1. Introduction

Title

Analysis and Optimization of Radiation Source Terms for QinShan Nuclear Power Plant

Purpose

The main work of this paper is to sort out and analyze the formation mechanism and composition structure of the radiation source term of Qinshan Nuclear Power Plant], track and analyze the variation trends of the main radionuclides of the unit during several cycles, and propose the targeted purification measures according to the characteristics of the nuclides.

Four pathways for dose reduction

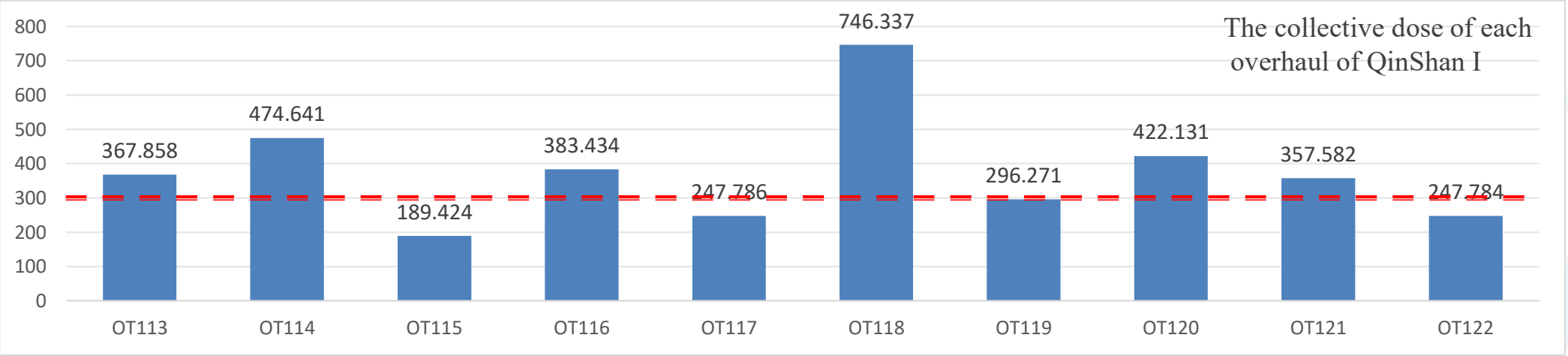
- **Optimization of Radiation Source Term Control**
- **Optimization of maintenance projects**
- **Optimization of maintenance process and workflow**
- **Optimization of Radiation Protection Management**

Optimization of radiation source term control is the foundation for reducing collective dose during overhaul。

1.Introduction

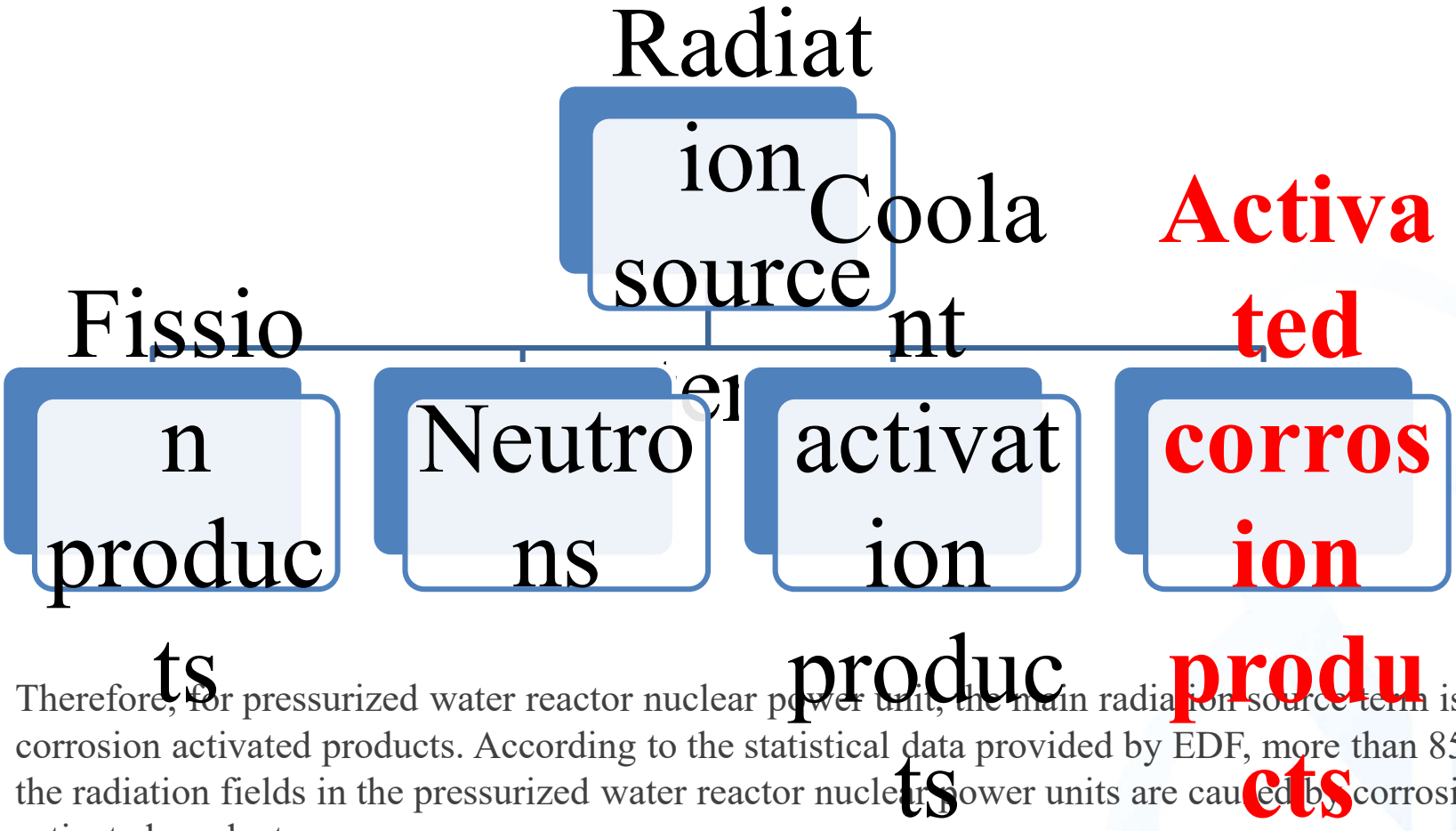
Collective dose index becomes a weak point

