Source Term Control Technologies for Key Radionuclides in Nuclear Power Plants

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严格按照法规标准和政府监管部门的要求开展核能技术创新和工程建设工作，落实安全质量责任，保证核安全始终处于最高优先地位，维护公众、客户和其他相关方的利益。

3 完善管理体系

构建科学合理的管理和技术标准体系，建立和完善体系持续改进的机制，做到“凡事有章可循，凡事有据可查，凡事有人负责，凡事有人监督”，保证所提供的产品和服务的安全质量。

4 践行安全行为

各级领导充分发挥表率和示范作用，严格执行程序，及时回应并解决相关方报告的安全质量隐患；全员践行“献身的工作精神、质疑的工作态度、严谨的工作作风、沟通的工作习惯”，不断提升核安全文化素养。

5 营造适宜环境

关注外部环境，建设适宜的内部工作环境，保障人员健康安全；提倡“全员学习、终身学习”；建立公开公正的激励机制；营造相互尊重、高度信任、团结协作、坦诚透明的工作氛围。

6 促进坦诚沟通

以开放的心态倾听公众、客户和其他相关方的意见，鼓励全体员工自由报告安全质量相关问题，并妥善处理各方诉求。通过各种途径和多种形式，确保相关方的知情权、参与权和监督权。

Introduction

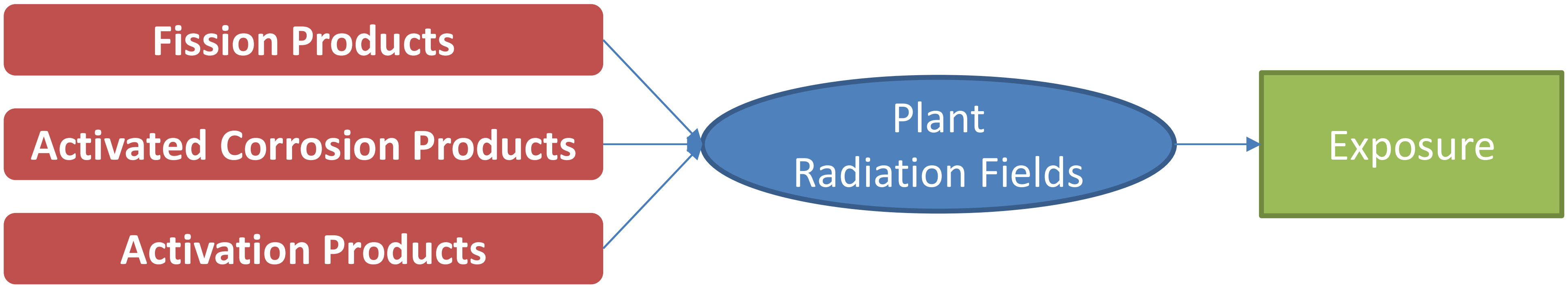
In nuclear power plants, the control of radioactive source terms is a fundamental aspect of ensuring reactor safety, environmental protection, and regulatory compliance.

For this presentation:
The source term specifically refer to the composition, quantity, and release pathway of radionuclides generated during reactor's normal operation.

Key Radionuclides in Commercial NPPs

PART 01

Collective radiation exposure (CRE), often measured as the sum of the individual doses received by workers in a given time (***Collective Dose***), is used as a **performance indicator** by regulators, industry groups, and individual utilities to challenge stations to decrease occupational exposure to plant radiation workers.



1、Key Radionuclides in Commercial NPPs

Major Occupational Dose Contribution

Activated Corrosion Products

- **Co-58 (Short Term)**
- **Co-60 (Long Term)**
- Nb-95
- Mn-54
- Fe-59
- Zn-65(plants with zinc injection)
- Ag-110m (Silver contamination)

Contribution 80%~90% (or even more)

Minor Occupational Dose Contribution

Fission Products

- Low Fuel Defects
- Low Fuel Contamination

Activation Products

- C-14
- H-3 (internal exposure)
- Etc.

