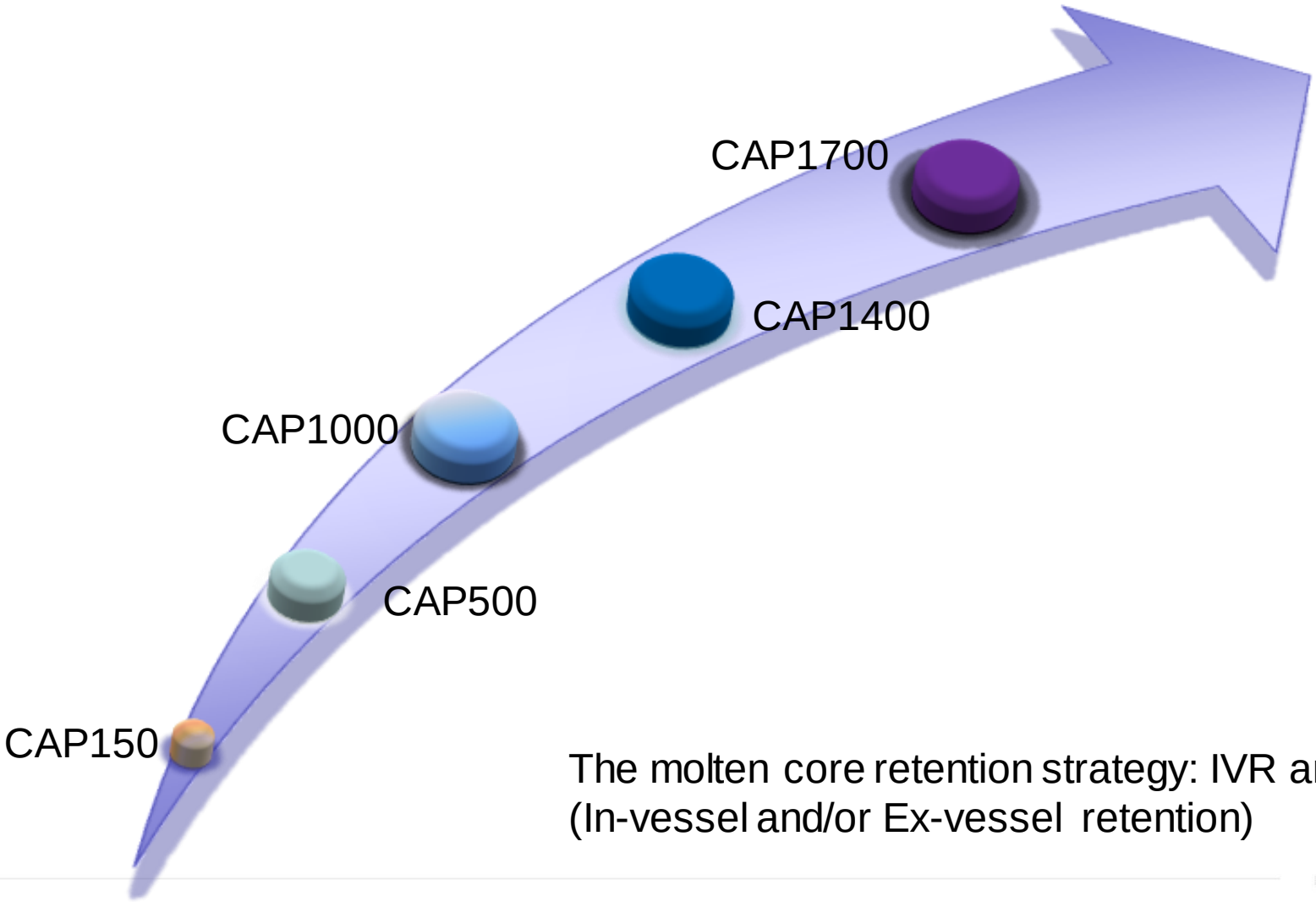
CAP1400 Core-Melt In-Vessel Retention Measure Design and Research

国家核电 SNPTC 上海核工程研究设计院
SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

Contents

Introduction

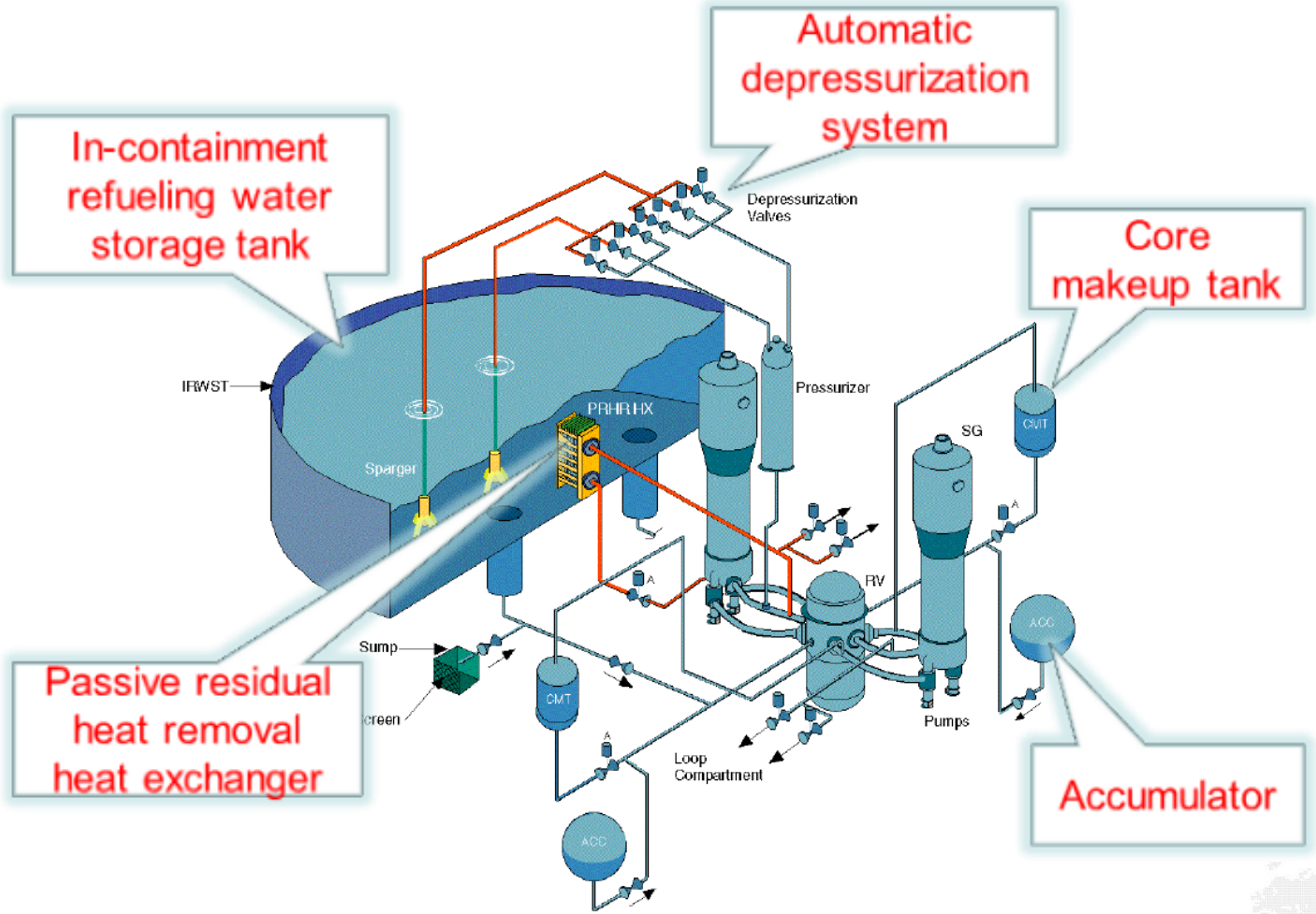
Passive nuclear power plant is majored in SNERDI



The molten core retention strategy: IVR and/or EVR
(In-vessel and/or Ex-vessel retention)