There is certain pressure on the collective dose performance indicators of the current unit, and the collective dose for the overhaul often cannot achieve the three-star target.



Currently, some optimization measures have been taken within the framework of the four dose reduction paths, but in recent years, there is a certain gap between the collective dose index of Qinyi Factory's overhaul and the ASP three-star index.Therefore, it is necessary to lay a solid foundation for the purification of radiation source terms, analyze the current situation of unit source terms, take targeted purification measures, and create a "clean" unit.

2.Radiation source term of the unit---activated corrosion products



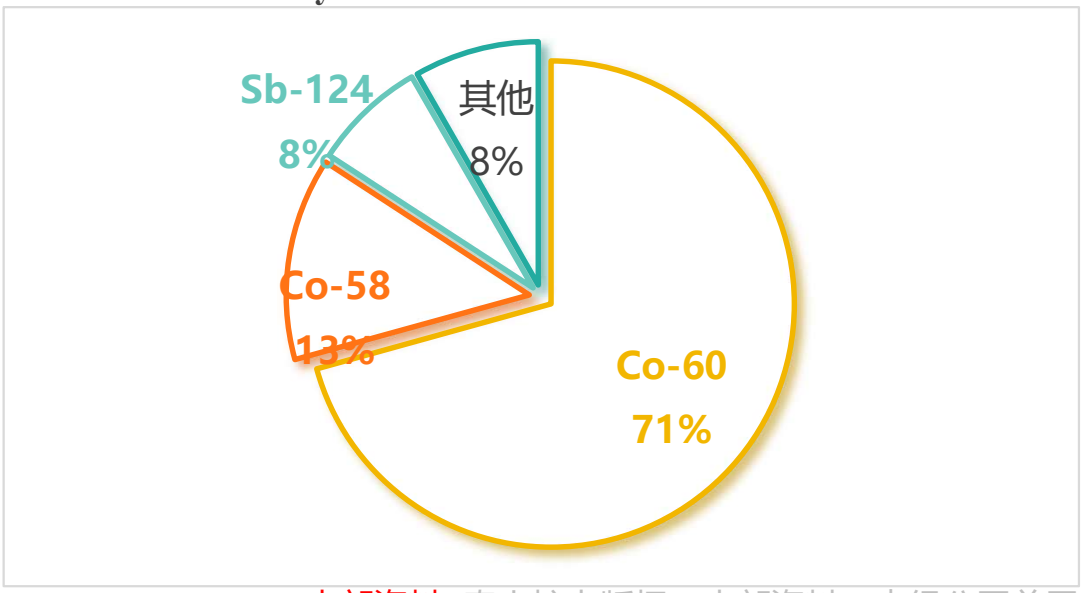
Therefore, for pressurized water reactor nuclear power unit, the main radiation source term is the corrosion activated products. According to the statistical data provided by EDF, more than 85% of the radiation fields in the pressurized water reactor nuclear power units are caused by corrosion activated products.