Cobalt Control

PART 02

2、Cobalt Control

Source of Co-58 & Co-60

Co-59 (n, γ) Co-60 $t_{1/2}$~5.27yr

Ni-58 (n, p) Co-58 $t_{1/2}$~70.86d

- Co impurity control
  - **most fundamental and long-term** approach
  - good industrial practice
- **Zinc injection**
  - reduces both Co-58 & Co-60 by significant amount
- **Water Chemistry control**
  - reduces deposition & radiation field

Co impurity control

Nowadays, Co impurities in new reactors have already been well controlled

Reference requirements of Co impurities

Area, Component, or Application	Maximum Weight Percentage of Cobalt (%)
Inconel and stainless steel components in fuel assemblies	0.05
Inconel tubing in steam generators	0.015
Components outside the core active region but in areas of high neutron flux, typically including: baffle plates, former plates, core upper plate, core lower plate, barrel cylinder, and neutron pad	0.05
Other surfaces of steam generators excluding heat transfer tubes	0.1
Other major components and weld overlay surfaces, excluding hardfacing and fasteners listed below	0.05
Auxiliary heat exchangers exposed to reactor coolant	0.05
Bolt materials in core internal components; other small components in high neutron flux areas	0.2
Bearings and hardfacing materials	Unlimited (use low-cobalt or cobalt-free materials as much as possible)
Auxiliary components, such as valves, piping, instruments, enclosures, etc., including bolt materials in both primary and auxiliary components	Unlimited (use low-cobalt materials as much as possible)
Welding materials excluding those with weld overlays	Unlimited (use low-cobalt materials as much as possible)

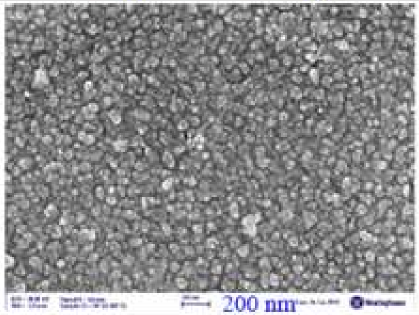
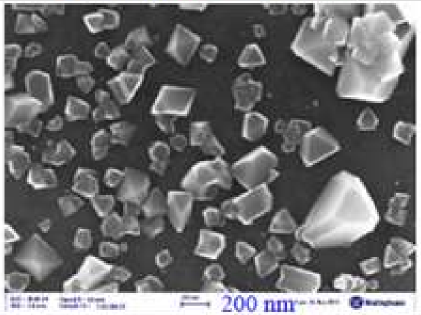
Zinc Injection

Zinc substitutes Nickle at the oxide layers of fuel claddings by:

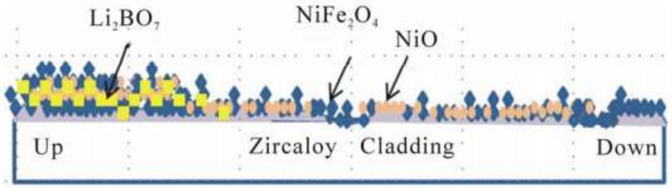
$$NiO + Zn^{2+} \rightarrow ZnO + Ni^{2+}$$

$$NiFe_2O_4 + Zn^{2+} \rightarrow ZnFe_2O_4 + Ni^{2+}$$

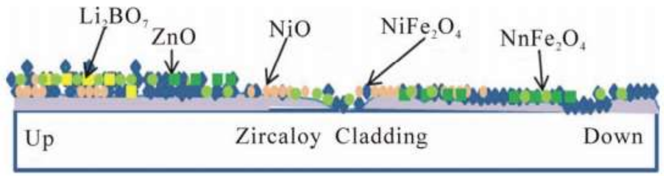
AP1000 SS Surface --- After hot test

AP1000 Chemistry	Traditional Chemistry
	

Schematic diagram of the deposition of fuel oxides before zinc injection.



Schematic diagram of the deposition of fuel oxides after zinc injection.



