Changes in Ionizing Radiation Field During the First Cycle after Zinc Injection into the Primary Circuit of Operating Nuclear Power Units

Haiju Shen

CNNC Nuclear Power Operation Management Co., Ltd

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Overview

Background of Zinc Injection Operation

- In pressurized water reactor nuclear power plants, activated corrosion products typically account for over 95% of the collective occupational radiation dose.
- The key nuclides in activated corrosion products in M310 units include ^{58}Co, ^{60}Co, 110mAg, ^{54}Mn, ^{124}Sb, and others.
- Zinc injection into the primary system for replacement and corrosion inhibition is an important measure to reduce the radiation source term in nuclear units.
- Over 100 nuclear power units worldwide have implemented zinc injection into their primary systems, achieving certain effectiveness in reducing the radiation source term.

Overview

Impact of Unit Design on Radiation Source Term Control

Letdown purification rate
Minimum

The equipment arrangement is compact
Elevated radiation levels in the area

Dual-reactor arrangement
Resulting in cross-contamination of source terms

Equipment materials
Resulting in elevated source terms

Stellite alloy
Increase Co-60 source term

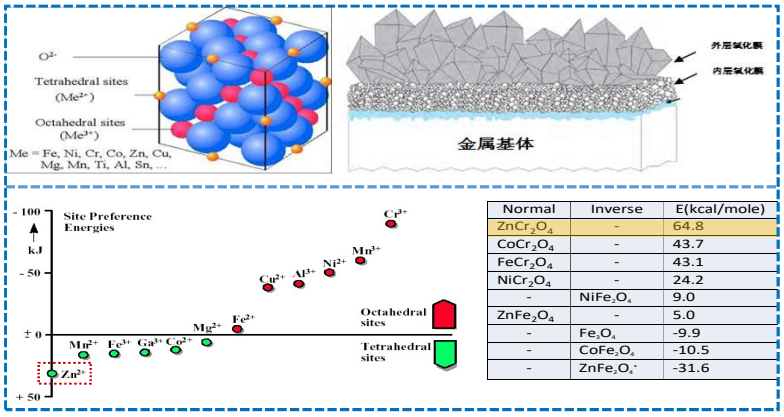
Li-B coordination curve
Hard-to-control corrosion-activated products

The M310 unit from France has certain inherent disadvantages in source term control.

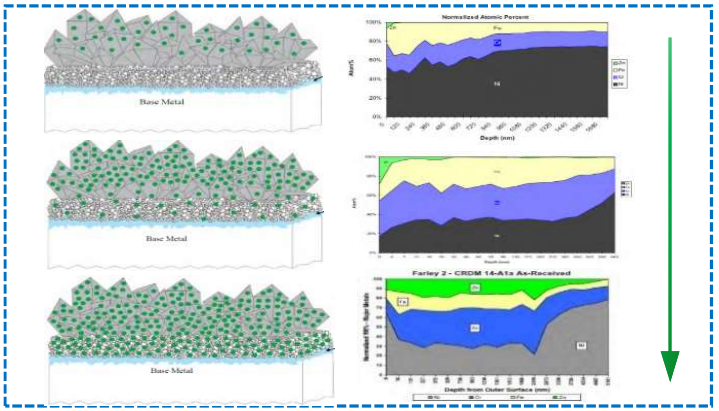
Overview

Purpose of Zinc Injection Operation

- The radiation source term level in M310 units is generally higher compared to other units.
- Zinc is preferentially incorporated into the inner oxidation layer composed of chromite ($FeCr_2O_4$), displacing divalent radionuclides such as cobalt (^{58}Co, ^{60}Co) from the inner oxide film of nickel-based materials. Meanwhile,and the incorporation of new radioactive cobalt into the oxide layer is suppressed. More importantly, this process reduces the corrosion rate of nickel-based alloys, particularly Stellite alloys.



Normal	Inverse	E(kcal/mole)
$ZnCr_2O_4$	-	64.8
$CoCr_2O_4$	-	43.7
$FeCr_2O_4$	-	43.1
$NiCr_2O_4$	-	24.2
-	$NiFe_2O_4$	9.0
$ZnFe_2O_4$	-	5.0
-	Fe_3O_4	-9.9
-	$CoFe_2O_4$	-10.5
-	$ZnFe_2O_4$	-31.6



Overview

Radiation Monitoring of Zinc Injection into the Primary System at Fangjiashan Unit

- Started zinc injection in August 2024, in Fangjiashan plate.
- Completed its first cycle of zinc injection operation.
- Radiation level of filters in the chemical and volume control system during operation.
- Radiation level of waste resin .
- Radiation level of pipeline equipment in the chemical and volume control system during operation.
- Radiation level of important pipeline equipment and the reactor building during outages.
- Source term measurements during outages.