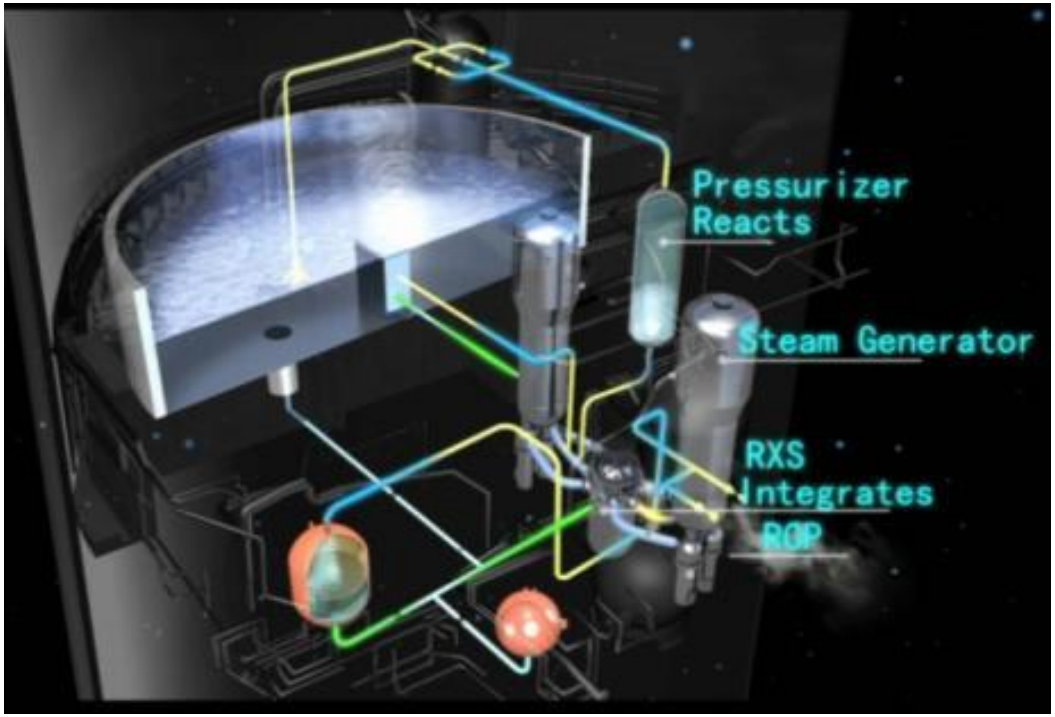
Introduction

Large-Scaled Passive Plant Schematic PXS



Introduction

Large-Scaled Passive Plant Schematic diagram of PXS

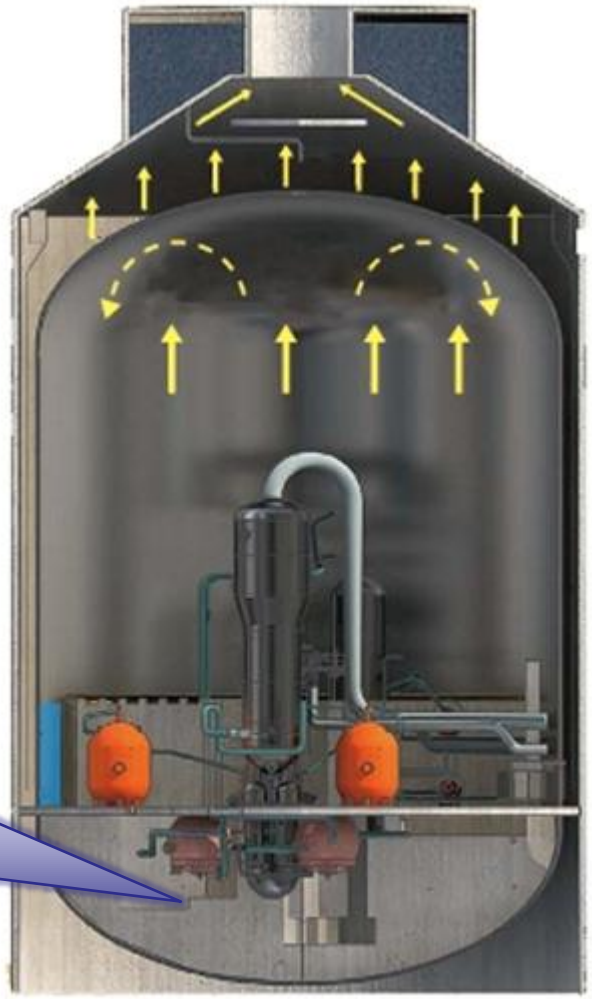


Passive Core Cooling System (PXS) includes:

1. Passive Residual Heat Removal Subsystem: PRHR-HX, IRWST
2. Passive Safety Injection Subsystem: CMT, ACC, IRWST
3. Automatic Depressurization Subsystem: ADS1-3, ADS4

Introduction

Large-Scaled Passive Plant Schematic Diagram of PCS



Optimized containment layout

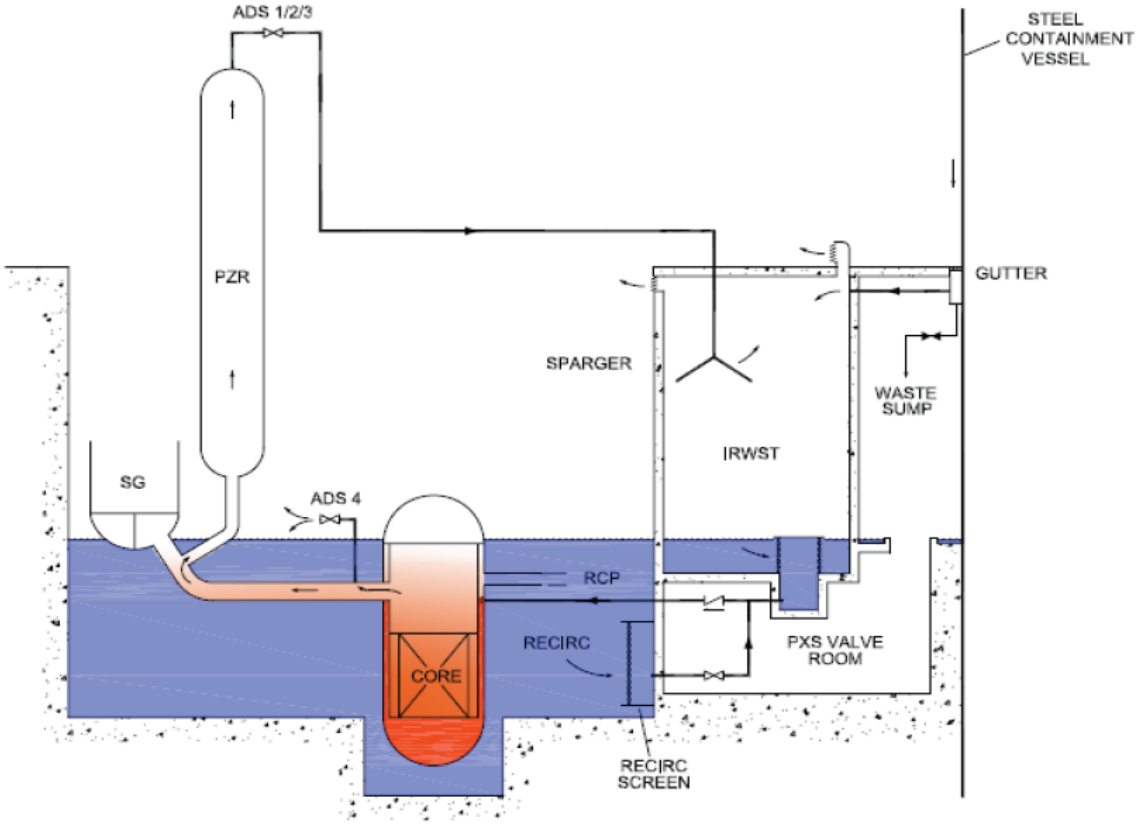
Passive Containment Cooling System (PCS):

remove the heat through the steel containment wall by water spraying and natural air circulation