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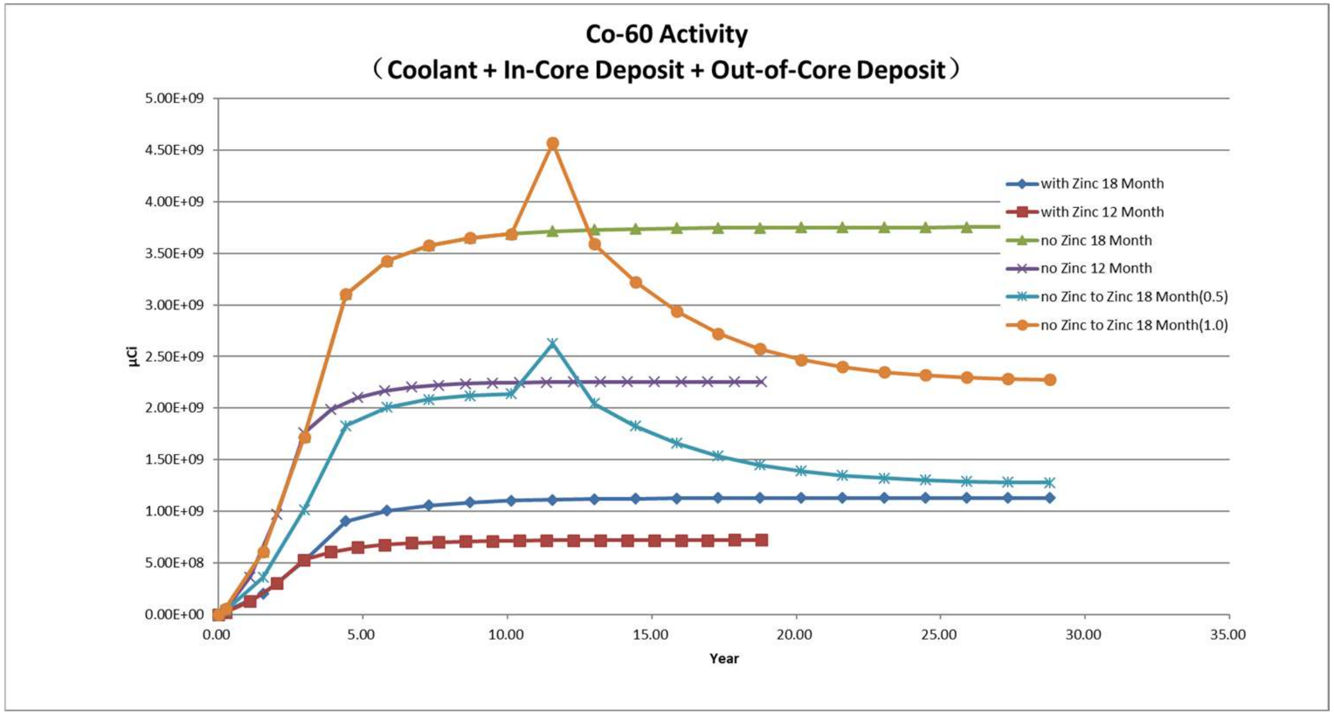
2、Cobalt Control