The main ACPs of QinShan I

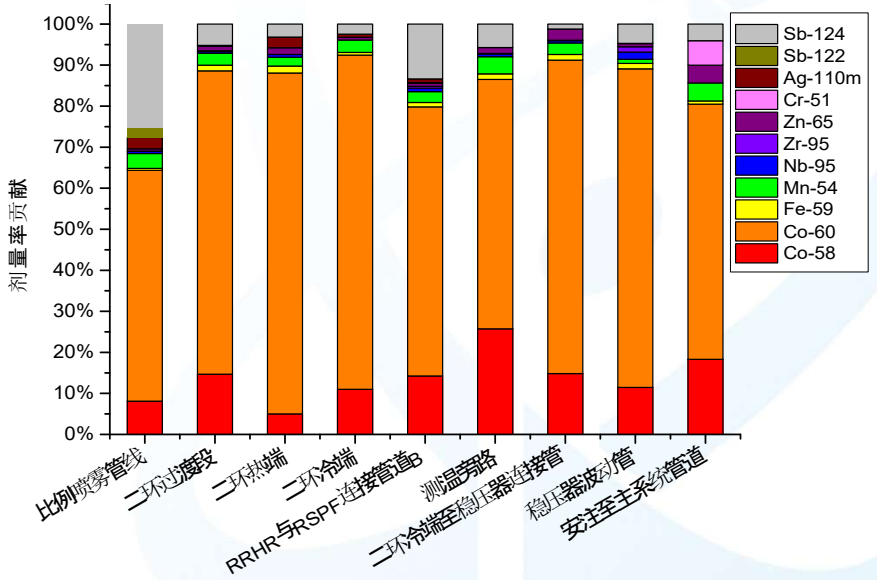
Sort out the data from the investigation of radiation source items in Q1-OT122 overhaul, and the contribution of dose rates of each nuclide in the main system is shown in the figure.

^{60}Co、^{58}Co、^{124}Sb are the main nuclides in QinShan I.

Dose rate contribution ratio of key nuclides of main system



Contribution of deposited nuclides to surface dose rate in each pipeline of main system



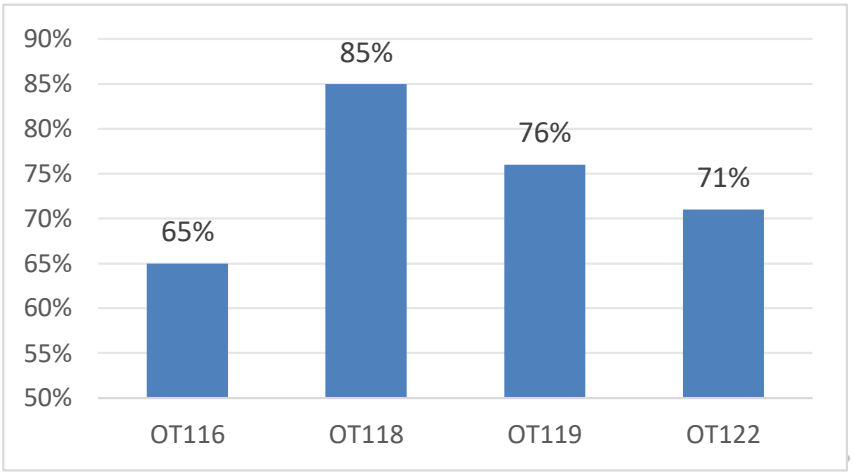
2.Variation trend of critical nuclide---^{60}Co

