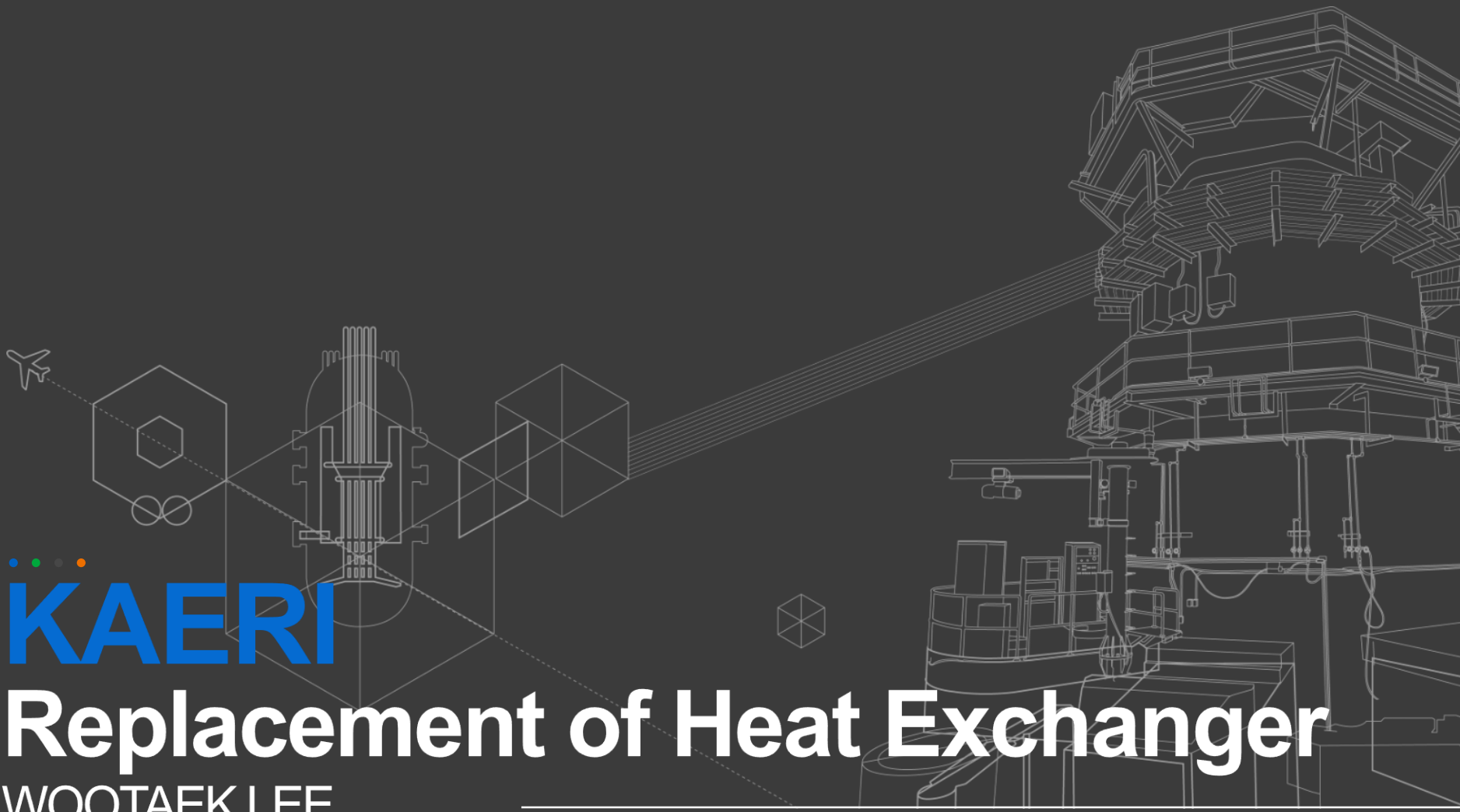

KAERI

Replacement of Heat Exchanger

WOOTAEK LEE
HANARO Management Division

2025.06.18

KAERI Korea Atomic Energy Research Institute

Replacement of Heat Exchanger

CONTENTS

KAERI Korea Atomic Energy Research Institute

Introduction

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Introduction

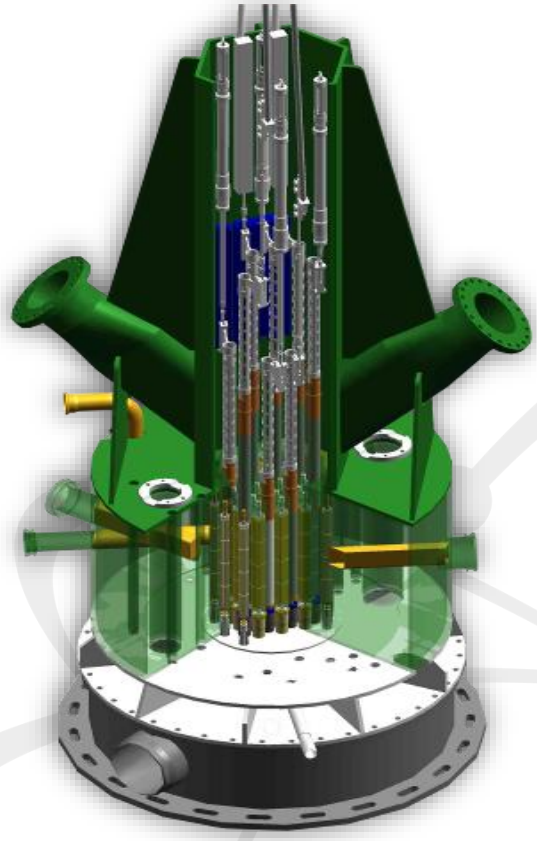
HANARO

High-Flux Advanced Neutron Application ReactOr

- ✓ First criticality on 8 Feb. 1995
- ✓ 30MWth(Design Power)
- ✓ Primary Coolant is light water
- ✓ Reflector uses heavy water
- ✓ 32 Fuel assemblies are loaded
- ✓ 28 days of operation period
- ✓ Multi-purpose Research Reactor

General Features of HANARO

Type	Open-tank-in-pool
Power	30 MW_{th}
Coolant	Light water
Reflector	Heavy water
Fuel Materials Enriched	U_3Si, 19.75%
Absorber	Hafnium
Reactor Building	Confinement
Max Thermal Flux	$4x10^{14}$ n/cm^2s
Typical Flux at Port Nose	$2x10^{14}$ n/cm^2s
7 Horizontal Ports & 36 Vertical Holes	
Vertical Hole for Cold Neutron Source	
Operation Cycle	28 days@5 weeks