Zinc Injection

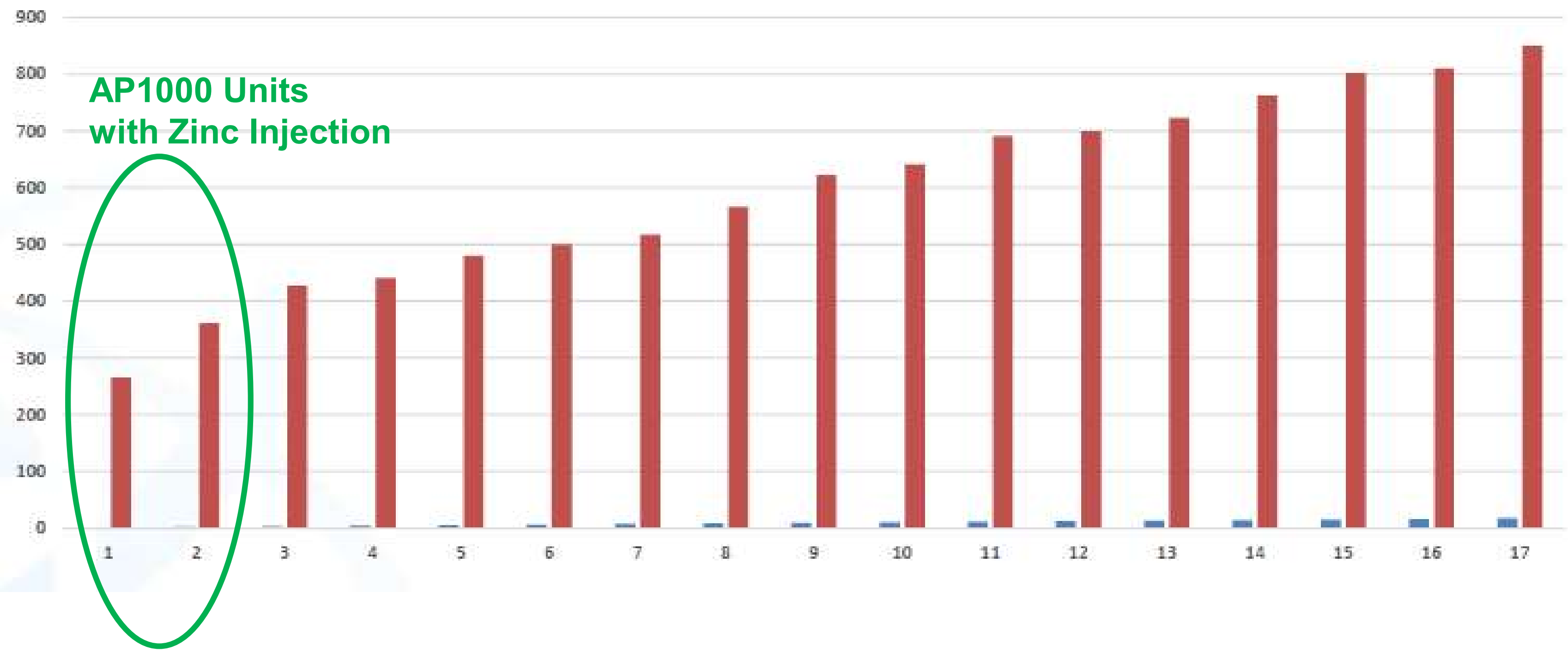
- During the **initial cycle startup tests**, prior to criticality, the core power is low, resulting in minimal risk of zinc deposition and a higher zinc absorption rate. Therefore, the zinc injection rate can be increased (**~40 ppb**),.
- During **normal operation**, typical zinc injection rate of **~15ppb**
- In the latter half of the cycle, when the risk of CIPS/CILC events is lower, the zinc injection concentration can be increased to achieve optimal radiation field control.

Simulated Co-Activity in a PWR



Zinc Injection

Collective Dose of the first refueling outage at various domestic nuclear power plants



Shutdown Chemistry Controls

- **Control Coolant pH, Control Acid Reducing/Oxidizing Conditions**
  - increase solubilization of in-core and ex-core deposits
  - increase corrosion product and activity removal
- **Optimize RCP Operations & Purification Flowrates**
  - promote dissolution of deposits present on system surfaces
  - minimize core flow transients to minimize particulate entrainment which will increase dose rates and particulate contamination levels in low flow regions.
  - maximize cleanup capability
- **Reduce Dissolved Hydrogen Prior to Opening the RCS**
  - prevents formation of combustible/explosive mixtures in containment
- **Mid-Cycle Shutdown Chemistry Control**
  - decisions regarding remaining in acid reducing chemistry or changing to acid oxidizing conditions
  - minimize ex-core deposition

Ag-110m Control

PART 03

3、Ag-110m Control

Why important?