Contents

The research undergoing

IVR



SNERDI focused on IVR research for a long time

The research undergoing

IVR

The IVR Issue

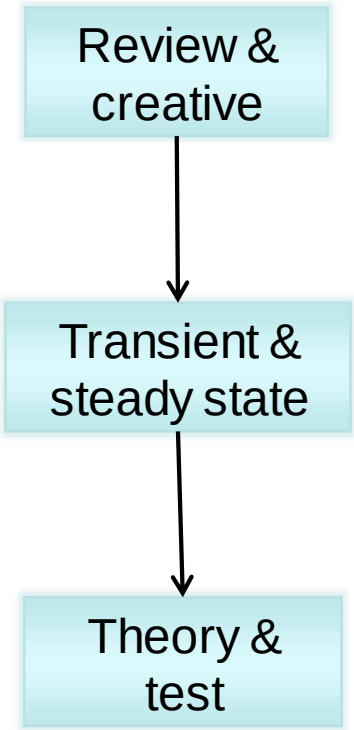
Item		Possible action	Purpose
Transient analysis	Core melting analysis		Understand the core melt progression
	Core relocation	From bottom From side	The action for melt relocation, support the pool configuration judgment
Steady state analysis	Pool configuration	2 layer 3layer	Determine the pool configuration, 2layer or 3layer
	Pool heat transfer	Top layer, Oxide layer, bottom layer	Determine the heat flux

The research undergoing

IVR

SNERDI developed systematical IVR research

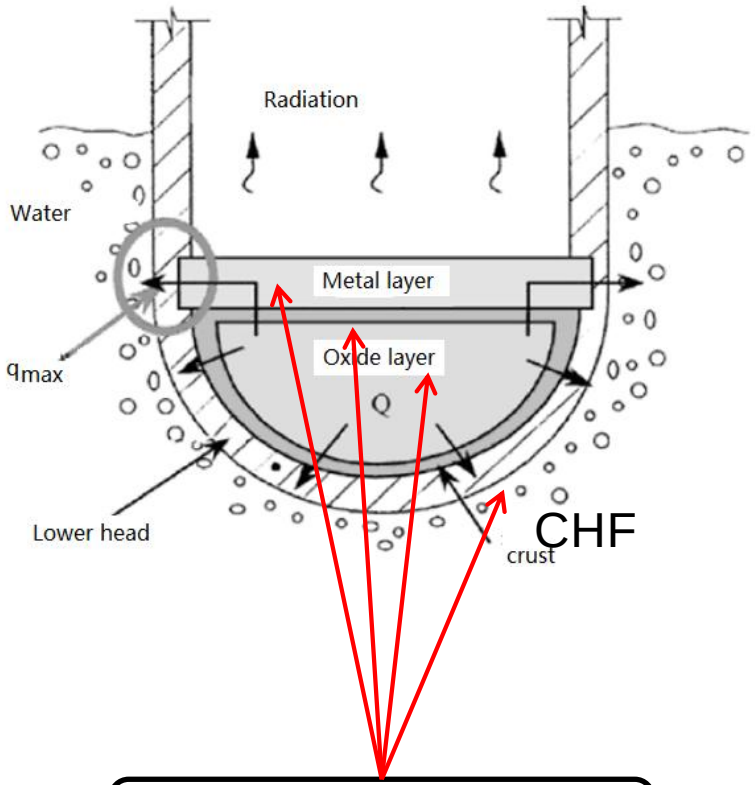
- Theory study
  - Core melting & relocation
  - Molten pool configuration mechanism research
  - RPV structure analysis
  - Molten pool heat transfer analysis
  - IVR enhancement
  - Cavity flooding
- Test study
  - CHF test
  - Pool heat transfer test



The research undergoing

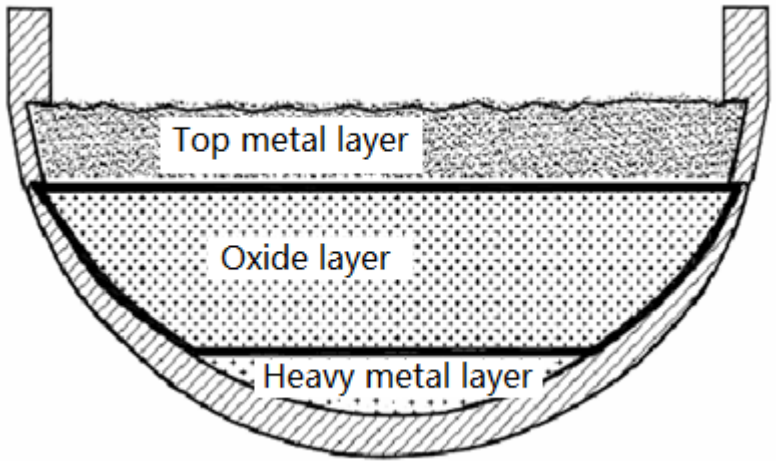
IVR

2 layer configuration



Special Analyzed

3 layer configuration



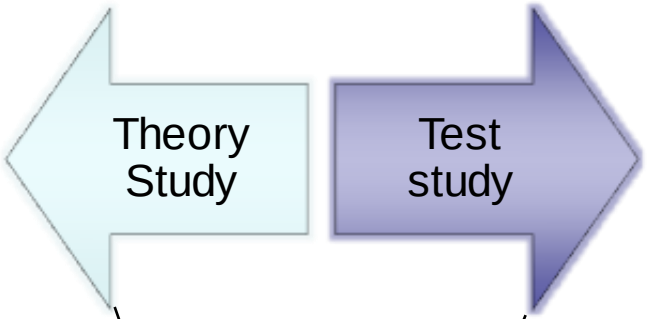
Designs benefit for IVR:

- ADS
- No penetrations in RPV
- Containment flooding area
- Optimized insulation

The research undergoing

IVR

The special & creative IVR work in SNERDI



- CFD flow & heat transfer
- Crust strength
- Thermodynamic study
- Core injection strategy

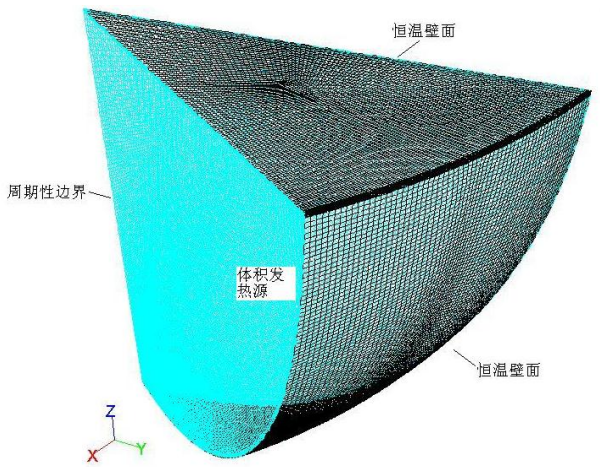
- ERVC
- KCHF
- Metal layer

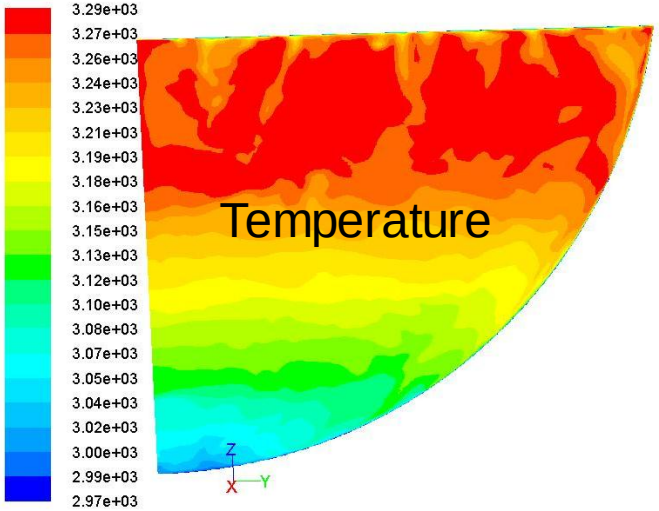
The research undergoing

IVR Study

Molten pool CFD simulation

- **Purpose**
  - Find out flow & heat transfer phenomena
- **Contents**
  - Oxide pool simulation
- **Results**
  - Compared with ACOPO test
  - Vortex existed: large scaled & small scaled
  - Temperature layered





