중대사고관리능력확보를 위한 조화로운 접근

중대사고 현안해결을 위한 국내/외 연구개발 현황

하 광 순

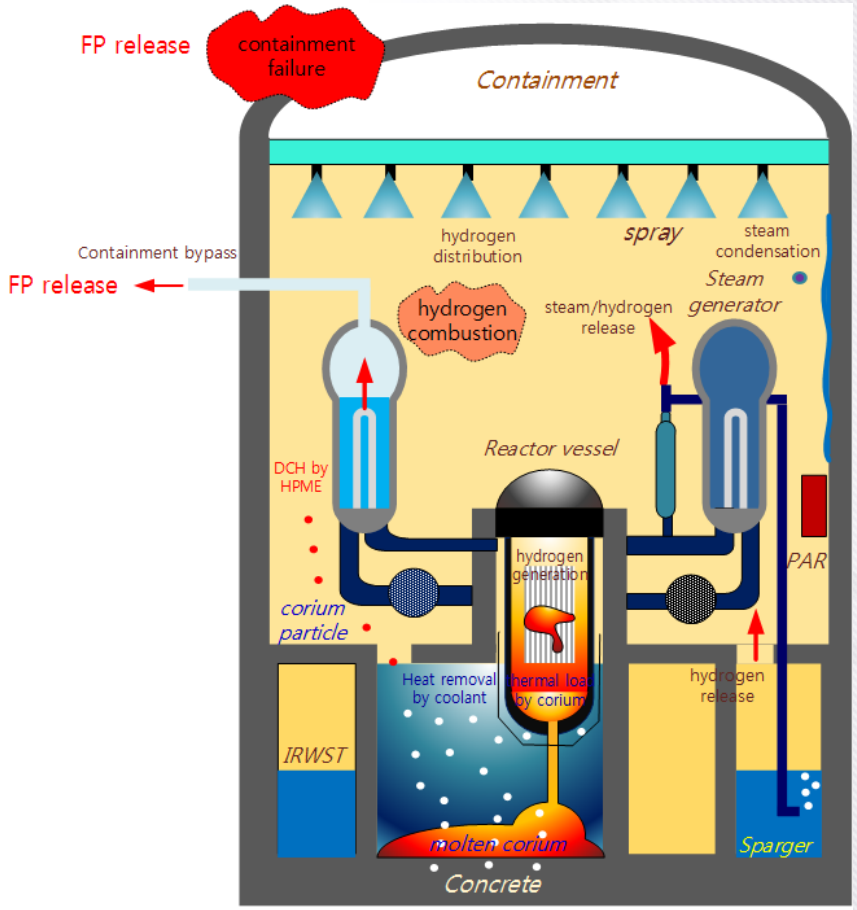
열수력·중대사고 안전연구부
한국원자력연구원

CONTENTS

Research Topics on Severe Accident

Severe accident phenomena

- In-Vessel
  - Core un-cover & heat-up
  - Cladding oxidation – hydrogen generation
  - Melting, liquefaction
  - Core slumping, quenching, reheat
  - Reactor vessel failure
- Ex-Vessel
  - Direct containment heating
  - Fuel coolant interaction
  - Core concrete interaction
  - Hydrogen combustion
  - Containment failure
- Fission product
  - Aerosol generation, transportation, deposition
  - Iodine chemistry



중대사고 현안

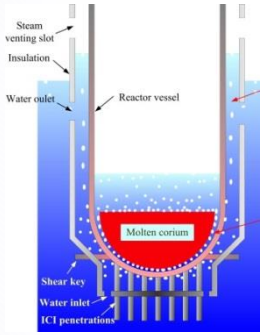
- 사고관리계획서 작성/평가
  - 사고 해석, 현상평가, 방사성물질 방출량
- 안전목표 만족
  - 방사성 핵종 Cs-137의 방출량이 100TBq을 초과하는 사고 발생 빈도의 합이 1.0×10^{-6}/년 미만일 것

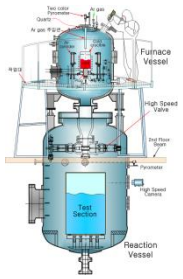
Severe Accident Researches – KAERI

Event on the Nuclear Industry

- 1997: Start in SA research
- 2002: Decline SA national project
- 2007: Export APR1400 to UAE; EU-APR1400
- 2012: Fukushima Accident
- 2017: SMART-PPE with Saudi Arabia; New regulation on SA