Source and characteristics of key radionuclides

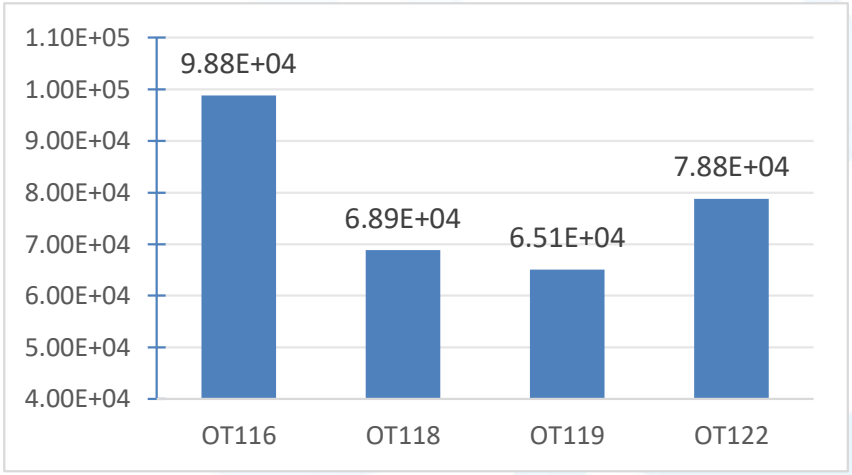
	Radionuclide	Target core	Nuclear reaction equation	Reaction Cross Section（b）	Source of target core
来源	^{60}Co	^{60}Ni	n, p	2.0E-3	【nickel-based alloy】SG heat transfer tubes(Inconel800)
	^{60}Co	^{59}Co	n,γ	**37.45**	【**Stellite hard alloy**】Sealing Surface of Valve
	^{60}Co	^{63}Cu	n,α	6.0E-4	\

	Half-life	Decay Energy	Exposure Rate Constant	Existence Form	particle diameter
特性	**5.27a**	1.17/1.32 MeV	$12.94R \cdot cm^2 \cdot mCi^{-1} \cdot h^{-1}$	Insoluble Metal Particles	0.2-0.4μm

Dose rate contribution accounting



Trend of changes in the surface activity



2.Variation trend of critical nuclide---^{60}Co

Analysis of variation trend

01

There are two main sources of ^{60}Co in the main system:

1. Under certain thermal and hydraulic conditions, ^{60}Ni in the nickel-based alloy used for SG heat transfer tubes is corrosively dissolved into the coolant and neutron-activated into ^{60}Co;
2. After the Stellite alloy is ground, the particles containing ^{59}Co remaining in the valve cavity enter the primary circuit and are activated。

02

^{60}Co accounts for more than 70% of the dose rate in the main system, which is the main radionuclide affecting the radiation level of the unit。

03

The surface activity of ^{60}Co in the pipeline decreased year by year after the 116 overhaul, and increased by about 20% after the 122 overhaul.

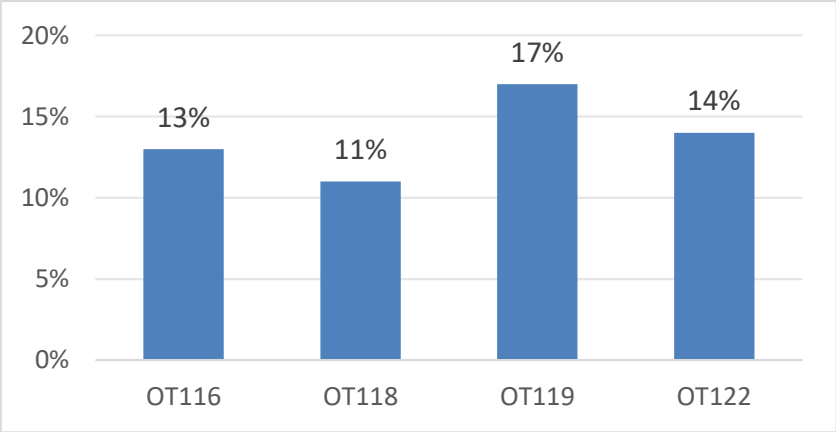
2.Variation trend of critical nuclide---^{58}Co

Source and characteristics of key radionuclides

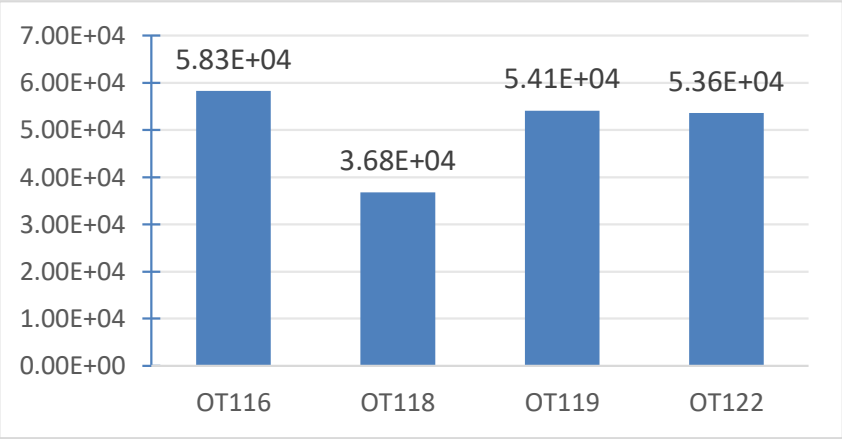
	Radionuclide	Target core	Nuclear reaction equation	Reaction Cross Section（b）	Source of target core
Source	^{58}Co	^{58}Ni	n, p	0.111	【nickel-based alloy】SG heat transfer tubes(Inconel800)