Zinc Injection Mission Monitoring

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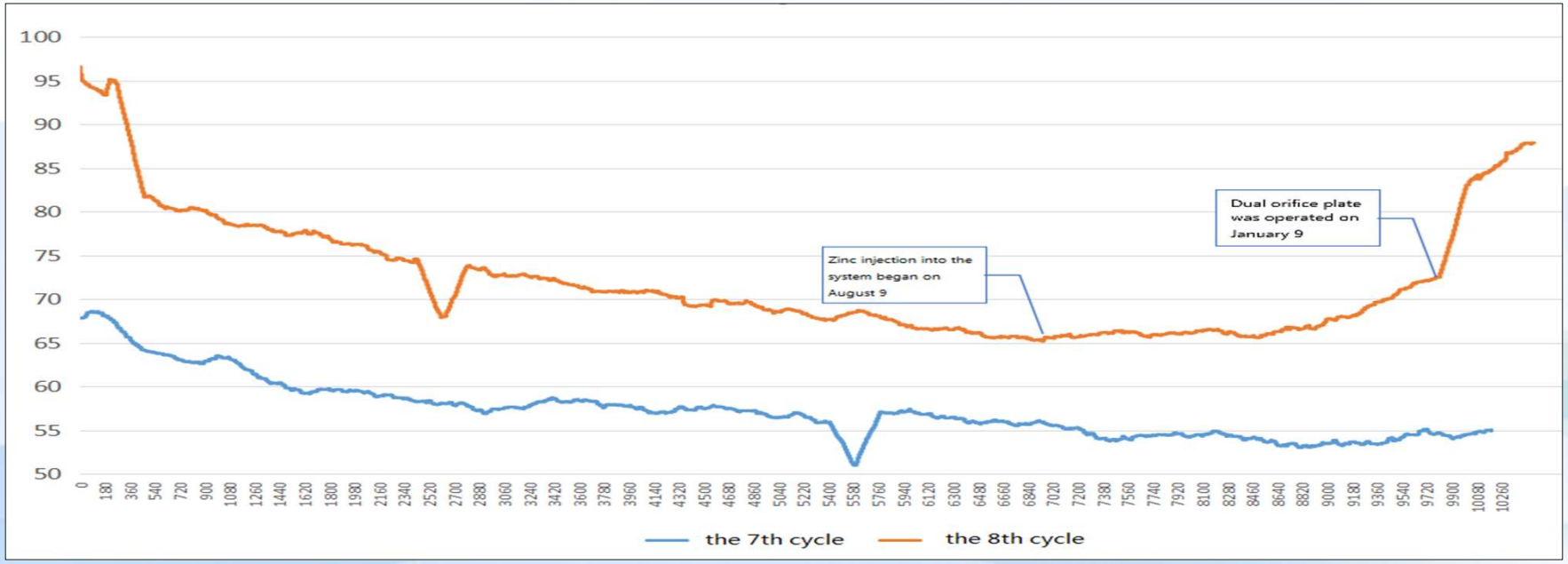
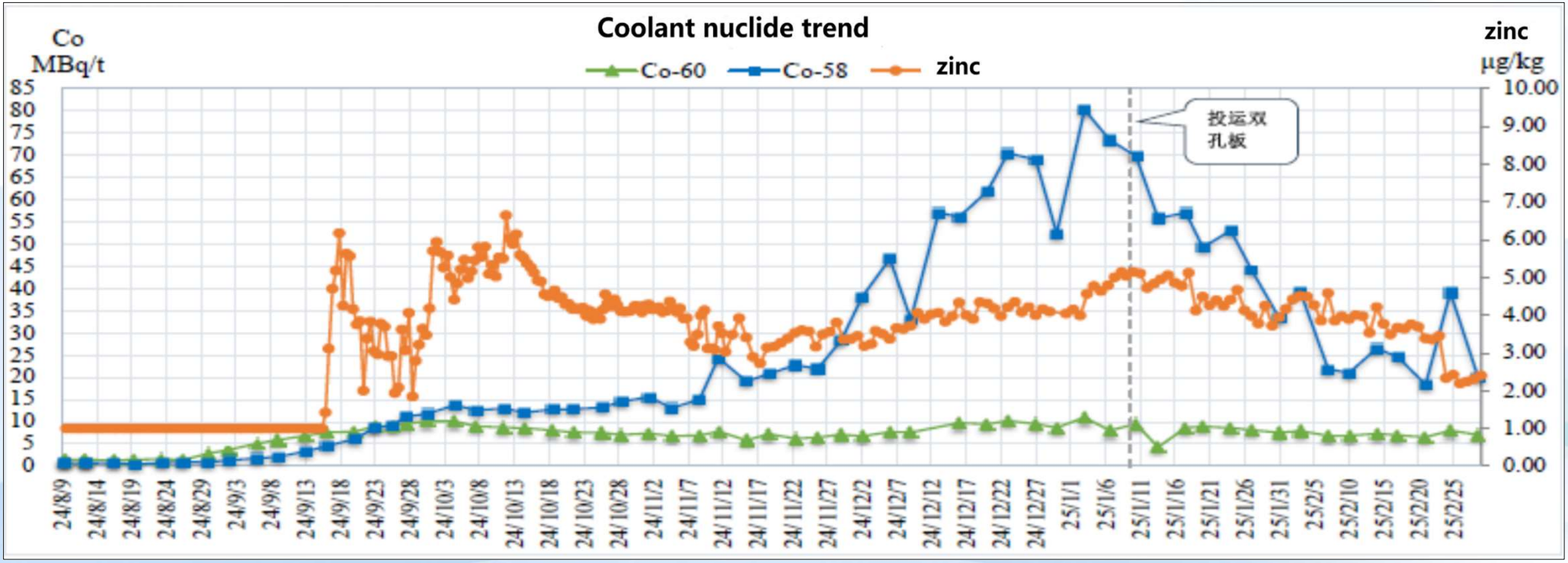
KRT radiation monitoring of the chemical and volume control system letdown piping

- Monitoring the radiation monitoring detector (1KRT001MA) installed on the chemical and volume control system letdown pipeline during the operation of Unit 1.
- In the 7th and earlier fuel cycles, the 1KRT001MA showed a slow downward trend from the beginning of the operation cycles.
- Zinc injection in the 8th cycle,the 1KRT001MA began to shift, gradually increasing and rising rapidly after the dual-orifice plate was put into operation.
- After zinc injection, the rapid release of activated corrosion products from the primary system coolant led to increased deposition of source terms in the chemical and volume control system letdown pipeline, resulting in elevated radiation levels.



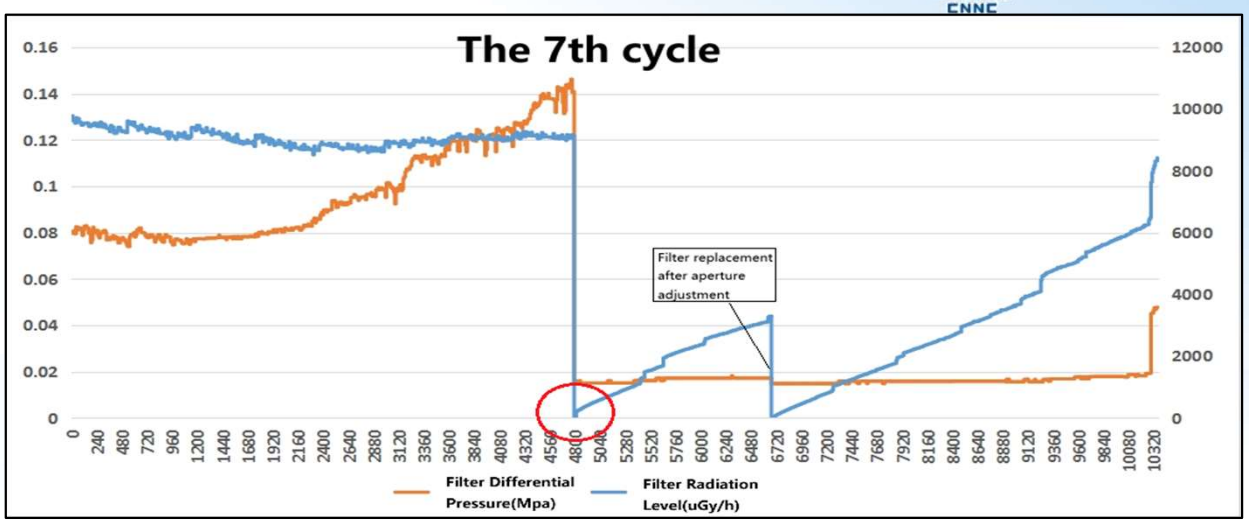
KRT radiation monitoring of the chemical and volume control system letdown piping