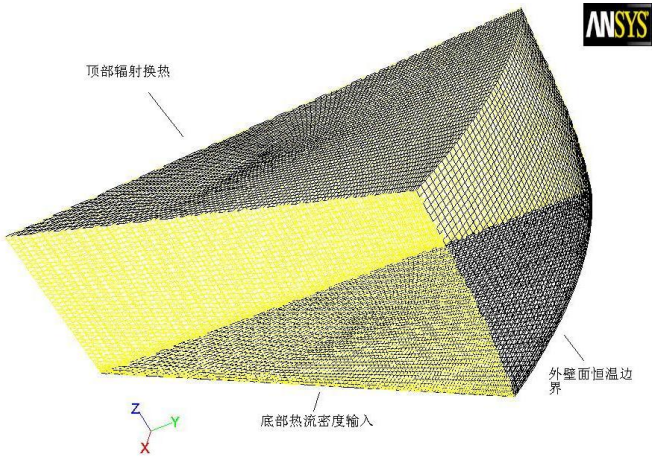
Oxide pool

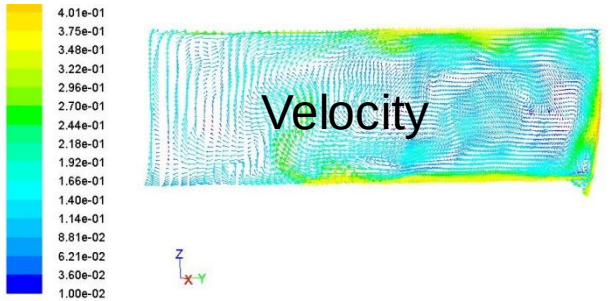
The research undergoing

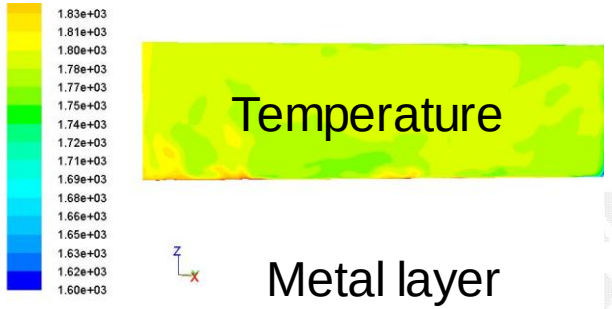
IVR Theory Study

Molten pool CFD simulation

- **Purpose**
  - Find out flow & heat transfer phenomena
- **Contents**
  - Metal layer simulation
- **Results**
  - No stagnant area found
  - Bulk temperature distribution
  - Bottom temperature is highest







The research undergoing

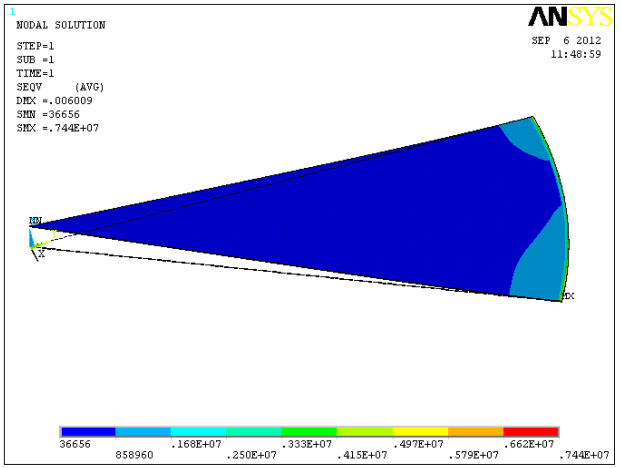
IVR Study

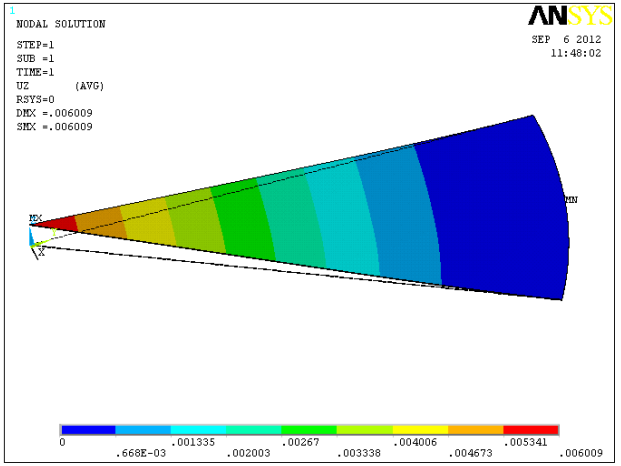
Crust intensity study

- **Purpose**
  - **Find out the possibility of totally mixture**
- **Contents**
  - **Crust simulation**
  - **Based on molten pool CFD simulation results**
- **Results**

Crust thickness (mm)	Max stress (MPa)	Max strain (mm)	MACE test stress (MPa)
2.9	4.97	6	**11**

The crust is probability to keep intensity, the oxide and metal may not well mixed



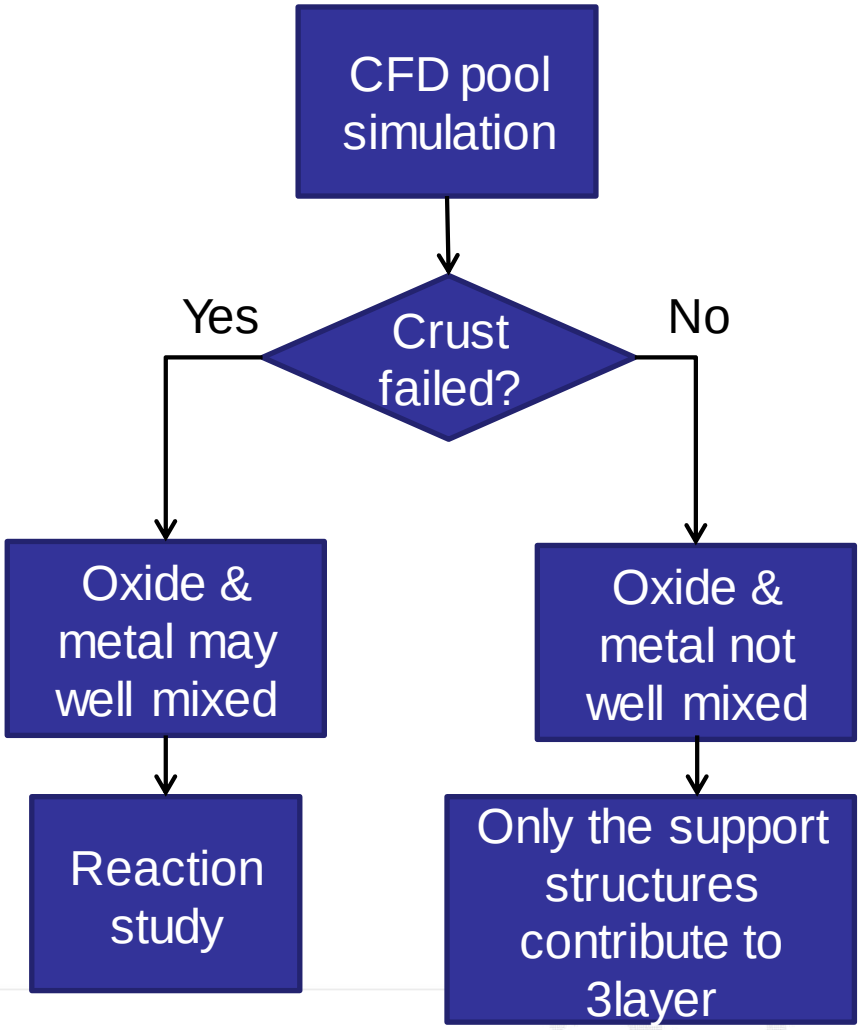


The research undergoing

IVR Study

Crust intensity study

- **Purpose**
  - **Find out the reaction in the pool**
- **Contents**
  - **Pool configuration study**
  - **Reaction under the very high temperature**
- **Results**
  - **May generate U**
  - **The heavy layer is mixture**