Introduction

Need for replacement of HX in reflector system

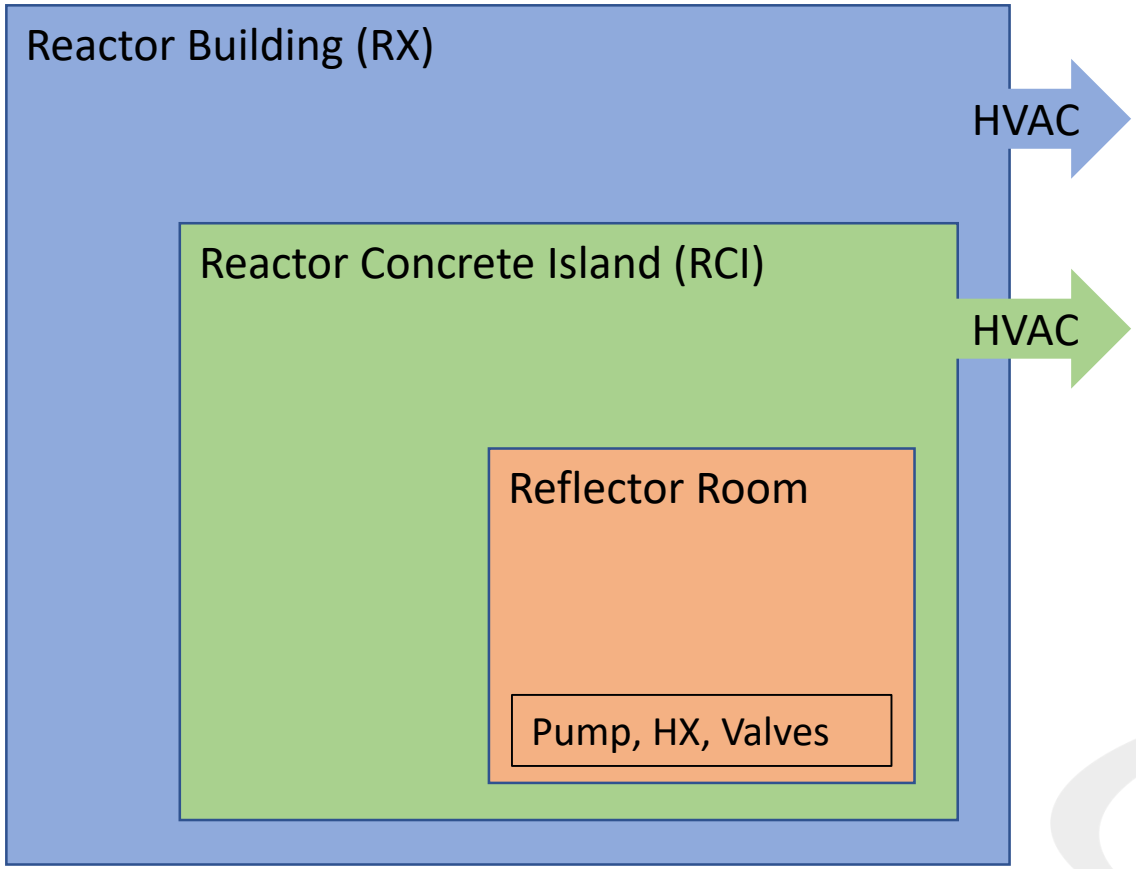
<Reflector Heat Exchanger>

- ✓ A few leakage events occurred on the secondary side of the heat exchanger
- ✓ After each leakage incident, the heat exchanger was further tightened to prevent additional leaks
- ✓ Eventually, tightening reached the minimum allowable stacking thickness, making further tightening no longer possible

Reflector System Overview

Reflector System Overview

Positional Overview of Reflector System



- ✓ Reflector room is maintained in a sealed condition
- ✓ RCI is maintained at a lower negative pressure than RX
- ✓ During maintenance, the reflector room must be opened and the negative pressure in the RCI can no longer be maintained
- ✓ Tritium management is essential during heat exchanger replacement

Preparation and Set-up

3

- Integrity of Spare Plates
- Mock-up Training
- Tritium Release Assessment
- Internal Exposure Estimation

Preparation and Set-up

Preparation of spare plates

- ✓ Visual Inspection and Hydraulic pressure tests on spare plates

Mock-up training

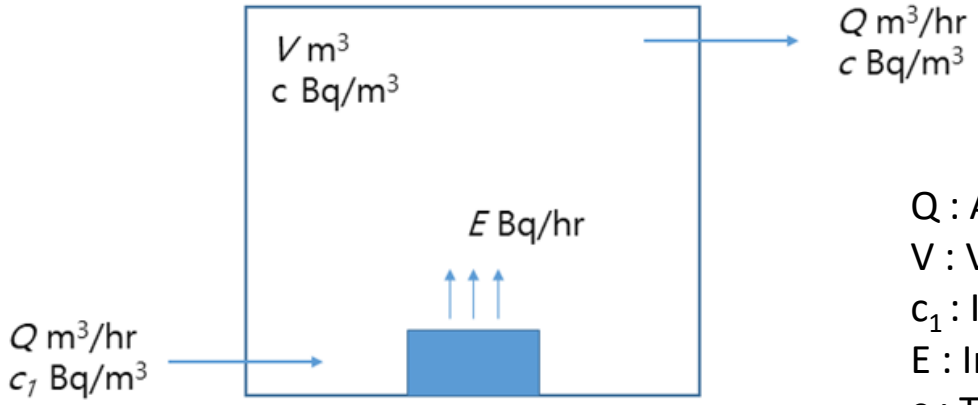
- ✓ Disassembly and Removal of Existing Plates
- ✓ Installation and Reassembly with New Plates
- ✓ Estimate of Operation time and Potential Process water spill

Preparation and Set-up

Tritium Release Assessment

✓ Evaluation Assumptions

1. All tritium exists in the form of tritiated water vapor (HTO) in air
2. 21% of tritium in the RCI migrates into the RX
3. Continuous spillage of heavy water during HX replacement



$$c = c_0 e^{-\frac{Q}{V}t} + \left(\frac{E + Q c_1}{Q}\right)\left(1 - e^{-\frac{Q}{V}t}\right)$$

Q : Airflow rate through the reflector room
V : Volume of RCI (or RX)
c_1 : Initial tritium conc. in air
E : Increase in airborne tritium due to evaporation
c : Tritium concentration released through stack