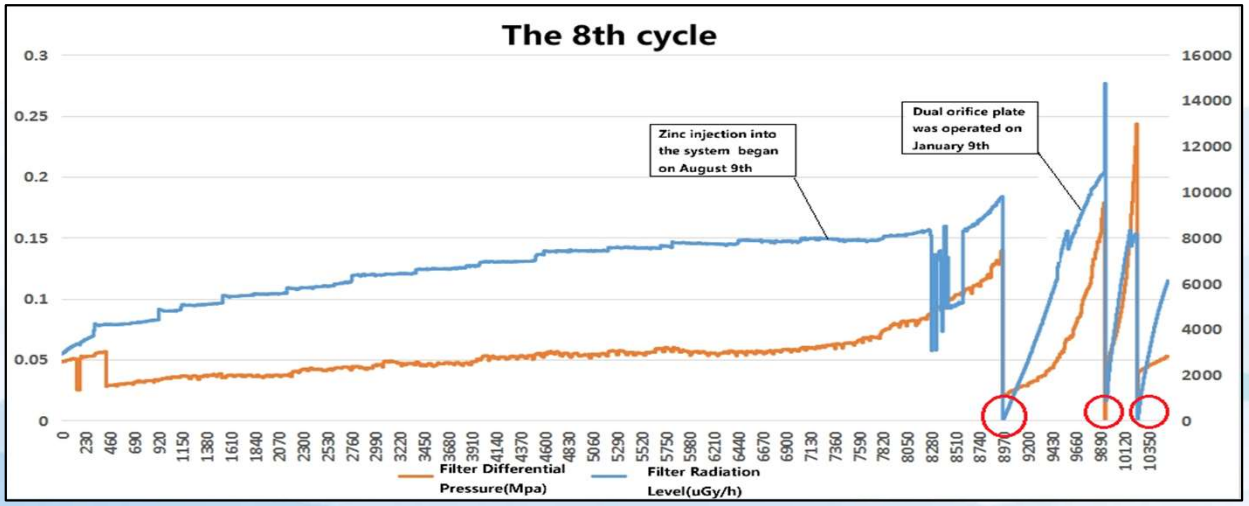
- To address the rapid increase of Co-60 and Co-58 nuclides in the primary system coolant, the unit activated the second letdown orifice plate train ahead of schedule.
- With the increase in purification flow rate, the specific activity of Co-60 and Co-58 nuclides in the primary system coolant showed a significant downward trend.
- Sufficient purification reduced the deposition of activated corrosion products in the system.



Monitoring of the Pre-filter for the Chemical and Volume Control System Purification Bed （1RCV010FI)

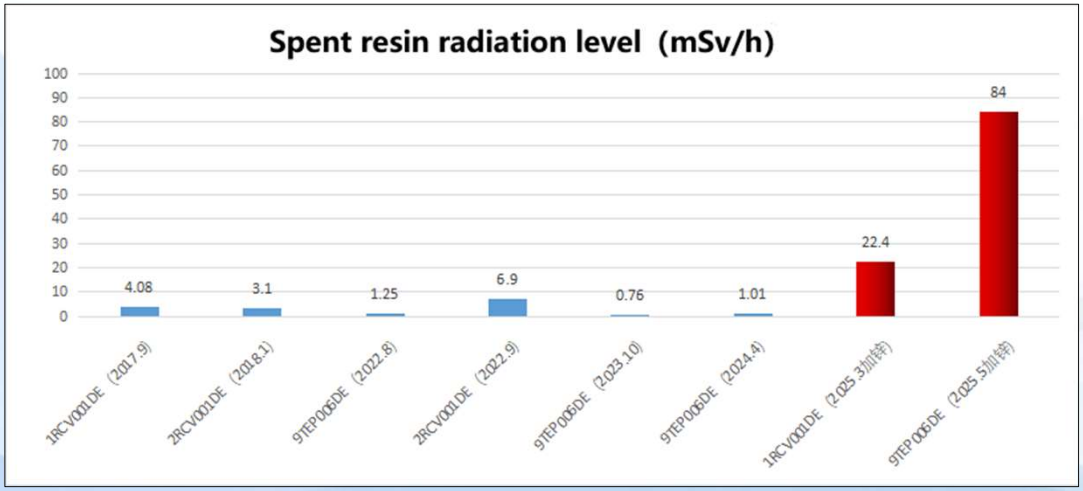
- Monitoring the radiation level of the pre-filter during operation. In the 7th and earlier fuel cycles, typically 0 to 1 pre-filters were replaced over the entire operation cycle.
- In the 8th fuel cycle， a total of 3 pre-filters were replaced before the outage.
- After zinc injection, the activated corrosion products significantly increased and were subsequently purified.