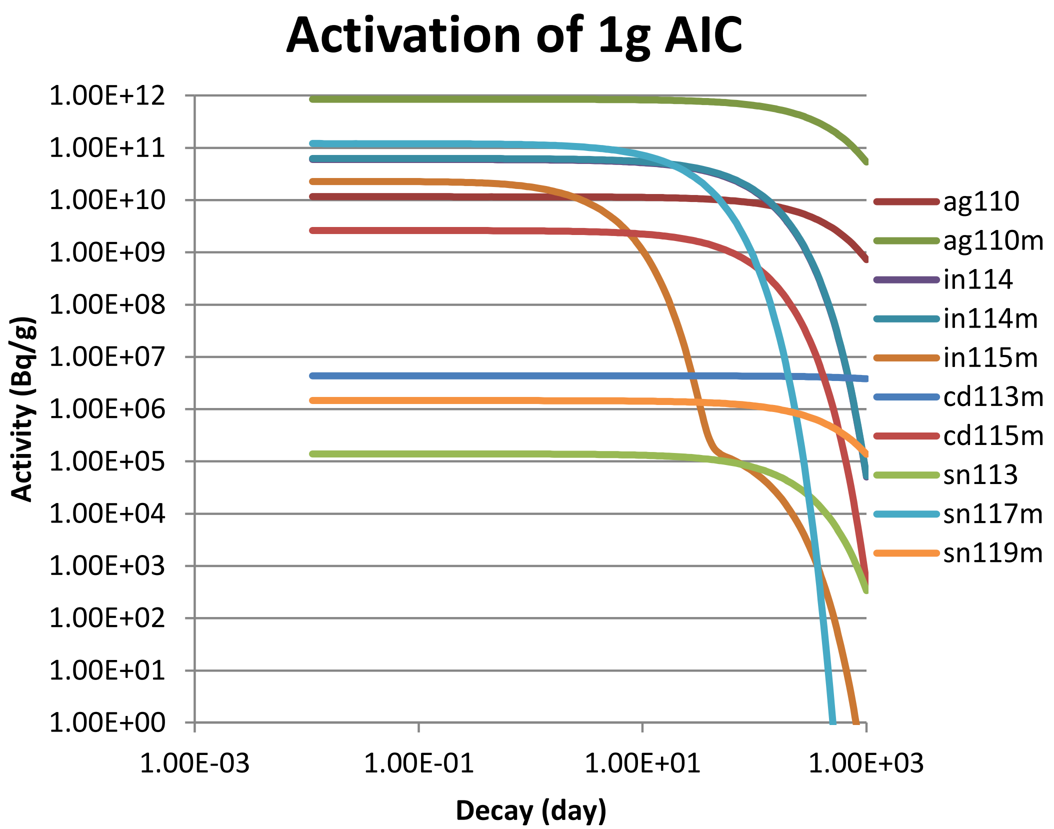
- **Long half-life ~253 days**
- **strong gamma emitter**
  - 658keV(94.3%)
  - 885keV(72.7%)
  - 937keV(34.2%)
  - 1.38MeV(24.9%)
- **High dose contribution**
  - ~15 % for EDF units, if contaminated