Research Topic





- In-vessel corium behavior with simulant(SONATA)
- Ex-vessel steam explosion with corium(TROI)
- OECD/NEA SERENA2 Project
- Ex-vessel core catcher(VESTA, CE-PECS)
- SA analysis code(CINEMA)
- Hydrogen behavior in containment(SPARC)
- Filtered containment venting system(ARIEL)

Research Contents

Severe accident phenomena (Steam explosion, Vessel coolability) Sever accident analysis(MELCOR)	Development of SA Mitigation system (IVR-ERVC, Ex-Vessel Core Catcher) Domestic SA code (CINEMA)	Improvement of modeling (CINEMA-SMART) Fission product behavior(FCVS)

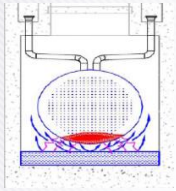
Applications

Evaluation of SAMG (IVR-ERVC, MELCOR)	Support to export APR1400 (CINEMA, Ex-vessel core catcher)	Support and Improvement of SAMP based on new regulation

Severe Accident Researches

중대사고 분야 정부 주도 원자력 연구개발 변천사

ISAAC



TROI

구체적인 연구 성과

미·일 중심,
중대사고연구 약화

1997-2006

중대사고 연구 기반 구축

MIDAS/ISAAC
– 경수로 및 중수로 중대사고 해석 코드 개발

TROI (실제 핵연료 물질 이용 증기폭발실험)

수소 연소 소염망 개발

2007-2011

국내 중대사고 연구 소강 상태

OECD/SERENA 증기 폭발 국제 공동연구 수행

VESTA 시설 구축 (EU-APR1400 지원)

UAE 원전 수출

후쿠시마 원전 사고

SMART 중대사고 해석
EU-APR1400 코어 캐처 개발

2012-2016

중대사고시 격납 건물 거동 모의 SPARC 실험 시설 구축

PWR관통부/후쿠시마 원전 관통부 파손 실험

핵분열생성물 물리화학거동 기반 기술 구축

중대사고 종합해석 코드개발

여과배기설비 검증 실험/성능해석

2017-2021

중대사고 대처 능력 향상노내·외 노심용융물 냉각 성능 평가,
SPARC 이용 격납건물 수소제어계통 중대사고 조건 모의 실험 및 해석,
중대사고 관리 전략 검증 및 개선

중대사고 해석기술 고도화
중대사고 종합 해석 코드 선진화
수소 연소, MCCI 등 중대사고 개별현상 코드 개발

핵분열생성물 거동 예측 및 저감 기술 개발
격납건물 우회 사고 대처
노심 용융물 및 핵분열 생성물 물리화학 거동 실험/해석 기술 개발

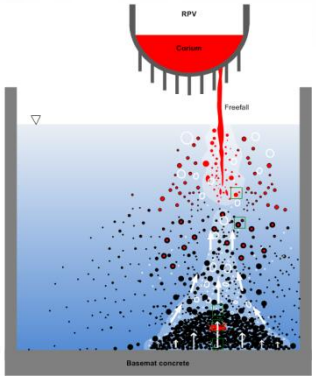
고속로 중대사고쟁점 규명 및 해석 기술 개발

SMART PPE 중대사고 대처 기술 개발

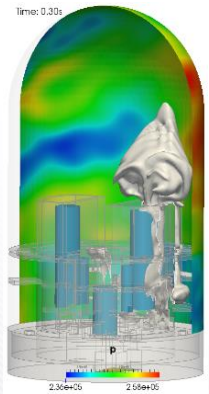
Severe Accident Researches (2017~2021)

» **Development of a technology for the prediction of the severe accident progression and mitigation radiological releases**

Ex-Vessel Corium cooling



Hydrogen mitigation in containment



Containment protection

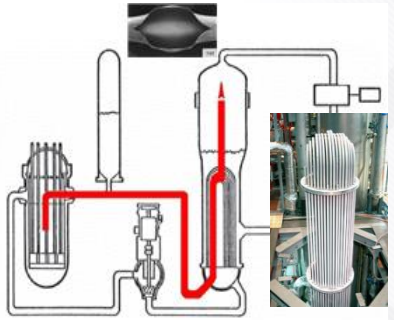
Fission product reduction on containment bypass