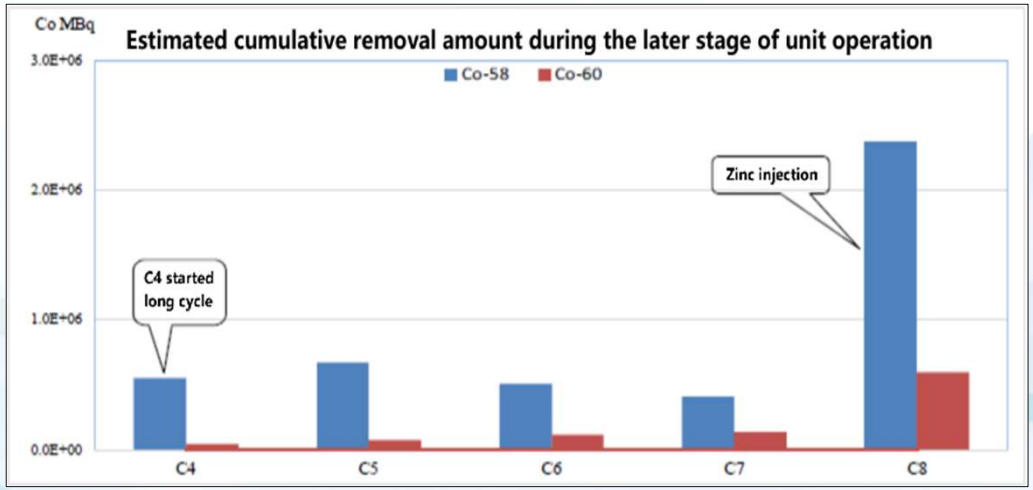




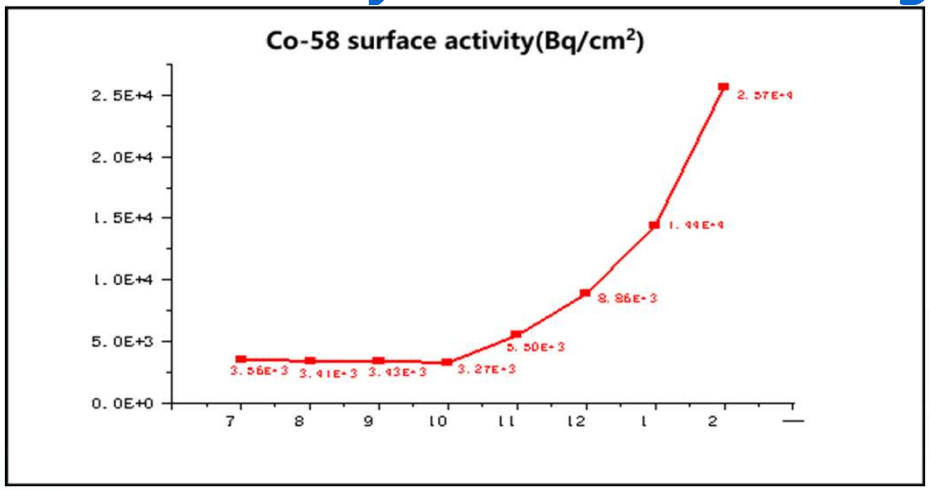
Monitoring of purification bed resin

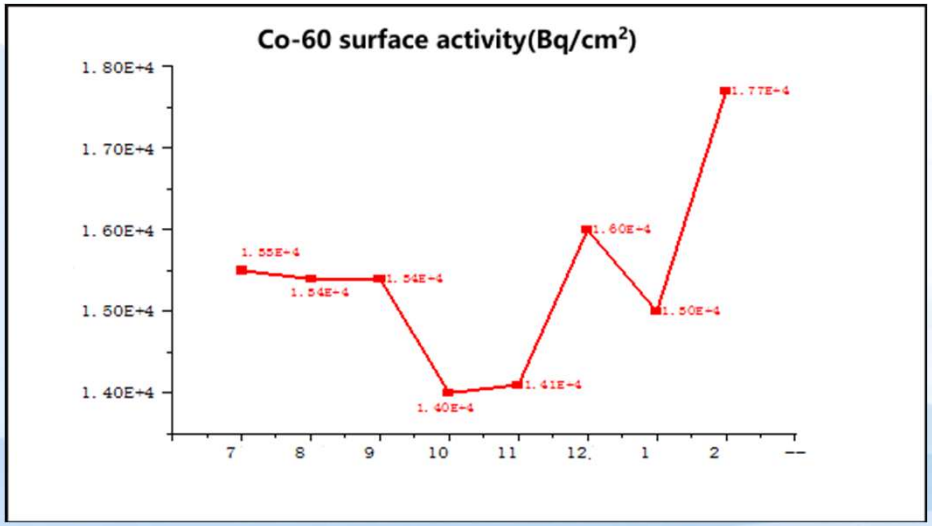
- Monitoring the radiation level of spent resin from the purification beds 1RCV001DE (replaced every two operating cycles) and 9TEP006DE (replaced after each outage).
- After the implementation of zinc injection operation, the dose rates of the spent resin showed a significant increase .
- This indicates that during zinc injection operation, the resin purification removed more activated corrosion products.



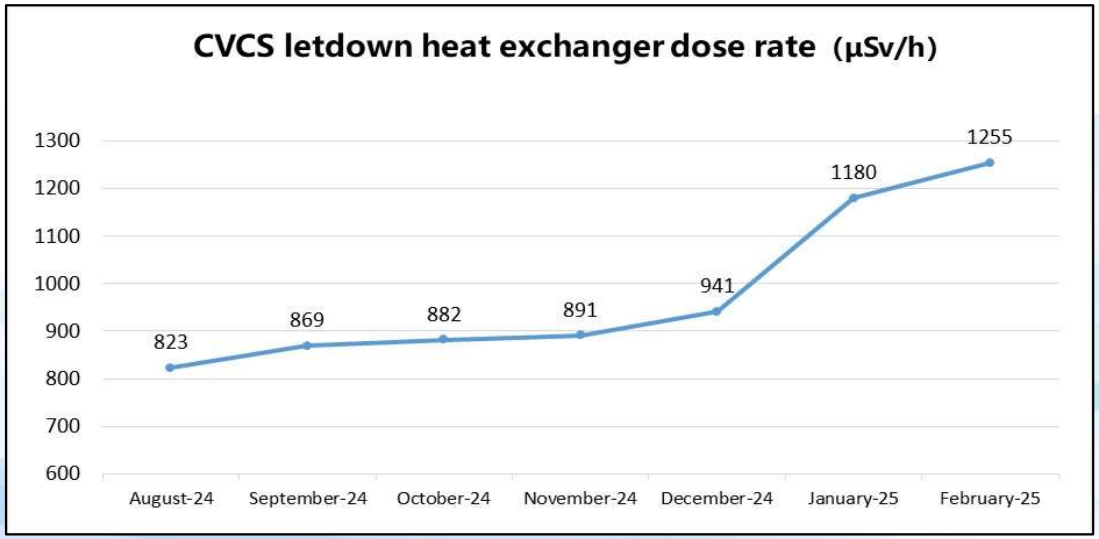


Radiation monitoring of the chemical and volume control system heat exchanger (1RCV002RF)