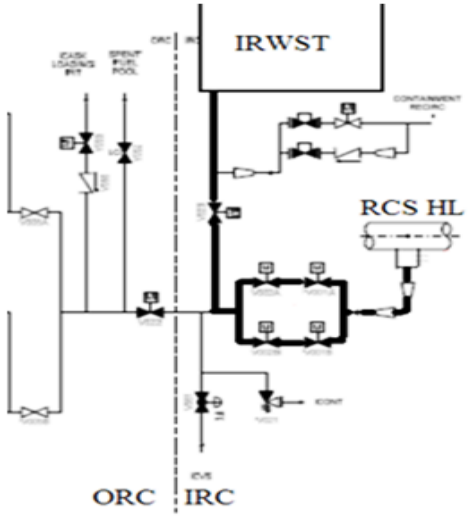


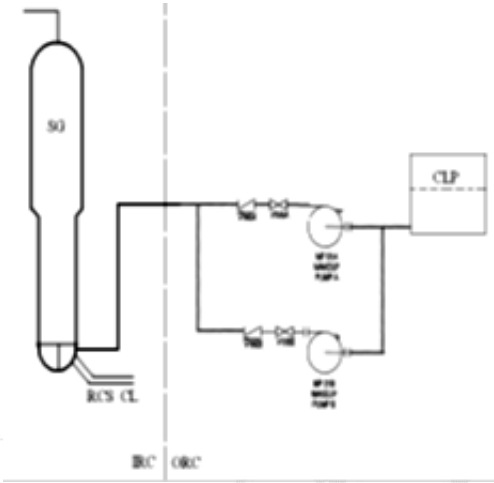
The research undergoing

IVR Study

Core Injection

- **Purpose**
  - Find out the IVR effectiveness based on PSA
- **Contents**
  - Core injection manners
  - Decomposition Event Tree analysis
- **Characteristic**
  - High probability of successful injection
  - In-Vessel & Ex-Vessel cooling of the pool
  - Written to the SAMG





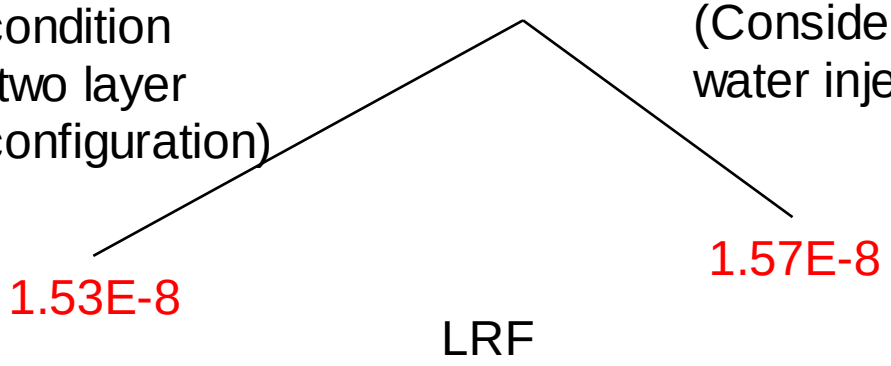
The research undergoing

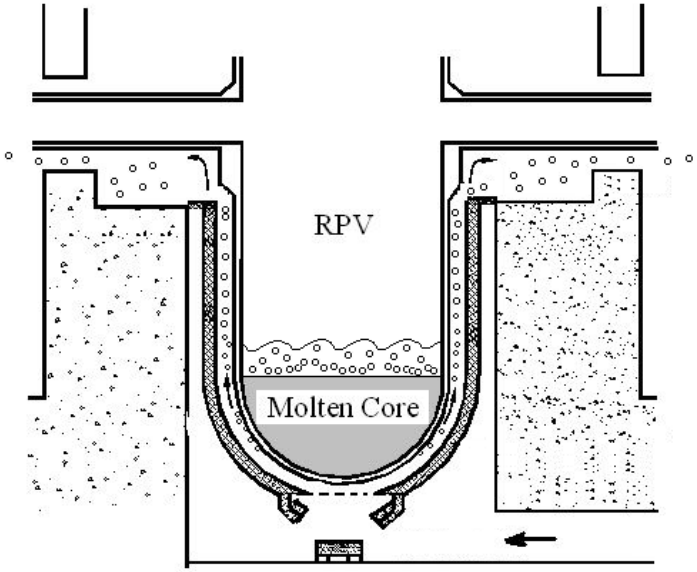
IVR Study

Core Injection analysis results(CAP1400)

Normal condition (two layer configuration)

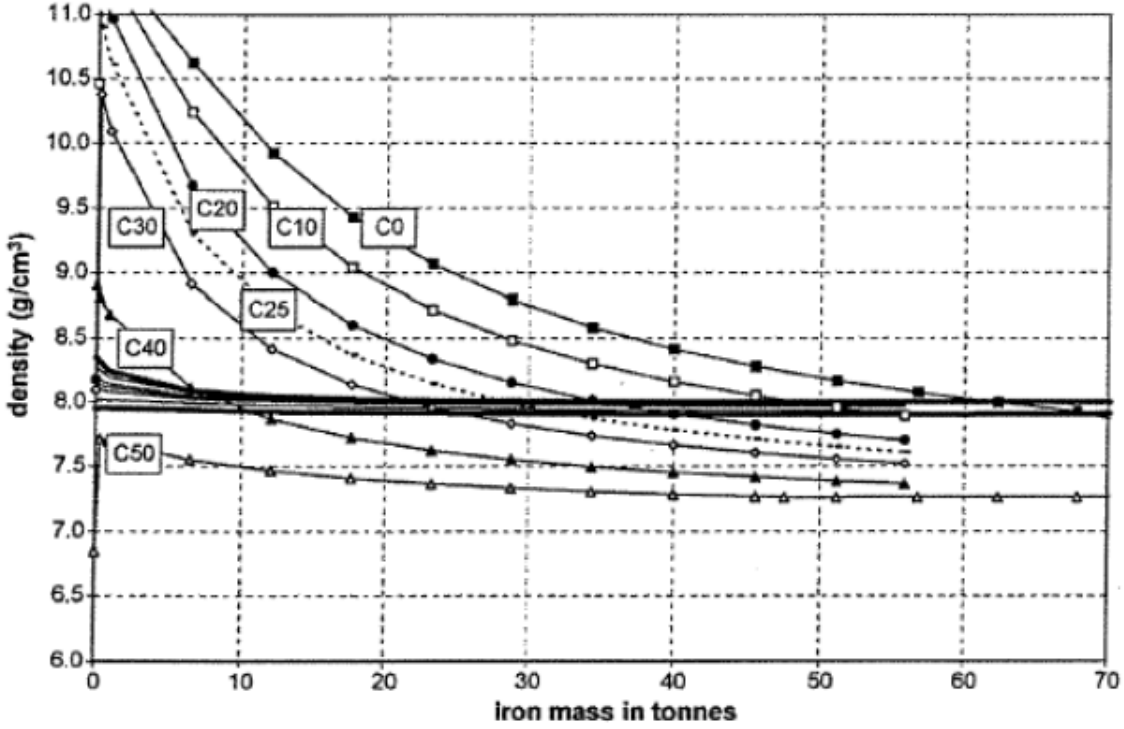
Three layer configuration (Consider water injection)





The research undergoing

IVR Study



Oxide (nearly horizontal lines) and Metallic Phases Densities as a function of the Mass of Fe in the U-Zr-Fe Mixture, Mass of UO_2 = 100 t and U/Zr = 1.45

Thermodynamic study

The research undergoing

IVR Study

Maximum Mass of Fe the Can Stratify below the Oxidic Corium ($M_{Fe\text{-}Max}$)

Fraction of Zirconium Oxidation (%)	Max Mass of Fe that can Stratify (kg)
0	60
10	48
20	35
25	32
30	24
40	10
50	0
100	0