	Half-life	Decay Energy	Exposure Rate Constant	Existence Form	particle diameter
Characteristic	70.8d	0.81 MeV	5.464R·cm^2·mCi^{-1}·h^{-1}	Insoluble Metal Particles	0.2-0.4μm

Dose rate contribution accounting



Trend of changes in the surface activity



2.Variation trend of critical nuclide---^{58}Co

Analysis of variation trend

01

^{58}Co originates from the corrosion activation of nickel-based alloy of SG heat transfer tube.

02

The contribution of ^{58}Co dose rate is basically between 10% and 15%.

03

The activity of ^{58}Co remained stable in the last few cyclic.

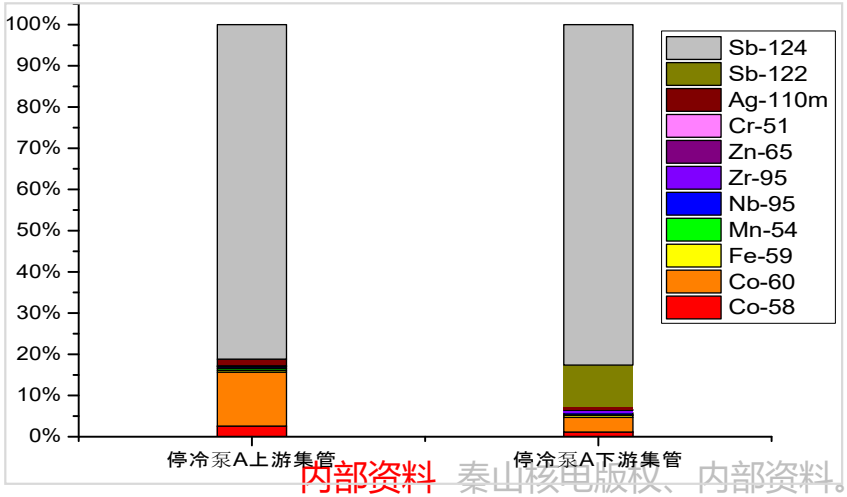
2.Variation trend of critical nuclide ---^{124}Sb

Source and characteristics of key radionuclides

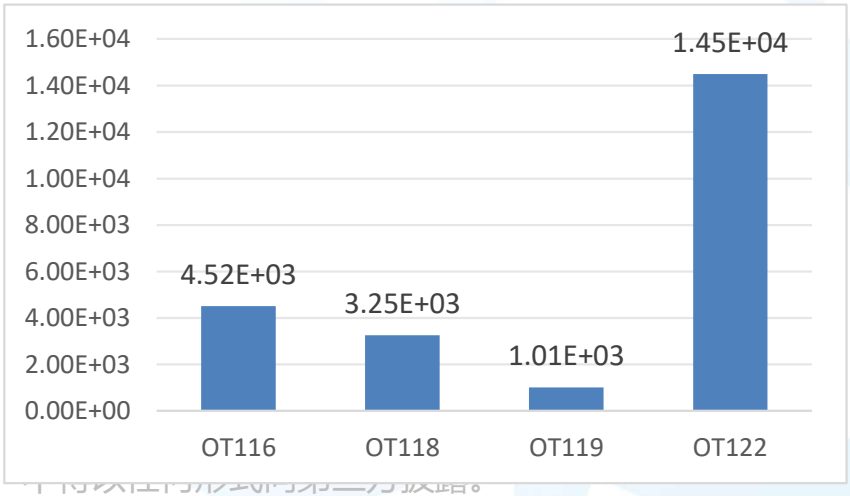
source	Radionuclide	Target core	Nuclear reaction equation	Reaction Cross Section（b）	Source of target core
	^{124}Sb	^{123}Sb	n, γ	4.145	thrust bearings、mechanical sealing rings

characteristic	Half-life	Decay Energy	Exposure Rate Constant	Existence Form	particle diameter
	60.2d	0.603 MeV	9.5R·cm^2·mCi^{-1}·h^{-1}	Soluble particle	0.08μm

Dose rate contribution accounting



Trend of changes in the surface activity (RRHR)



2.Variation trend of critical nuclide ---^{124}Sb

Analysis of variation trend

01

^{124}Sb is mainly deposited in the reactor shutdown cooling system，and its dose rate contribution proportion was higher than 80%.