Source term reduction

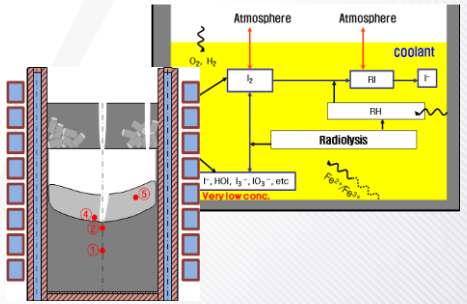
Issues on high-power reactor and multiple units

Corium cooling and uncertainty assessment

Source term evaluation under SGTR



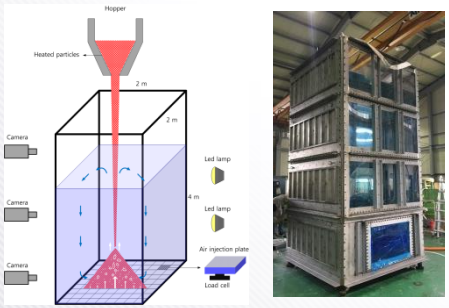
Chemical features of molten corium and fission products



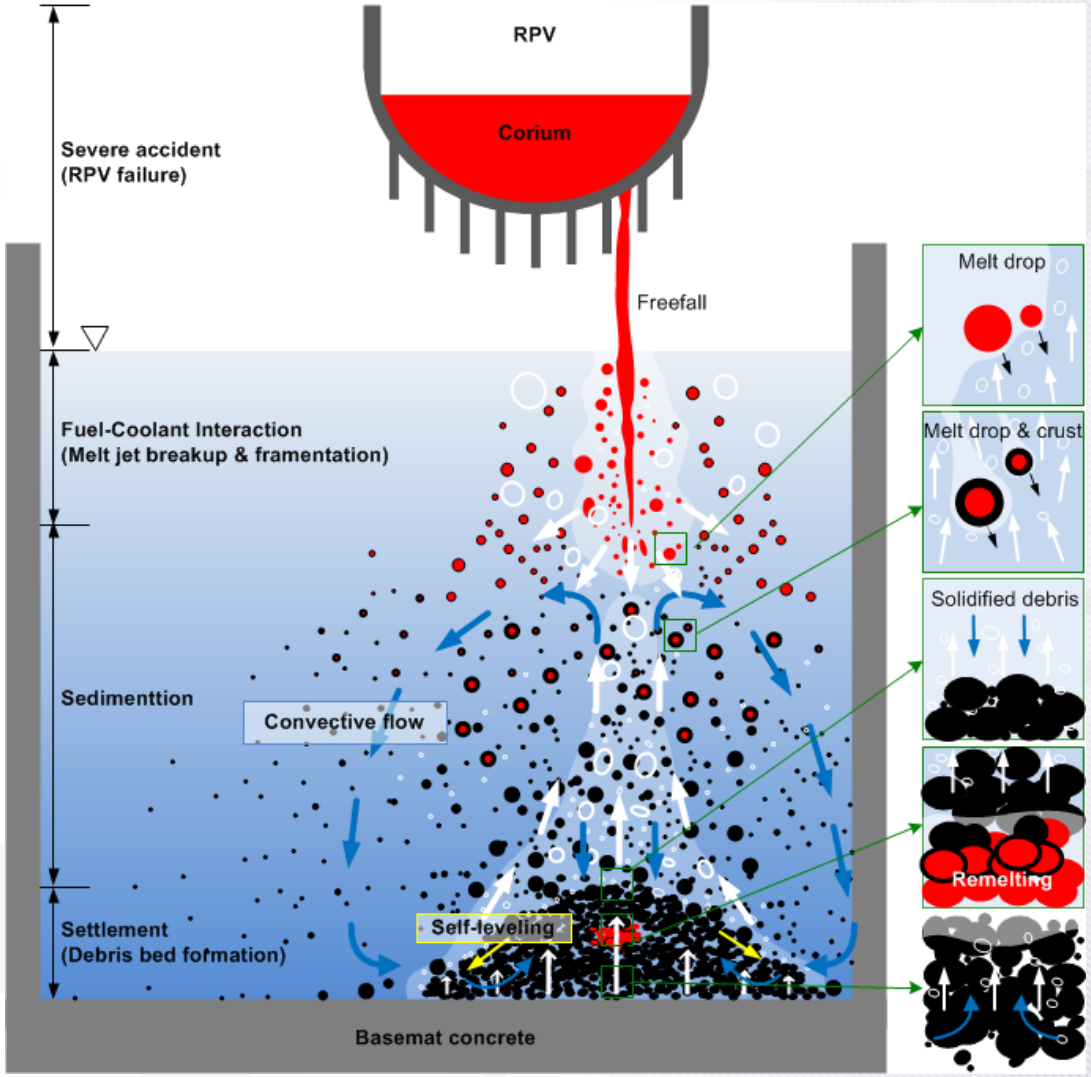
On-Going Research (1) – Ex-vessel debris coolability