Thermodynamic study

The research undergoing

IVR Study

ERVC full height test

- Purpose
  - Get the CHF correlation
- Contents
  - CHF impact factor sensitivity test
  - Surface character test
- Characteristic
  - Full height design
  - Full scaled of RPV radius
  - Sliced simulation
  - Natural circulation
  - RPV prototype material

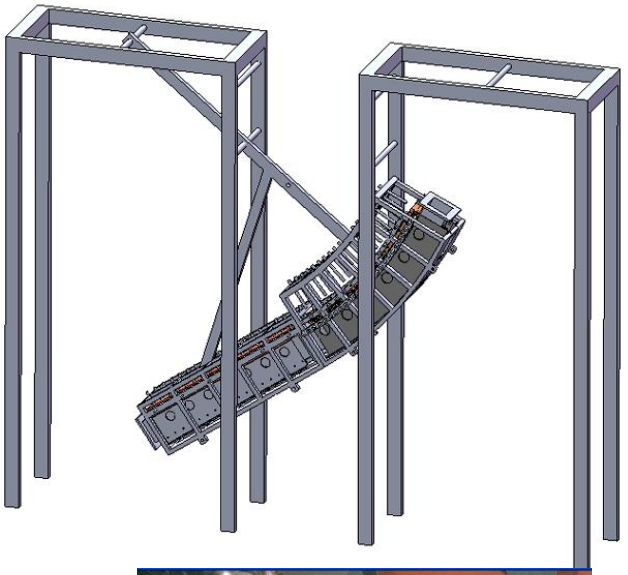
SNPTC

The research undergoing

IVR Study

CHF Key factor test

- Purpose
  - CHF sensitivity test
- Contents
  - Surface character test
  - Additive sensitivity study
- Characteristic
  - 30° & rotation design
  - Full scaled of RPV radius
  - Sliced simulation
  - Pumped circulation
  - RPV prototype material



The research undergoing

IVR Study

Metal layer test

- Purpose
  - Metal layer correlation validation
- Contents
  - Heat transfer with different Ra
- Characteristic
  - Water simulated
  - Natural flow
  - Bottom heated, top & side cooled
  - High Ra simulation

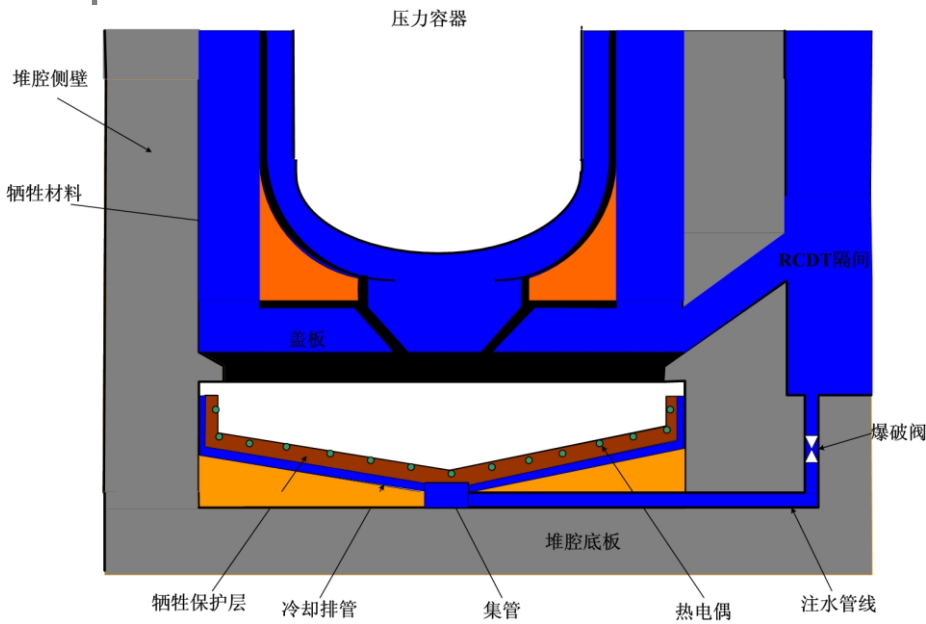
国家核电 SNPTC

The research undergoing

EVR Study

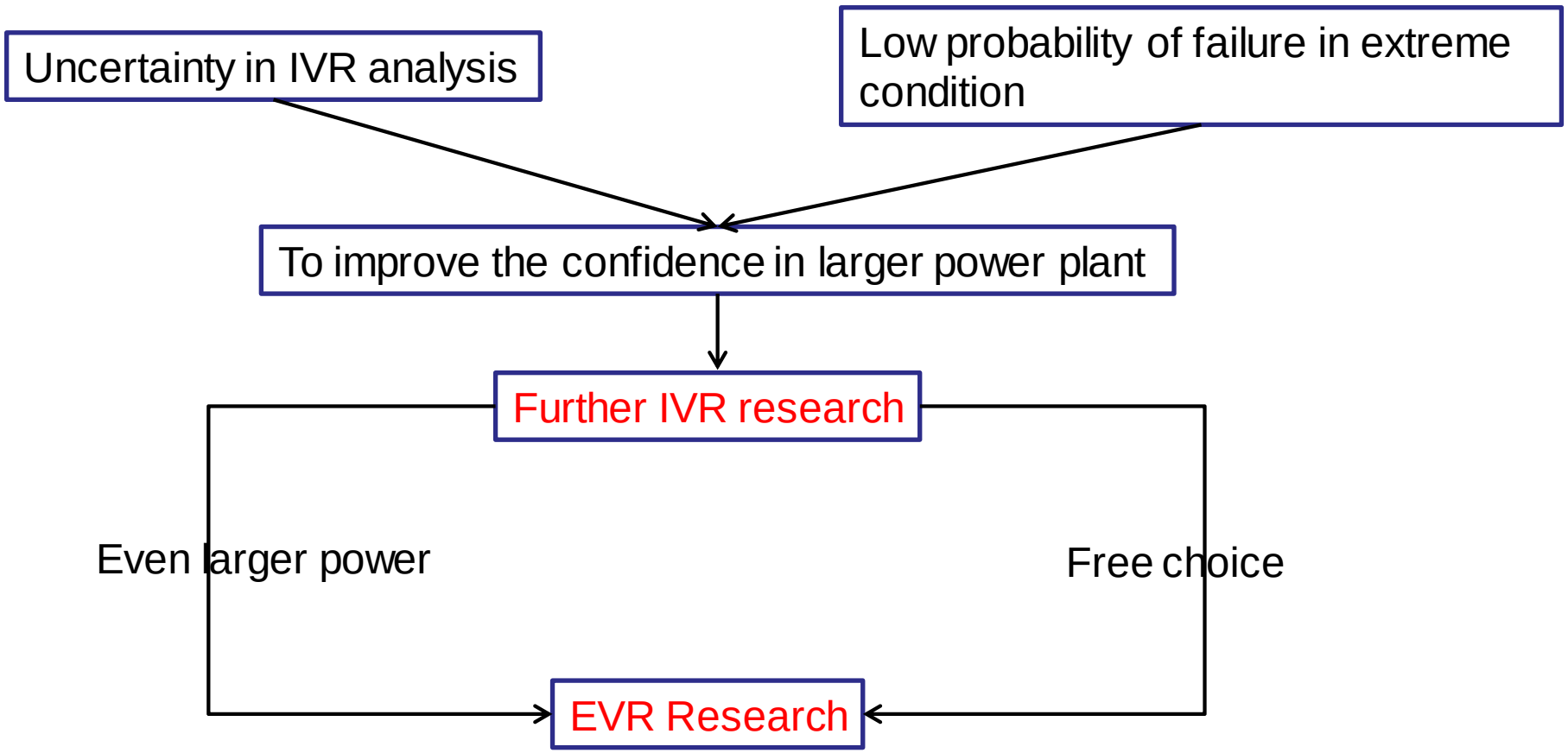
Structure study

- Purpose
  - Ex-vessel debris retention
- Contents
  - Configuration study
  - Important phenomena study
- Characteristic
  - Ex-vessel pool cooling
  - The catcher cooling
  - Consistent with IVR strategy
  - Consistent with plant design