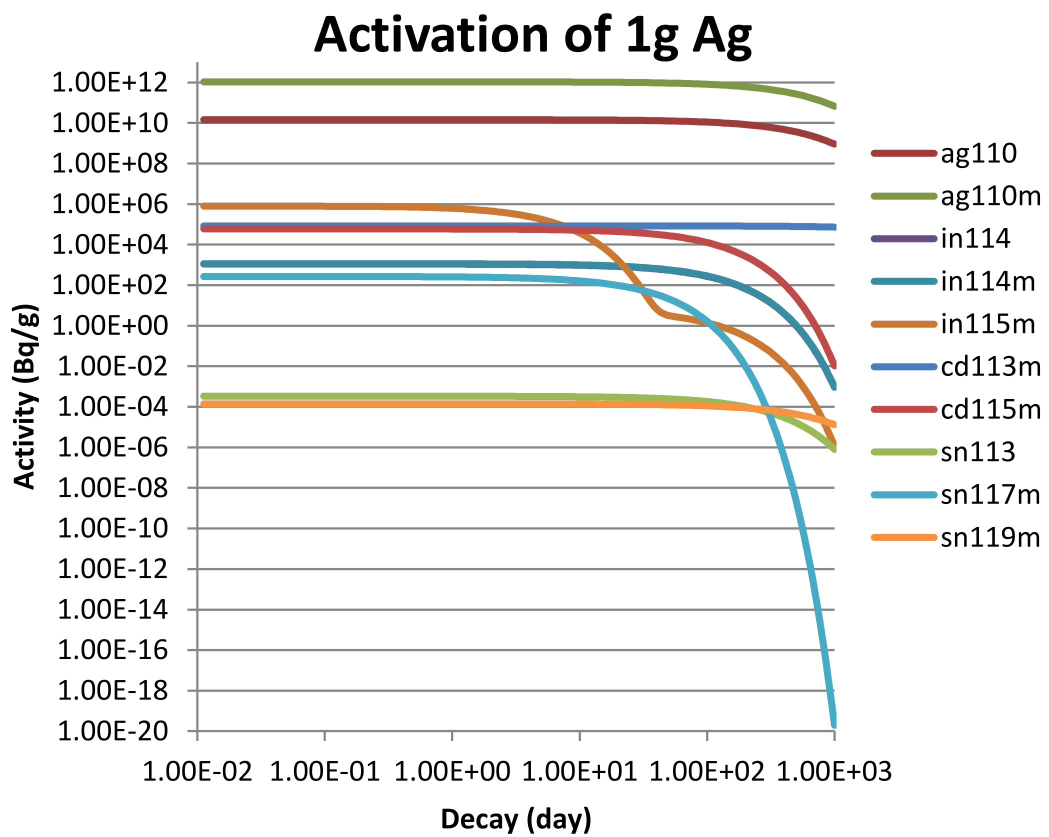
Major sources of Ag-110m in the primary loop that has been identified:

- failed Ag-In-Cd **(AIC) control rods**
- **silver-containing components** on the internal surfaces of the coolant loop
  - seals
  - rupture disks
  - gaskets

To ***distinguish*** whether the source of Ag-110m is from AIC control rods or other silver-containing surface components,
activation measurements of ***indium (In) and cadmium (Cd)*** can be performed.

3、Ag-110m Control





Tritium Control

PART 04

4、Tritium Control

Tritium readily forms water when exposed to oxygen.
Almost always found as water, or "tritiated" water.
Tritiated water may enter the body by

- inhalation,
- ingestion,
- absorption through the skin.

Most of the tritium is released to the environment, **minimizing H-3 in open water systems**

↓

Reduced dose from tritium

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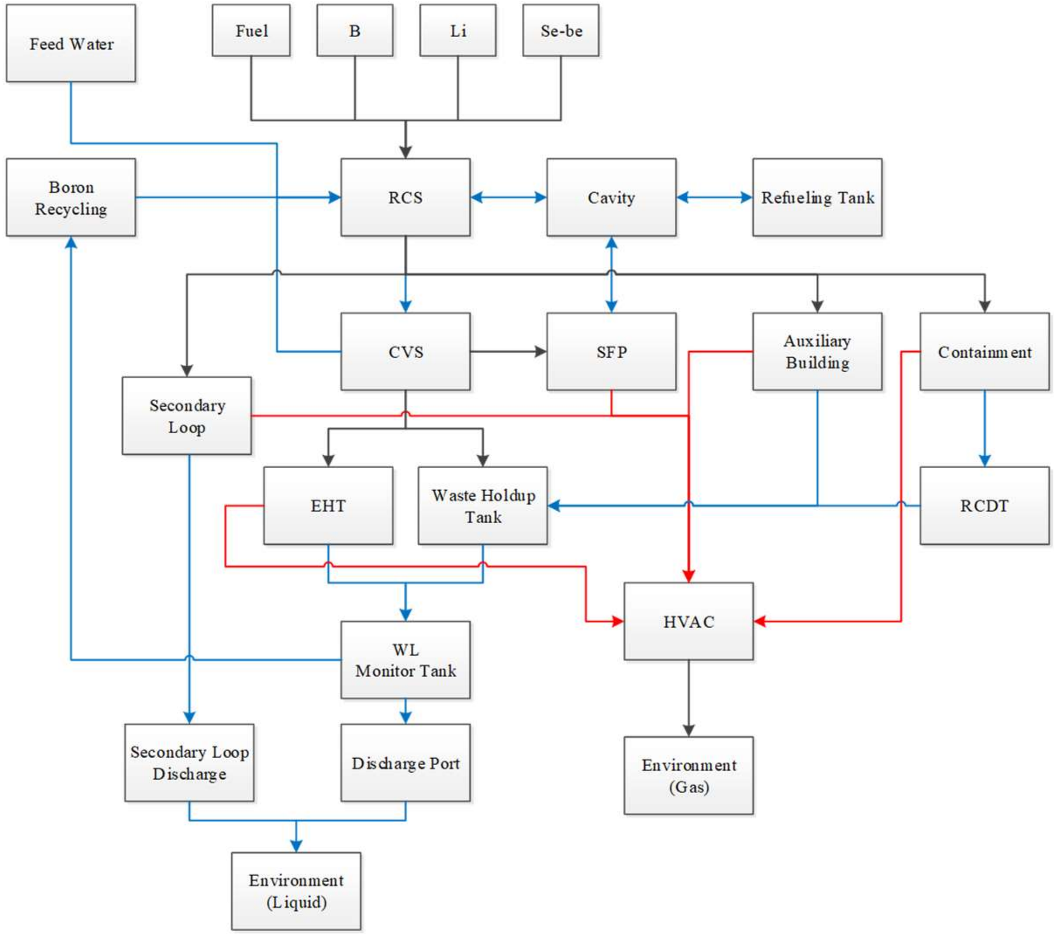
However, amount of Tritium exposed by workers still needs to be monitored and controlled, to minimize dose from **cumulated** tritium.