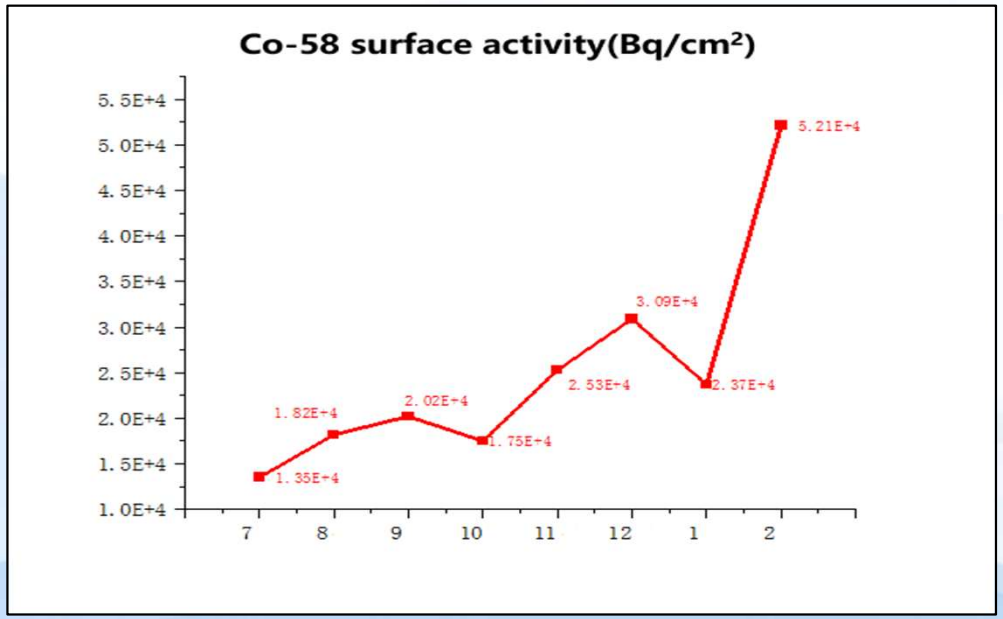


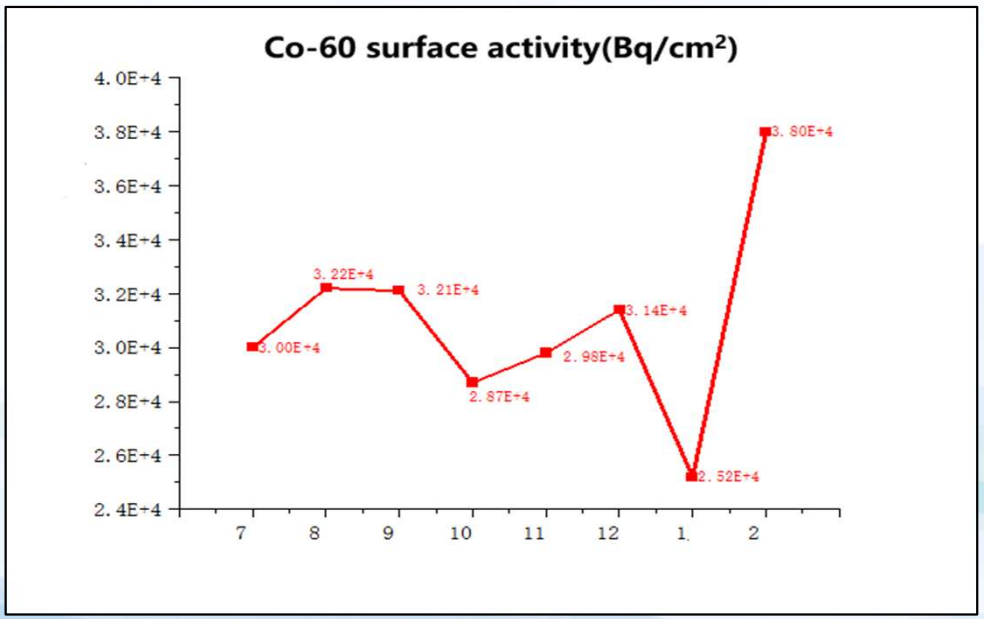
- Monitoring the radiation level and main source term at point 1RCV002RF(chemical and volume control system heat exchanger)during zinc injection operation.
- The data revealed a significant increase in both the main radiation source term and radiation level after zinc injection in August, which further demonstrates the rise in activated corrosion products.



Radiation monitoring of chemical and volume control system valve（1RCV010VP)

- Monitoring the main source term at point 1RCV010VP valve.
- A significant increase in the main radiation source term nuclides.
- This indicates that after zinc injection, the activated corrosion products in the coolant substantially increased, entered the chemical and volume control system, and led to elevated source term deposition on this valve.





Summary of Zinc Injection Operation Monitoring

- Zinc injection operation accelerated the release of activated corrosion products from the primary circuit. The increased activated corrosion products entered the chemical and volume control system, where they were **effectively filtered and purified,** contributing to the reduction of radiation source terms within the primary system. **Zinc injection played a positive role in promoting the early release of radiation source terms.**
- However, it also led to an increase in the number of **filter cartridge replacements** (by approximately 3-4 units) and a significant rise in the radioactivity level of spent resin.