02

Since the major overhaul of OT116, the surface activity of ^{124}Sb in the cooling system has been decreasing to a great extent.

03

The surface activity of ^{124}Sb in the cooling system during the major overhaul of 122 increased by an order of magnitude compared to that during the major overhaul of OT119.

3.Radiation source optimization measures-implemented

Control the formation of corrosion activated products

About Co-60

Source of ^{60}Co

- SG heat transfer tubes ^{60}Ni
- the sealing surface of valves ^{59}Co

As analyzed above, the surface activity of ^{58}Co remains stable, reflecting that the corrosion rate of SG heat pipe is basically unchanged. Therefore, the increase of ^{60}Co surface activity in 122 overhaul is not caused by the aggravation of ^{60}Ni corrosion.

Target nucleus：Co-59

↓

Material：Stellite alloy

↓

Application:Valve sealing surface

↓

Approach: Disassembly grinding

Measures I

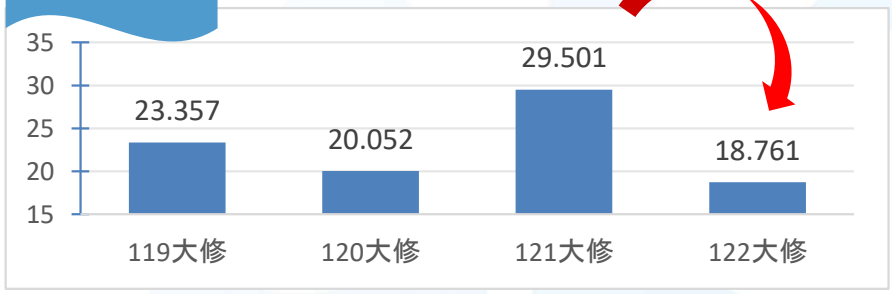
Adjust the pre-maintenance workload of the radioactive valve

In the overhaul of 122, the number of valve maintained has been reduced from more than 500 to 328