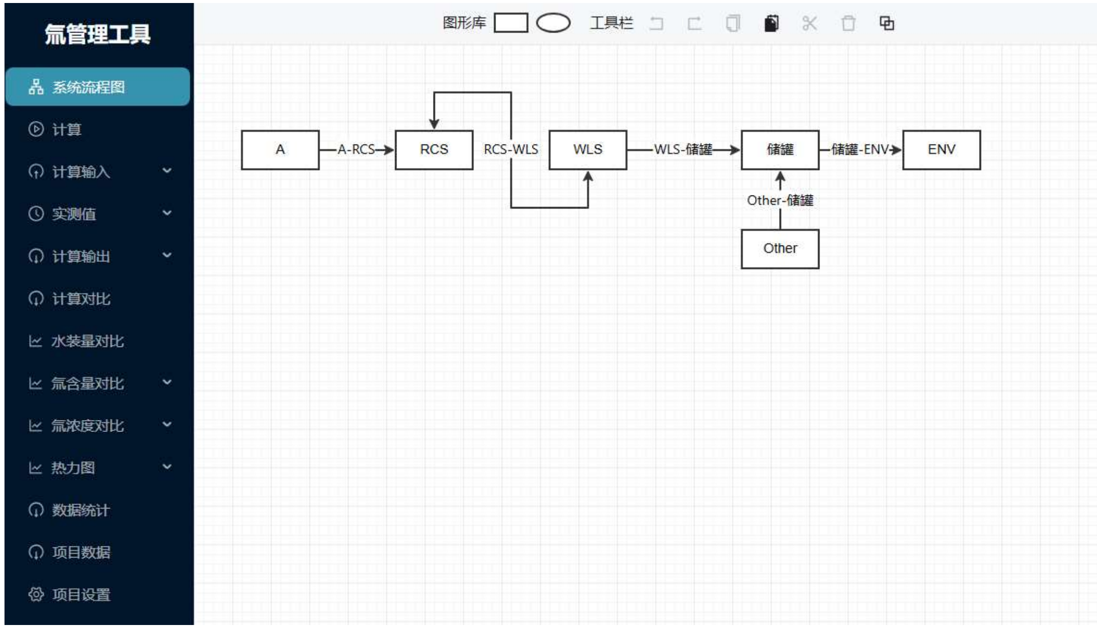
Example schematic diagram of H-3 flow path in PWRs



4、Tritium Control

Develop tools for better H-3 management

Setup system flow and inputs



Predict/monitor H-3 in each system

Thank you!

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