Development of ex-vessel corium cooling and stabilization technology

- Establishment and experiment of cooling performance test system for ex-vessel corium
- Development of cooling model and evaluation of cooling performance for ex-vessel corium
- Evaluation and improvement of the accident management strategy related to the cooling of ex-vessel corium



DEFCON facility



On-Going Research (1) – Ex-vessel debris coolability

R&D Framework of Ex-vessel Debris Cooling

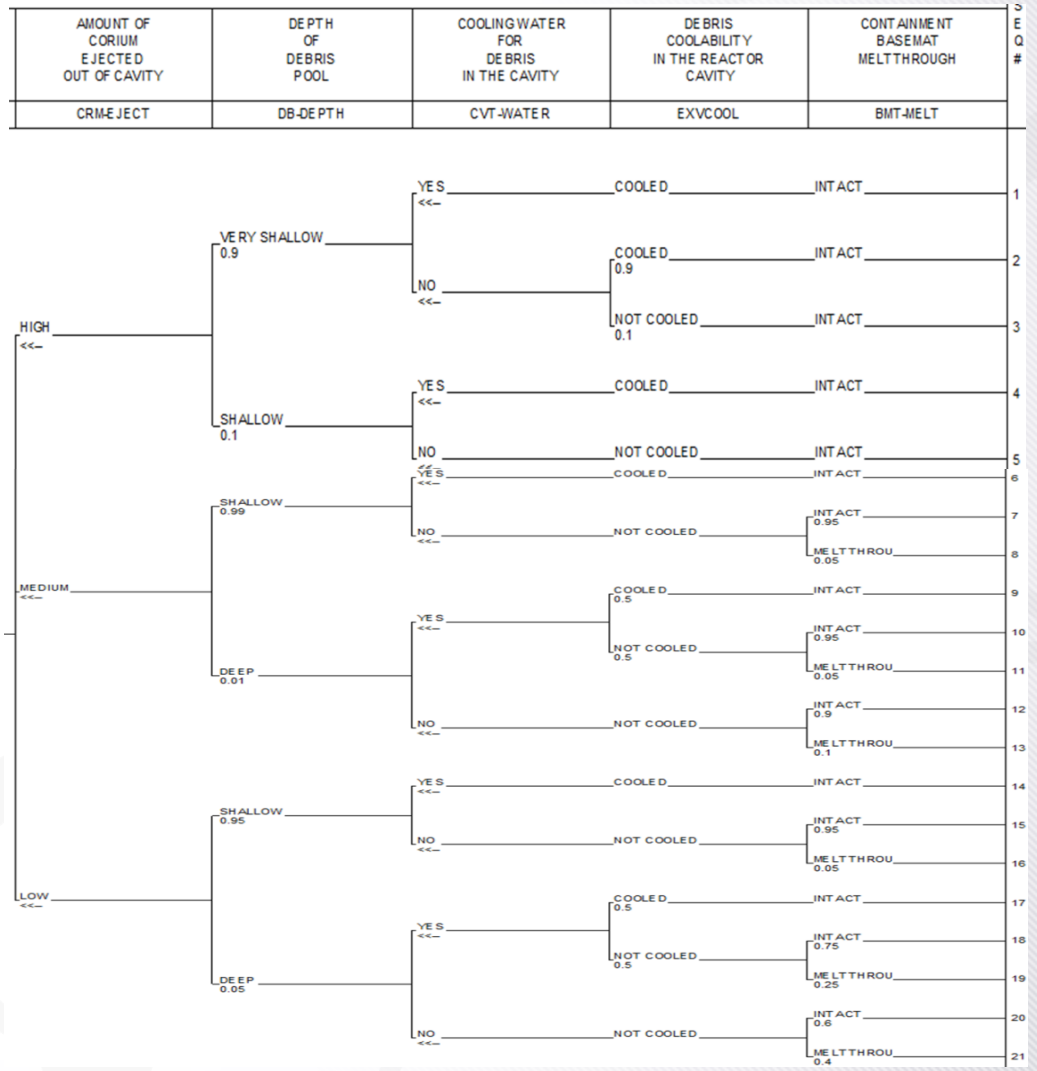
Experiment	Analysis	Severe Accident Management
Previous FCI or EDC experiments	SA scenario analysis	Current SA management strategy
Initial & boundary conditions of RV failure and ex-vessel corium release		
Ex-vessel Debris Size Analysis • Size distribution in the experiments using prototypic corium melt	**Development of Ex-vessel Corium Cooling Models and Analysis Code** • Melt jet breakup length • Fragmentation and debris size distribution • Heat transfer during particle sedimentation • Two-phase pressure drop in a debris bed • Dryout heat flux of a debris bed	**Revisit of current SAM strategy** • Review of SAMG • Level-2 PSA model assessment • Adverse effect assessment in the cavity pre-flooding strategy
Ex-vessel Debris Bed Characterization • Debris bed formation & shape • Two-phase pressure drop • Dryout heat flux		**Improvement of SAM strategy** • Suggest the branch information of CET in Level-2 PSA • Assessment of in a viewpoint of DSA
Development of thermal phase plane (TPP) and verification experiments	Development of TPP cooling model	