Filtration and purification equipment

Chemical and volume control system heat exchanger

Chemical and volume control system letdown pipeline

Chemical and volume control system valve

03

Radiation Level Changes

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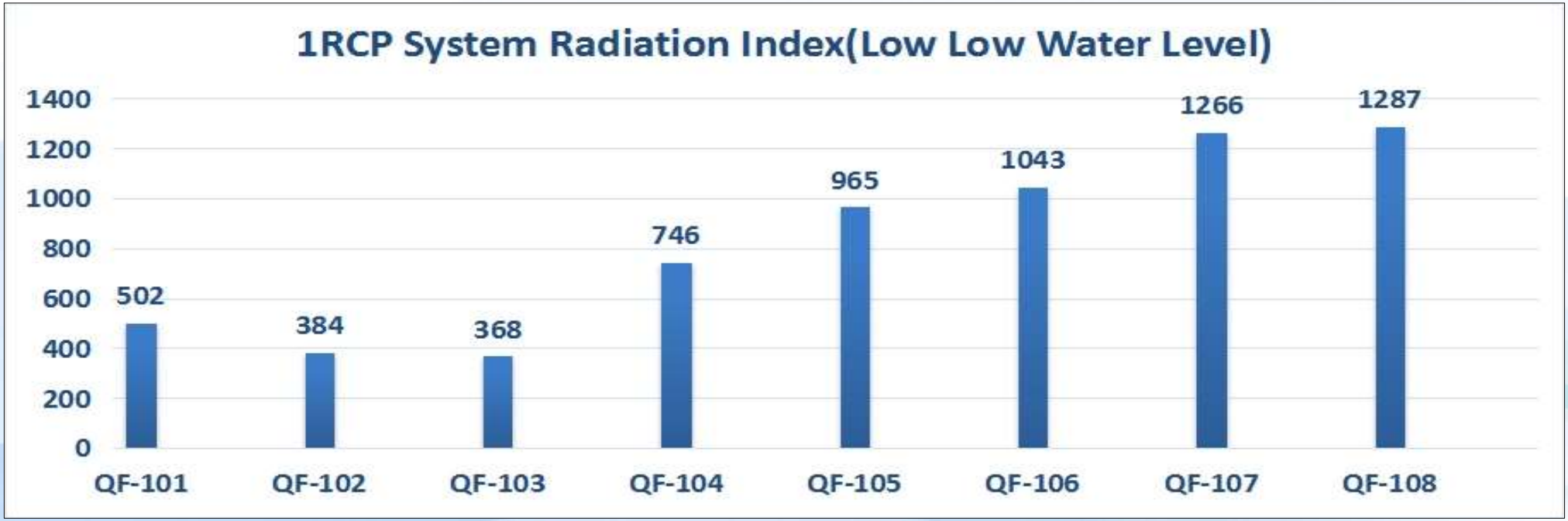
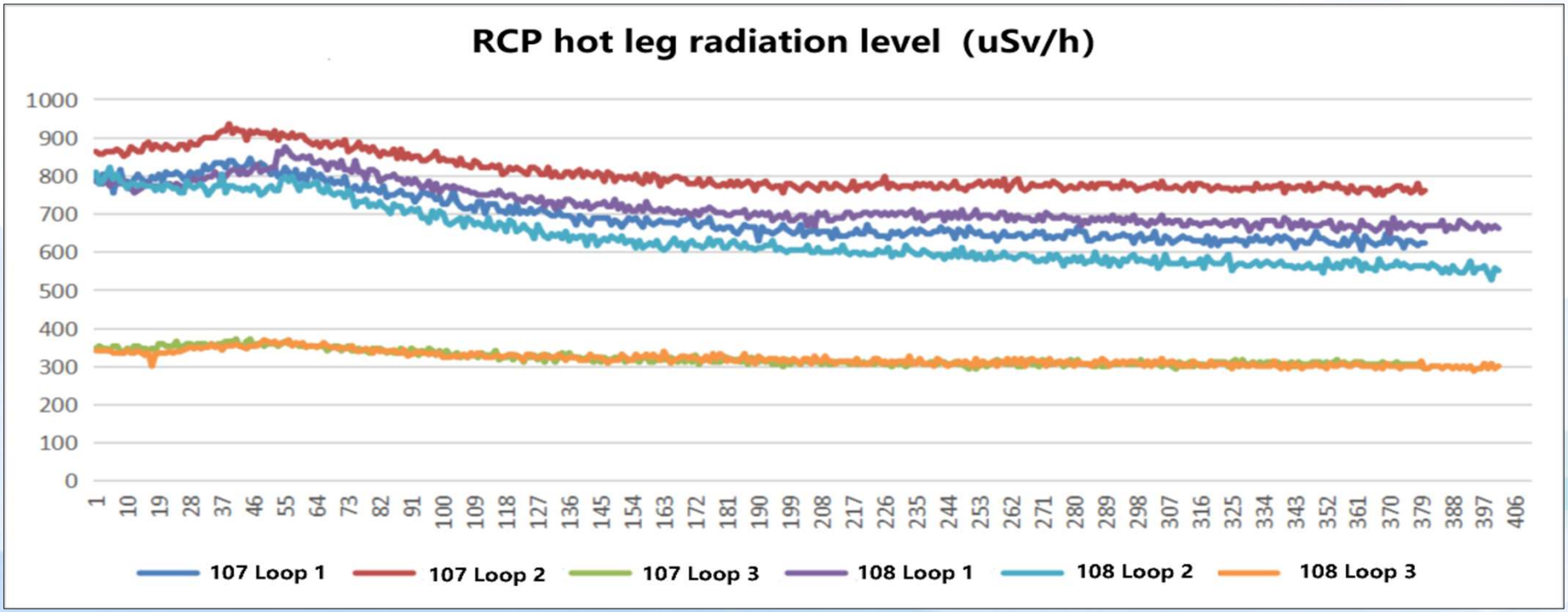
Reactor Coolant System (RCP) Radiation Index

- The radiation index of the Reactor Coolant System (RCP) during previous outages showed a gradually increasing trend.
- However, after zinc injection in the 108 outage, this upward trend was effectively suppressed.
- This demonstrates that zinc injection operation has had a favorable impact on reducing the RCP radiation index, thereby alleviating the rise in radiation source terms within the RCP system.