Contents

The plan



The plan

Key & Difficulty

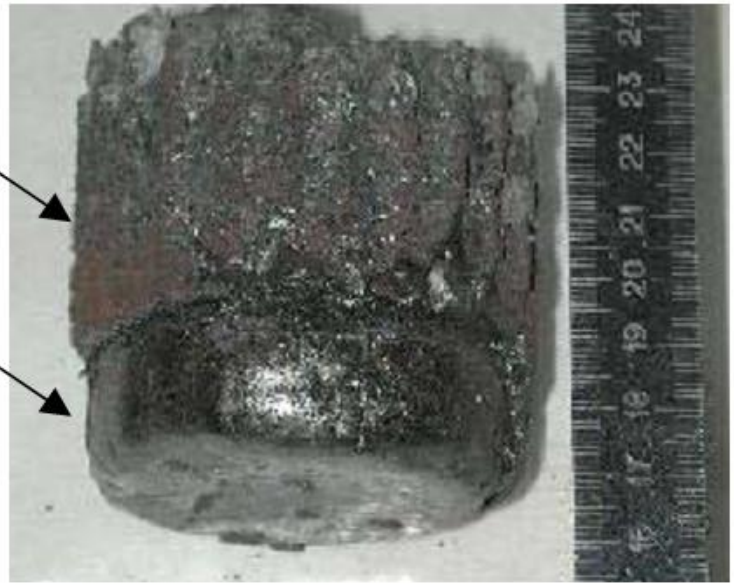
IVR

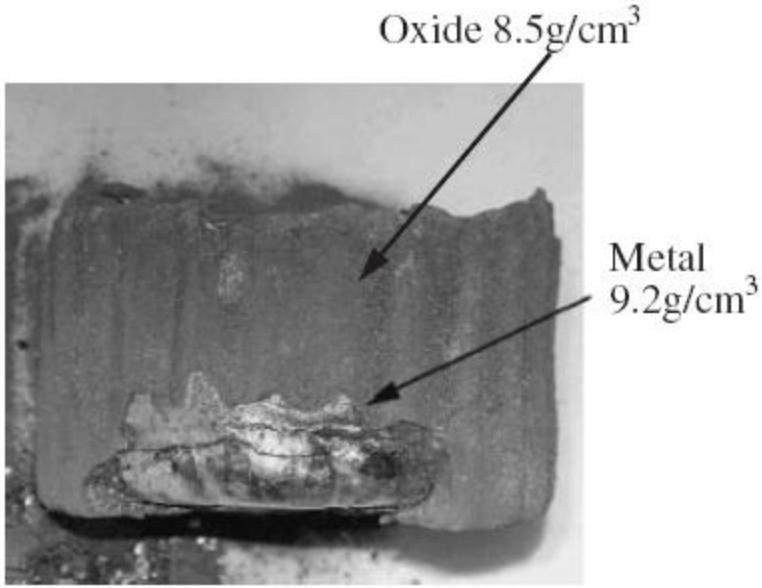
- Fluid & solid coupling
- Crust property
- Metallography
- 3 layer challenge

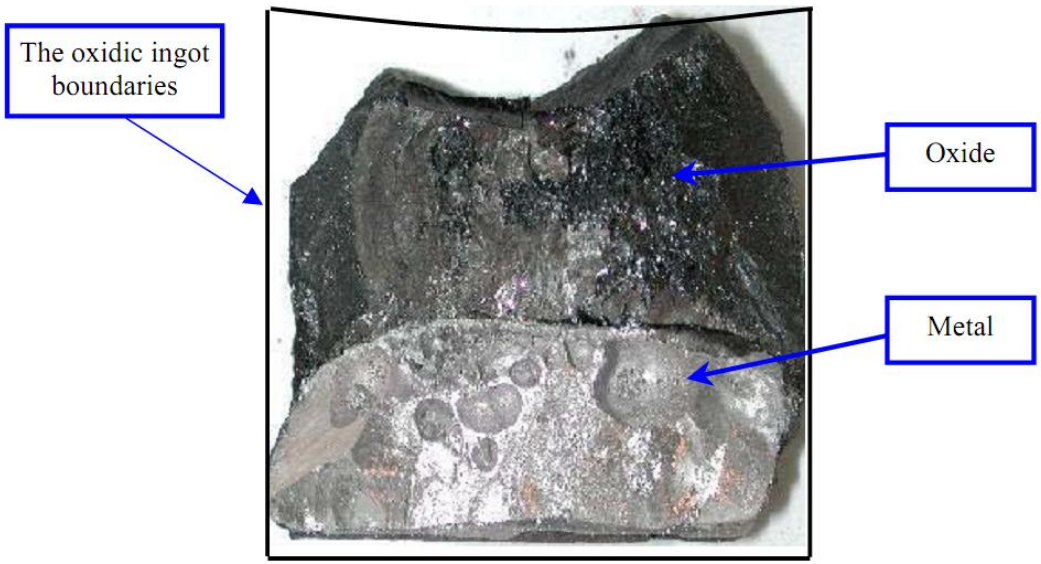
EVR

- Steam explosion
- Structure & layout
- Debris cooling
- The catcher cooling

Pool configuration test research





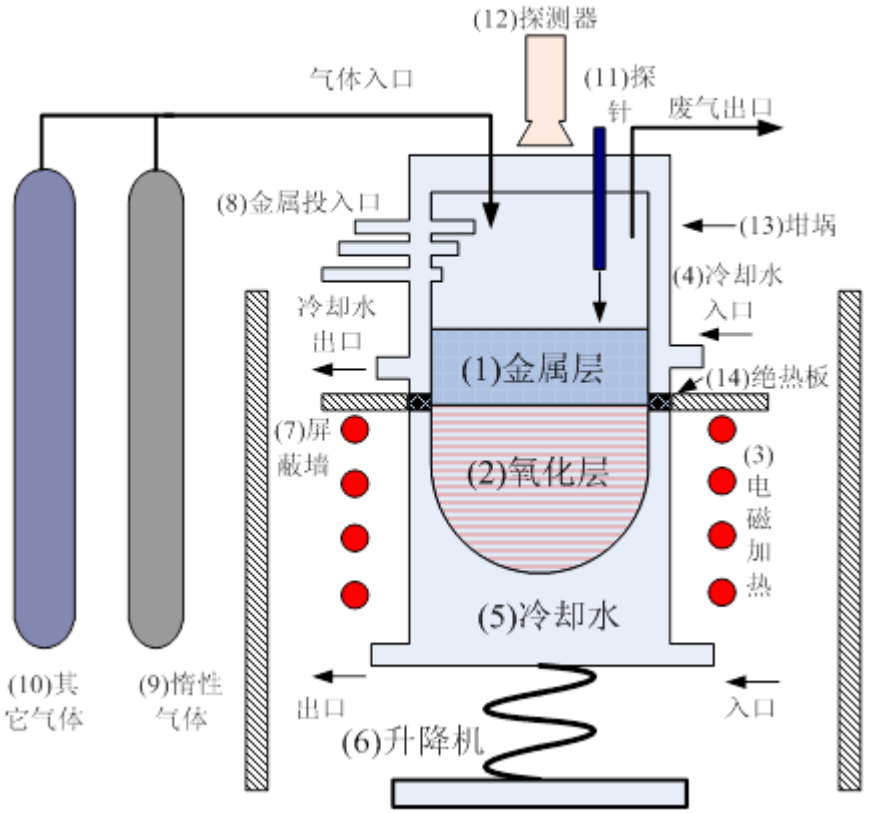


The plan

IVR

Pool configuration study

- **Purpose**
  - The components of the heavy metal layer
- **Contents**
  - Crust strength test
  - Configuration test
- **Characteristic**
  - Prototype material
  - Electromagnet heater
  - Consider the RASPLAV/MASCA test insufficiency