Preparation and Set-up

Tritium Release Assessment

Time(t, hr)	Release to the RX stack		Release to the RCI stack	
	Concentration (Bq/m^3)	Cumulative release(Bq)	Concentration (Bq/m^3)	Cumulative release(Bq)
DRL	5.07E+07	6.25E+13	3.92E+08	6.25E+13
0	1.00E+03	0.00E+00	1.00E+05	0.00E+00
0.5	7.21E+04	5.51E+08	9.21E+06	1.63E+10
1	1.27E+05	2.00E+09	1.02E+07	3.32E+10
2	1.68E+05	4.15E+09	1.03E+07	5.01E+10
4	2.68E+05	2.07E+10	1.03E+07	1.35E+11
6	3.00E+05	5.42E+10	1.03E+07	2.71E+11
8	3.03E+05	7.16E+10	1.03E+07	3.39E+11
12	3.04E+05	8.91E+10	1.03E+07	4.07E+11
24	3.04E+05	1.24E+11	1.03E+07	5.42E+11

The Derived Release Limit (DRL) represents a calculated threshold for tritium emissions, derived by back-calculating from the permissible dose to members of the public in the unrestricted area. The estimated release level was lower than this limit.

Preparation and Set-up

Estimate of Internal Exposure

- ✓ Tritium concentration in the reflector room exceeds 100 DAC
- ✓ Positive-pressure full-body suit are required for all work
- ✓ Internal exposure was estimated based on past maintenances
- ✓ Estimated internal dose per worker : ~10 μSv/8hr

Replacement Operation

4

- Replacement Workflow
- Unexpected Tritium Contamination

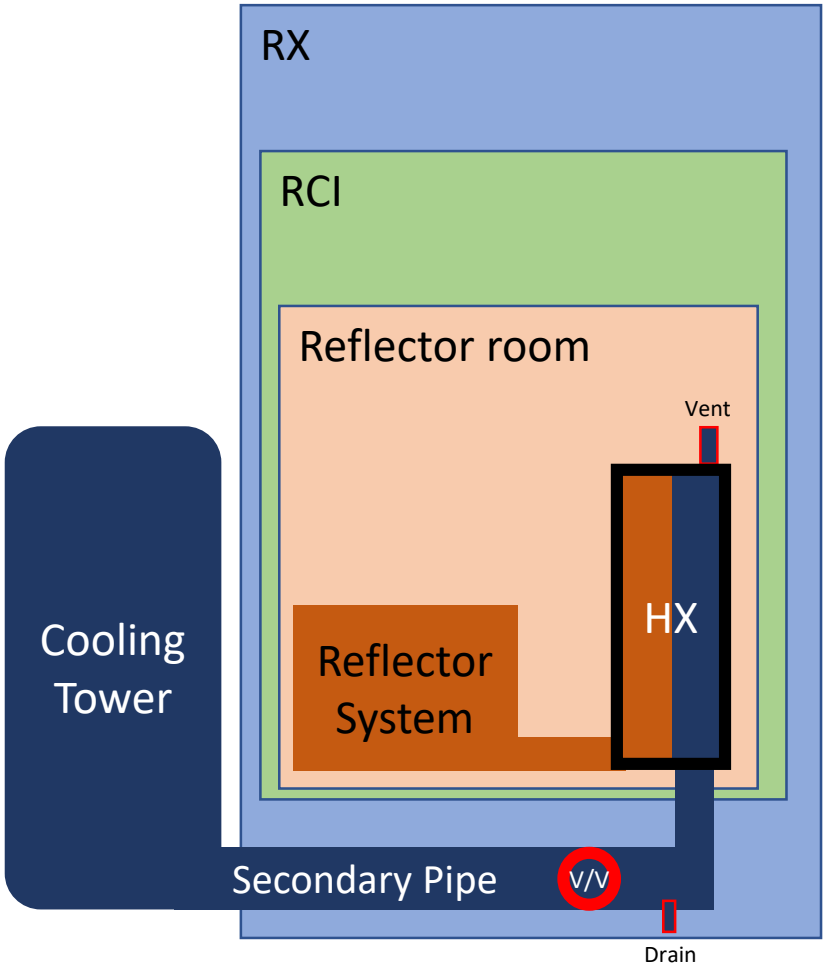
Replacement Operation

Replacement Workflow

- ✓ DAY 1 : Isolate/drain secondary cooling water and heavy water
- ✓ DAY 2 : Disassemble, replace 79 plates, reassemble
- ✓ DAY 3 : Refill cooling and heavy water
- ✓ DAY 4 : Pressurization test and leak inspection