Changes in radiation levels at the hot leg of the Reactor Coolant System (RCP) main pipeline

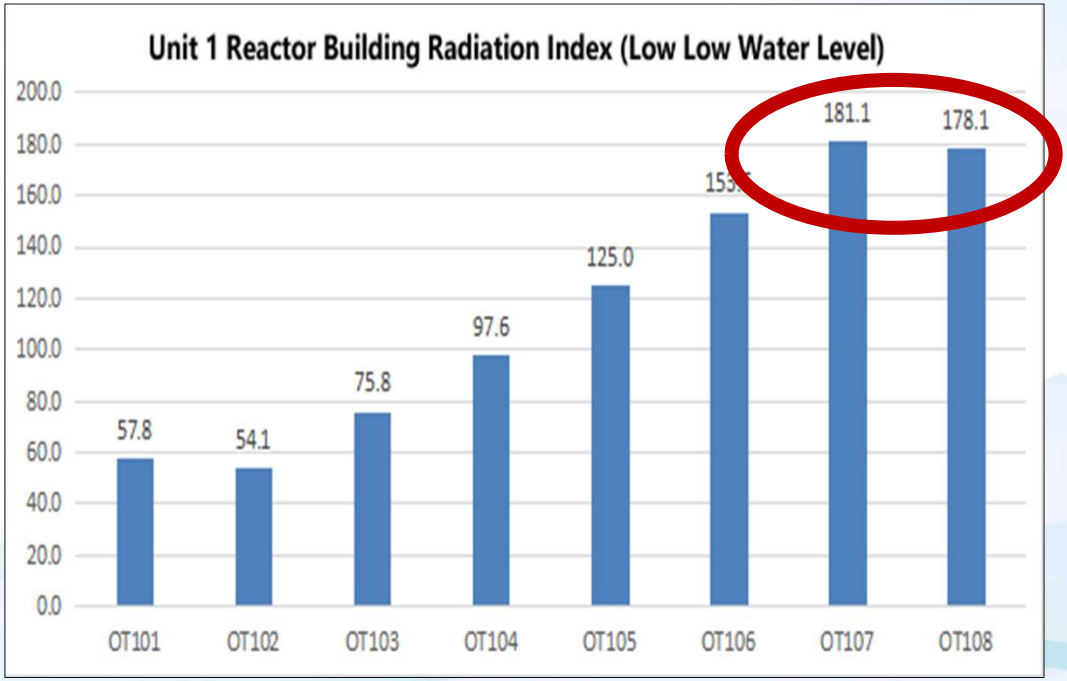
As shown in the figure, the dose rate level at the hot leg of RCP main pipeline during 107 outage (before zinc injection) and 108 outage (after zinc injection) are illustrated. After one cycle of zinc injection operation, the dose rate at the main pipeline decreased by approximately 8%.



Reactor Building Radiation Index

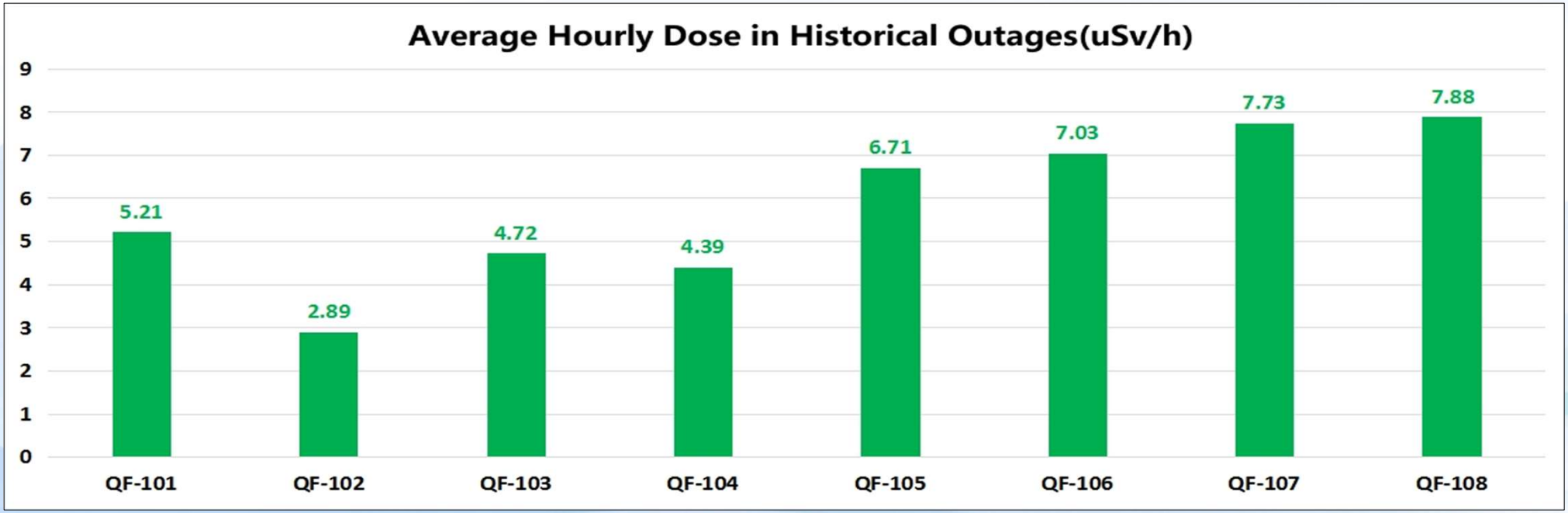
The trend of the Reactor Building Radiation Index has been effectively controlled.

- The radiation index of the 1RX building during previous outages prior to the 108 outage showed a gradually increasing trend.
- In 108 outage, this upward trend was significantly controlled, demonstrating the effectiveness of zinc injection in reducing source terms.