Measures II

Clean the valve cavity with the vacuum cleaning pump

achievement Collective doses for valve specializations

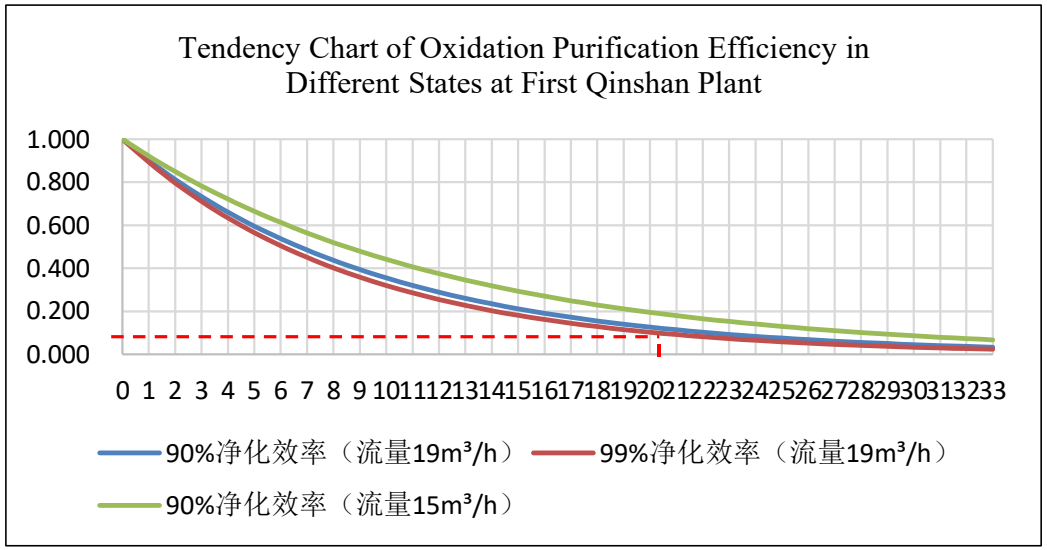


3.Radiation source optimization measures-implemented

Strengthen the purification of corrosion activated products

Extend the shutdown time of the main pump

Calculation of theoretical purification capacity

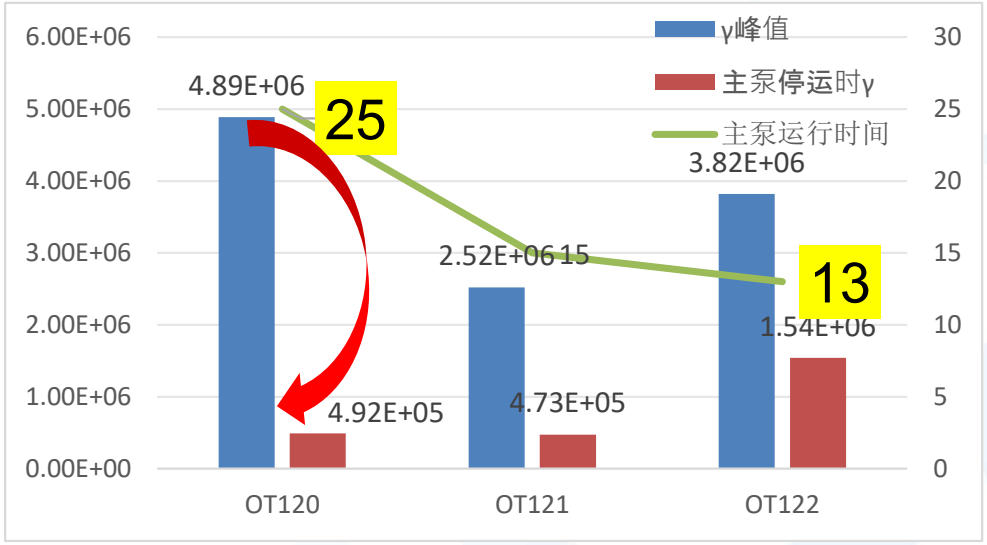


Formula $C_1 = \frac{A}{m_0} \cdot e^{-\alpha \frac{m}{m_0} \cdot t}$

Parameter $\frac{C_1}{C_0} = 0.1$; α=0.99; m=19; m_0=165

Results t=20.2

Practice in oxidation operation



OT120 purification**25h** reduction**90%**

OT122 purification**13h** reduction**60%**

3.Radiation source optimization measures-implemented

Eliminate the impact of corrosion products

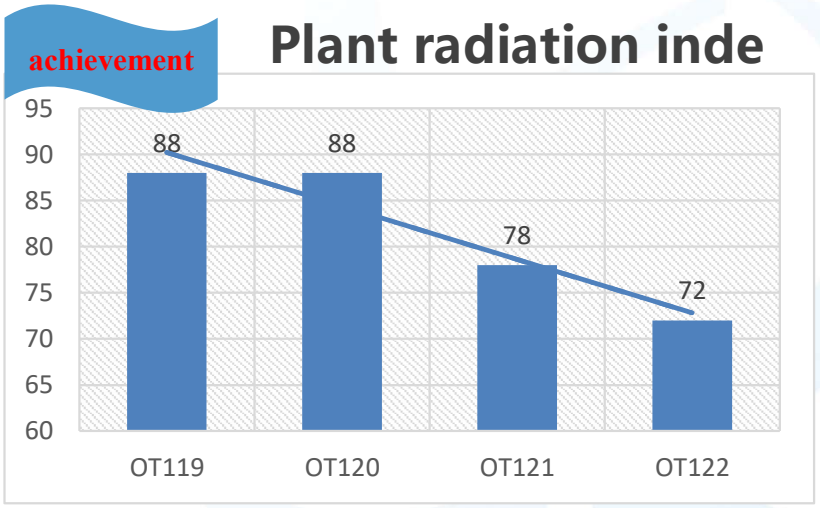
Hotspot flushing

mSv/h

Location of Hotspot	Exposure Dose Rate	Post-treatment Exposure Dose Rate	Environmental Dose Rate	Post-treatment Environmental Dose Rate
Fuel transfer carriage	120	**15**	1~4	**0.5**
01#210 Discharge pipeline	55	**6**	/	/

Hotspot shielding

In the overhaul of the Qin Yi Plant 122, more than 400 pieces of lead skin were used to shield 14 hot spots in 01# plant, which effectively reduced the dose rate level on site.