Replacement Operation

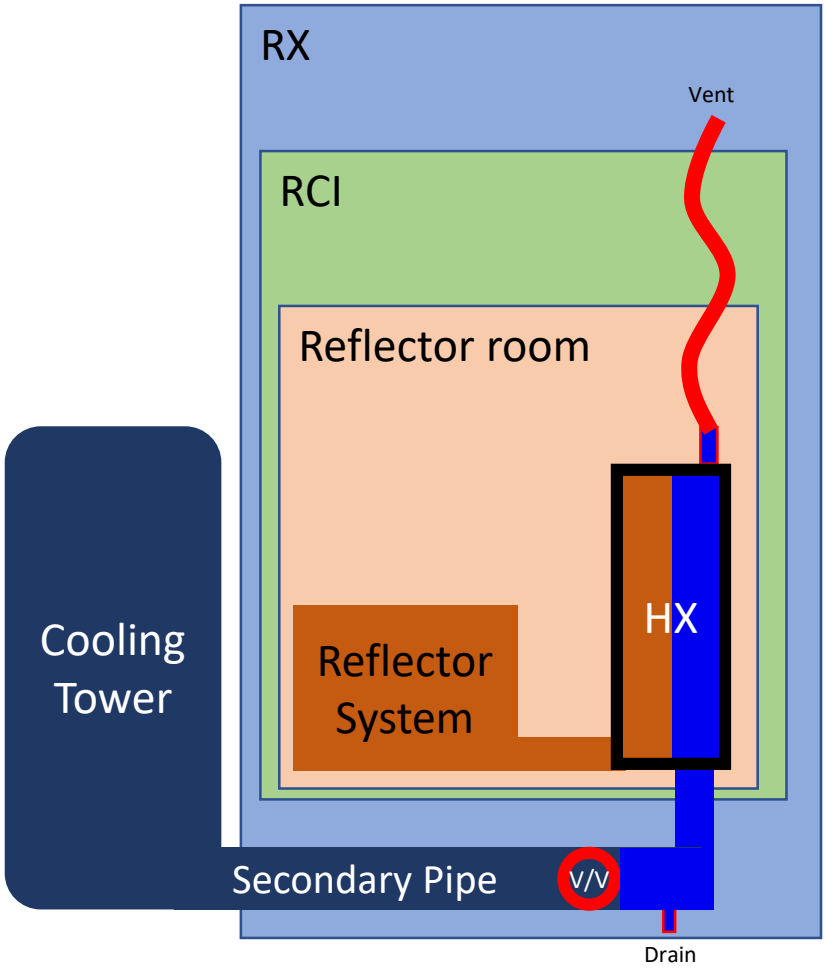
Unexpected Tritium Contamination



- ✓ Incident Overview
  - Prior to refilling the heavy water, the secondary side was filled first
  - Unexpected tritium was detected in the secondary-side water
  - Tritiated air from the reflector room entered the secondary side through the vent valve during the initial drainage process

Replacement Operation

Unexpected Tritium Contamination



- ✓ Corrective actions
  - Secondary side was flushed twice to remove tritium
  - Connected extension hose to vent valve to intake clean air and prevent tritium re-contamination
  - Tritium concentration reduced to normal levels
- ✓ Airborne tritium can easily dissolve into surface moisture, so this must be considered during the work

Results

- System Integrity and Performance
- Tritium Release
- Worker Radiation Exposure

Results

System integrity and performance

- ✓ No leakage was observed
- ✓ Normal heat exchange efficiency was verified through system operation
- ✓ No tritium was detected on the secondary side

열교환기 보수 HANTAP-05-OD-ROP-MA-03, 개정번호 7, 20/21

붙임 6. 반사체 냉각계통 열교환기 누수시험 점검표(개정7)

반사체 냉각계통 열교환기 누수시험 점검표

1. 반사체 냉각펌프 기동시험

내용	기준	초기	20분 후	40분 후	60분 후
유량	39~47.6 kg/s	45.1 kg/s	45.2 kg/s	45.1 kg/s	45.0 kg/s
펌프 입/출구 압력(개정7)	414~506 kPag(출구)(개정7)	440 kPa	440 kPa	440 kPa	440 kPa
2. 반사체 냉각계통 열교환기 누수 발생유무		없음	없음	없음	없음
점검자 서명/날짜		2024.7.29 이창동			