Schematic diagram of test

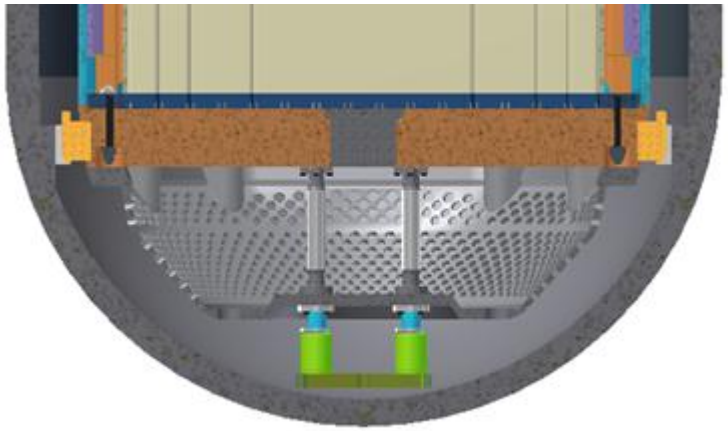
国家核电 SNPTC

The plan

IVR

Enhancement study

- Purpose
  - Improve the IVR effectiveness
- Contents
  - Internal structure mass increase study
  - Internal structure layout study
- Characteristic
  - Increase the performance of internal structure
  - Minimize the negative impact



Schematic diagram

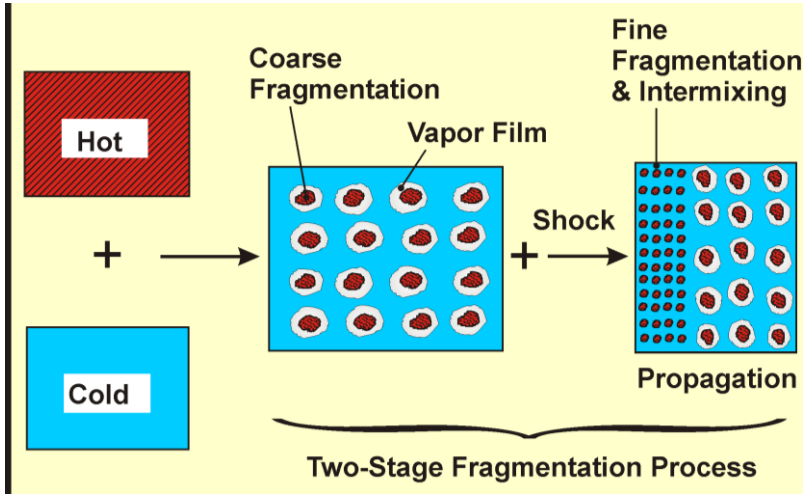
国家核电 SNPTC

The plan

EVR

Steam explosion study

- **Purpose**
  - Steam explosion consequence , optimize the structure
- **Contents**
  - The character after RPV failed with flooding cavity
  - The steam explosion result
- **Characteristic**
  - Theory/test study
  - Conservative methodology

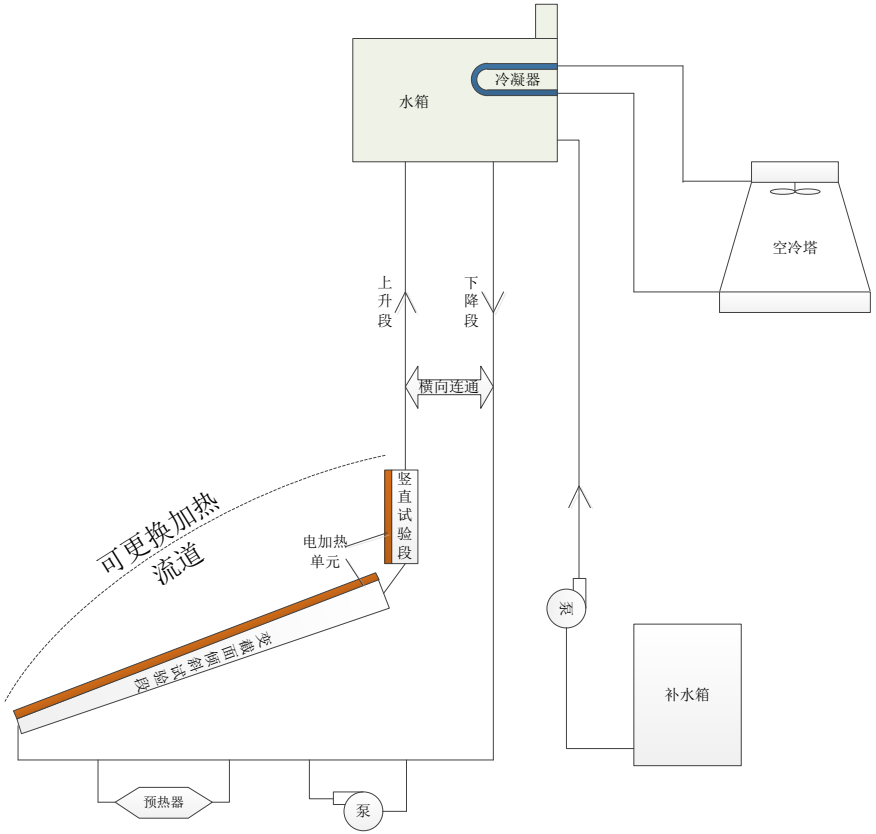


The plan

EVR

Core catcher coolability

- Purpose
  - Optimized flow channel
- Contents
  - Flow channel sensitivity study
- Characteristic
  - Pumped/Natural flow
  - Changeable channel
  - Heated channel

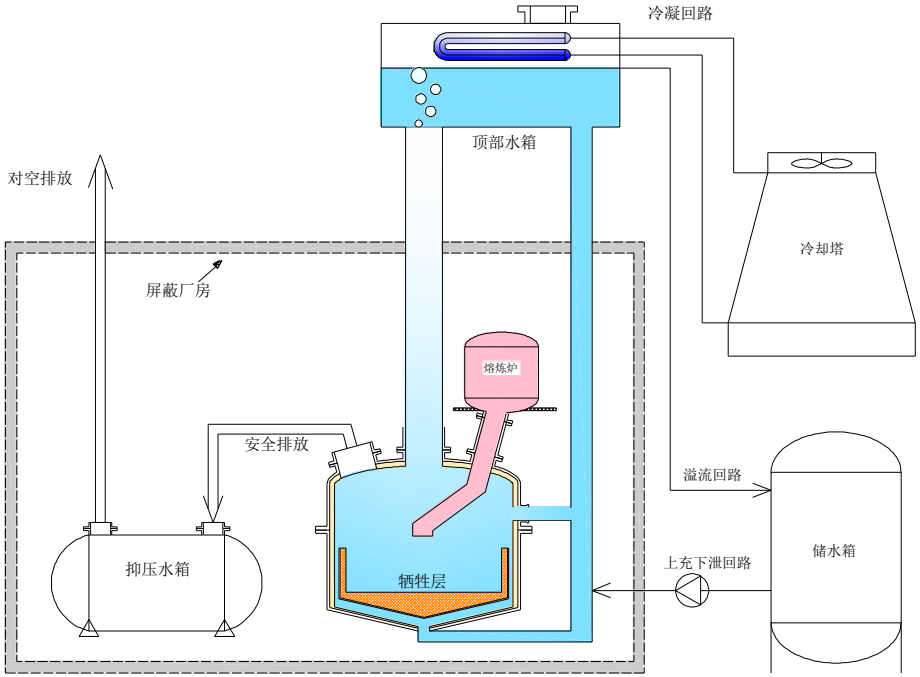


The plan

EVR

Core catcher integral test

- **Purpose**
  - Core catcher performance validation
- **Contents**
  - The natural circulation
  - The transient
- **Characteristic**
  - Full height
  - Thermite oxidation material



Contents

Summary

SNERDI do a lot of work in molten core retention study

- ✓ IVR is credited for certain power level plant, even reliable in larger power plant
  - ✓ 3 layer configuration is in low probability
  - ✓ the core injection can improve the IVR effectiveness
  - ✓ Other new research
- ✓ EVR is considered in the even larger power plant
  - ✓ The steam explosion is important for passive plant EVR

SNERDI will do further work for molten core retention

国家核电
SNPTC

更安全的核电
更美好的生活