3.Radiation source optimization measures-implemented

Establish a comprehensive shielding system

Spread out

Wrap up

Hang

Fastening

The overhaul of 122 site applications

Number	Shielding Object	Pre-shield dose rate	Shielding dose rate	Shielding method
1	V01-04B Valve	1.05	0.535	25 sheets of lead were laid in two layers
2	S08-01A Piping	0.532	0.33	Tungsten rubber + lead arch bridge wrapping
3	01#305 Piping	1.73	0.711	Hang 6 lead sheets
4	01#210 Trench	10	3.25	Lay 17 sheets of lead

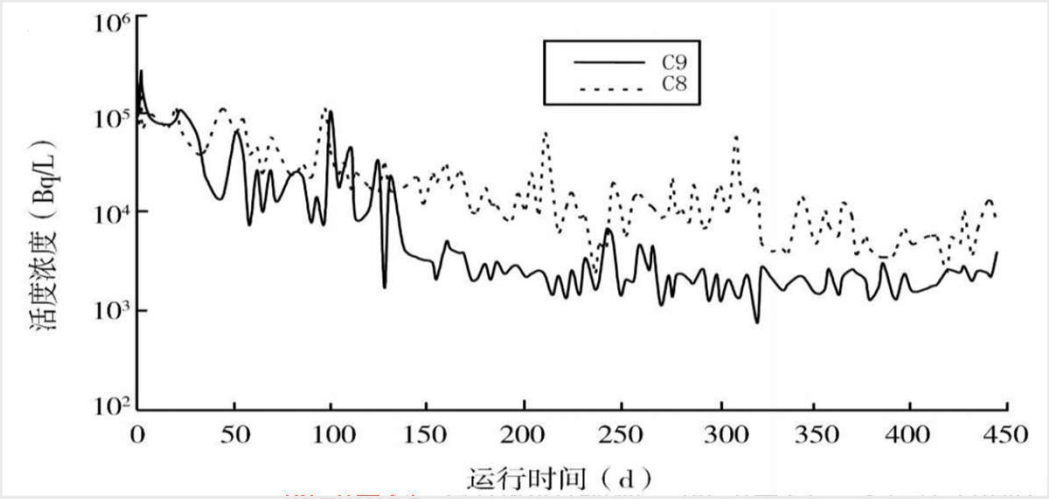
3.Radiation source optimization measures-improvement suggestions

Control the formation of corrosion activated products

About Sb-124

Replacing the material containing antimony has proved to be effective

During the R8 period, the First Qinshan Plant replaced the turbine guide bearing of the main pump with antimony-free materials. As a result, the antimony activity of the coolant decreased by 50% during the C9 period



improvement suggestions

At present, the Qin Yi Plant has adopted the material of antimony impregnated graphite for the rotating components of the refrigeration pump rotor. The added antimony (Sb) impurities enter the coolant after wear and activation to generate radioactive 124 Sb.
In the future, if there is any relevant change work, antimony-free materials can be given priority.

3.Radiation source optimization measures-improvement suggestions

Strengthen the purification of corrosion activated products

Optimize the filter pore size

Pore Sizes of Filters of Some Nuclear Power Units in China Unit：μm

Power Plant	Daya Bay	Ningde	Fuqing	Hainan	Tianwan	First Qinshan Plant	Fangjiashan
pore size	0.1	0.1	0.45	0.45	0.1	**1**	0.1

Improvement suggestion： The particle diameters of ^{60}Co and ^{124}Sb are generally 0.08-0.4μm. The filter capacity for such two radioactive nuclides shall be improved.

Extend the opening time of the double-discharge orifice plates after reaching the critical point

Type of Reactor	Water Inventory of Primary Circuit (m^3)	Purification Flow Rate (m^3/h)	Purification Rate/Hour
WWER	300	30	10.0%
AP1000	227	19.5	8.6%
CNP600	165	13.6	8.2%
Hualong	354	25	7.1%
CNP1000	278	13.7	4.9%
First Qinshan	165	**11.2**	**6.8%**

Improvement suggestion：
After the major overhaul of the unit reaches the critical point, the opening time of the double discharge orifice plates can be extended appropriately to enhance the purification capacity.

4.Sum up

01

The main deposition source terms at the First Qinshan Plant: ^{60}Co、^{58}Co and ^{124}Sb

1) ^{60}Co is a key factor affecting the radiation level of the unit.
2) The surface activity of ^{58}Co tends to become stable after the recent major overhauls without obvious fluctuation
3) ^{124}Sb showed a significant increase in the 122 overhaul cold system.

02

Improvements already made:

1) controll the entry of cobalt-containing particles into the primary circuit;
2) Optimize the oxidation operation and prolong the downtime of the main pump;
3) Develop hot spot flushing scheme and improve hot spot shielding method.

03

Achievements in improvement:

1) The collective dose of the 122 overhaul was completed, ranking the second in history.
2) The on-site dose rate level showed a continuous downward trend, and the radiation index of the plant decreased steadily.

04

Source optimization suggestions:

1) Promote the pore size change of filter element in chemical bed front filter;
2) Strengthen the purification capacity of the unit, and extend the opening time of the double discharge orifice plate after criticality;
3) Replace antimony-containing materials in the appropriate change window.

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