REVIEWED WITNESSED KAERI QA KIM EUI YOUNG 2024.7.29

반사체 냉각계통 점검(펌프,밸브,압력용기,열교환기), HANTAP-05-OD-ROP-PI-04-06, 개정번호:5, 7/11

붙임 2. 펌프 점검 기록지

펌프 점검 기록지

계통 명칭	반사체 냉각계통(321)	펌프 번호	321-P01
점검 일자	2024.7.31		

점검 항목	단 위	기 준 값	측 정 값
회전수	RPM	3550±5%이내(3373~3728)	3575
입구 압력	kPag	-	-
출구 압력	kPag	460±10%이내(414~506)	445
유 량	L/sec	43.3±10%이내(39~47.6)	45.1
체크밸브 번호		321-V003	
점검 결과 (양호,불량)		양호	

구 분	I			II			III			IV		
	H	V	A	H	V	A	H	V	A	H	V	A
진동 값(mm/s)	1.5	1.9	2.0	1.9	2.1	2.0	2.2	2.9	1.4	1.3	1.5	1.3
진동 기준값(mm/s)	양호: 4.0mm/s이하											
베어링 온도	31.4			50			47.9			39.0		
기준값	섭씨 75도 이하											
윤활유 상태	양호											

I II III IV MOTOR PUMP

종합평가	점검결과 특이사항 없음

REVIEWED WITNESSED KAERI QA YUN HWA KYUNG 2024.7.31

Count Conditions

```
Nuclide: 3H
   Quench Indicator: tSIE/AEC
   External Std Terminator (sec): 0.5 2s%
   Pre-Count Delay (min): 0.00
Quench Set:
   Low Energy: 3H
Count Time (min): 30.00
Count Mode: Normal
Assay Count Cycles: 1          Repeat Sample Count: 1
#Vials/Sample: 1               Calculate % Reference: Off
```

Background Subtract

```
Background Subtract: Off
Low CPM Threshold: Off
2 Sigma % Terminator: Off

Regions          LL          UL
A               0.0        18.6
B               2.0        18.6
C               0.0         0.0
```

Count Corrections

```
Static Controller: On          Luminescence Correction: Off
Colored Samples: Off           Heterogeneity Monitor: Off
Coincidence Time (nsec): 18    Delay Before Burst (nsec): 75
```

Cycle 1 Results

S#	Count Time	CPMA	DPM1	Eff Nucl In A	A:2S%
1	30.00	1038	2232	46.49	1.13
2	30.00	1057	2272	46.51	1.12

Demi Wtr Re-Hx 2nd

Results

Tritium Release and Public Dose

- ✓ Total tritium release: < 0.06% of daily release limit
- ✓ Peak concentration: < 0.5% of limit at both RX and RCI stacks
- ✓ Public dose: only 0.02% of the annual legal dose limit

Table 2 Daily Tritium Release: Actual, Estimated, and Limit Values

	RX		RCI		Total
	Peak conc. (Bq/m^3)	Cumulative release(Bq)	Peak conc. (Bq/m^3)	Cumulative release(Bq)	Cumulative release(Bq)
Day 1	3.75E04	2.80E09	1.41E06	6.23E10	1.43E11
Day 2	2.40E05	3.17E10	1.77E06	4.64E10	
Estimate	3.04E05	6.16E11	1.03E07	2.44E12	3.06E12
Limit	5.07E07	6.25E13	3.92E08	6.25E13	-

Results

Worker Radiation Dose

- ✓ Max internal dose (most exposed worker): < 0.08 mSv
- ✓ Average internal dose: < 0.06 mSv
- ✓ Average total dose per worker (internal + external): < 0.06 mSv

- ➢ Although the levels are slightly higher than expected, they include all exposure accumulated during the preparation stage
- ➢ Moreover, the dose is still far below the annual exposure limit for radiation workers

Conclusion

6

Conclusion

Technical Outcome

- Heat exchanger replacement was completed without leakage
- System performance and efficiency remained stable

Radiological Safety

- Tritium release was well below regulatory limits, public dose was negligible
- Average worker dose stayed below 0.06 mSv

Operational Insight

- An unexpected tritium ingress was promptly identified and resolved
- Highlighted the importance of air management and pre-planning for tritium safety

THANK YOU

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