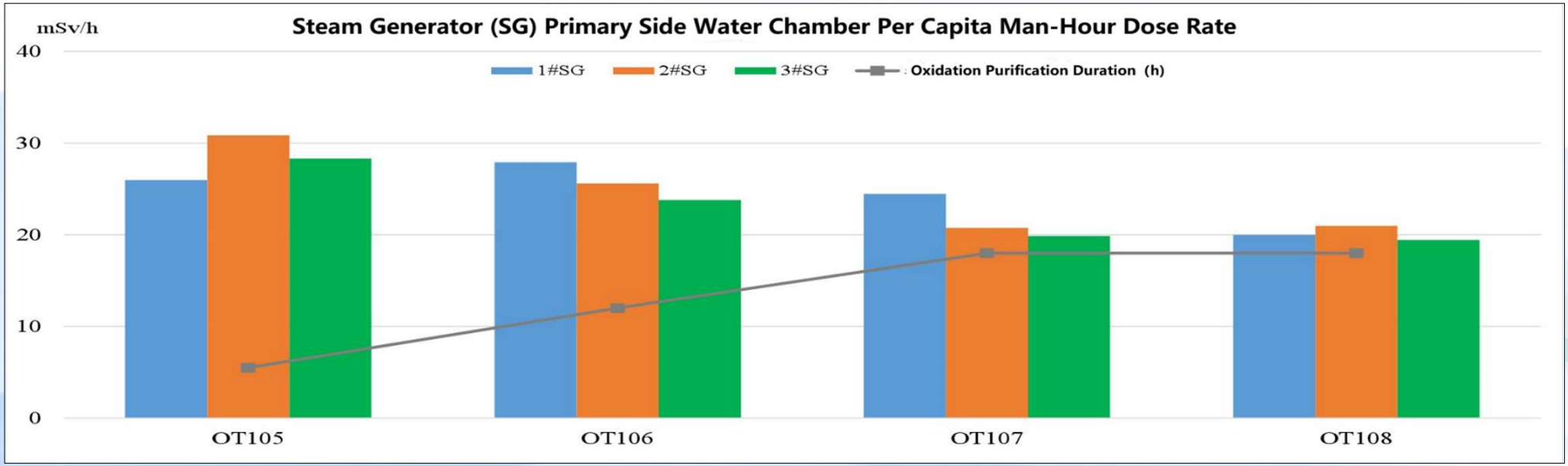
Average dose rate

- The average dose rate was calculated by dividing the collective dose during outage by the total man-hours to evaluate the radiation levels at the site during previous outages of Unit 1.
- In the seven outages prior to the 108 outage, this data showed a clear upward trend.
- However, during the 108th outage, the growth rate of this upward trend was effectively controlled.
- This indirectly demonstrates the positive role of zinc injection in controlling radiation source terms.



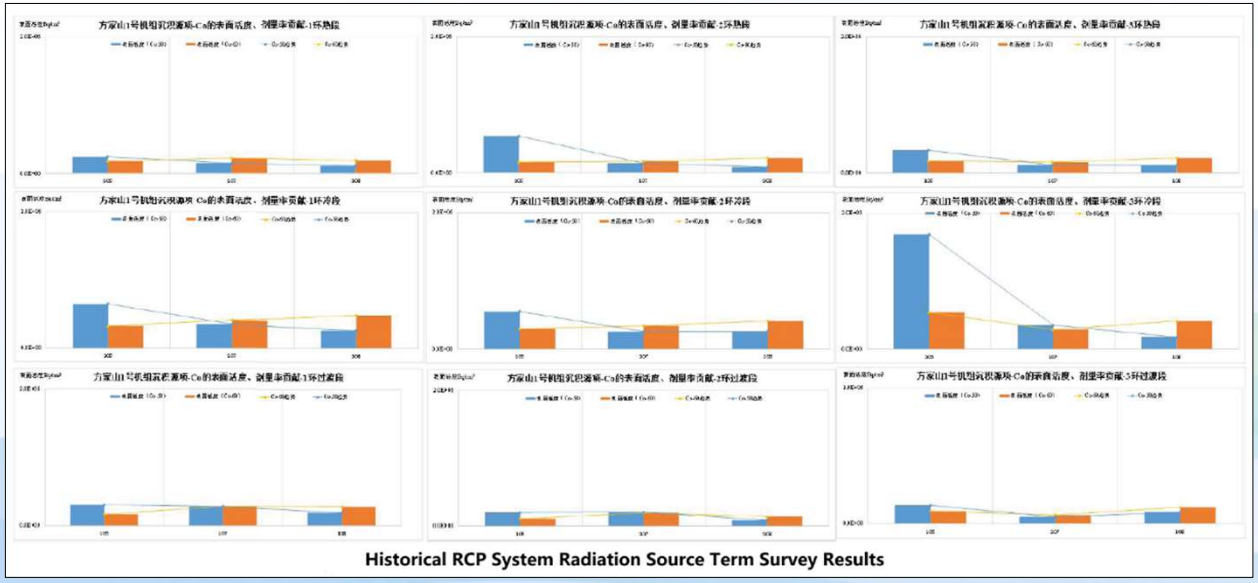
Steam Generator (SG) primary side radiation level

- The radiation level on the primary side of the Steam Generator (SG) water chamber was evaluated using the dose rate per man-hour during baffle plate installation work.
- During the 107 outage, with the implementation of an extended oxidation purification period, the radiation level on the primary side of the SG decreased.
- However, under the same duration of oxidation purification operation, the 108 outage showed an overall reduction of approximately 7–8% compared to the 107 outage , further demonstrating the role of zinc injection in reducing source terms.



Measurement of deposited radiation source terms during outage

- After one zinc-injection cycle, in 108 outage,the deposition of Co-58 in the main pipeline of RCP system showed a decreasing trend. The deposition of Co-60 exhibited a slight upward trend.
- This indicates that the first zinc-injection operation had a certain impact on reducing deposited source terms.



Historical RCP System Radiation Source Term Survey Results

Summary of Radiation Level Changes

- After zinc injection, **the radiation source terms were effectively controlled**, which to some extent suppressed the rapid increase in radiation levels in the primary system and the outage site. During the first cycle of zinc injection, the process contributed to radiation field control.
- However, radiation levels increased at certain specific locations, such as the pipelines downstream of the RCV system letdown heat exchanger.

Conclusion

04

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Conclusion

01

Coolant source term

The radiation source term level was gradually increasing.

02

Filtration and purification

The released source term was primarily filtered and purified in CVCS.

03

RCP radiation level

The rate of increase in radiation levels has slowed.

04

Area radiation level

The rapid upward trend of radiation levels in the outage site environment has been suppressed.

Conclusion

At Fangjiashan plate, the primary measure implemented during the 8th operational cycle and the 8th outage to control source terms was zinc injection. Comparative analysis indicates that zinc injection accelerated the release of activated corrosion products, which were then filtered and purified through the chemical and volume control system, thereby reducing radiation source terms within the primary system. Although radiation levels increased in some pipelines, the overall effect on radiation field control was positive.Zinc injection demonstrated a certain degree of radiation field control effectiveness even in its first cycle, contributing positively to the reduction of radiation fields. Continued monitoring over the next 2-3 operational cycles is necessary to further evaluate the impact of zinc injection on radiation fields.

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Thank you for your attention