On-Going Research (1) – Ex-vessel debris coolability

Applications

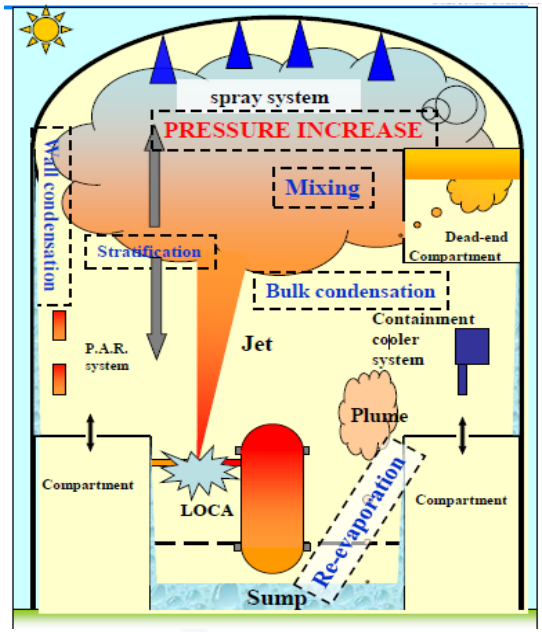
- PSA (2단계, mission time=사고 시작후 3일) 주요 필요 사항
  - (방출속도 등에 따른) 퇴적 형상/분포 및 이에 따른 노외파편물 두께(=깊이)
  - 퇴적되는 노심용융물 두께에 따른 노외파편물 냉각 기준 (EDC) 설정
- 결론: 분기확률 (CET 정량화 데이터) 제시

2단계 PSA (EDC-DET 모델링)

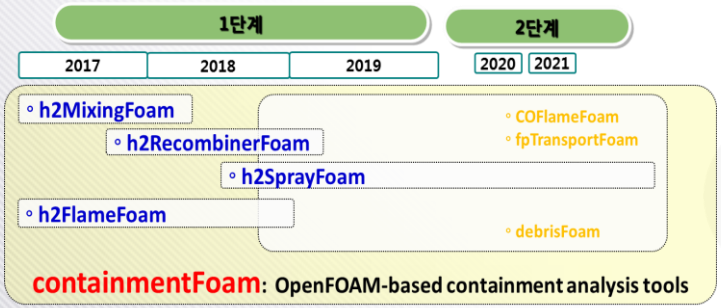


On-Going Research (2) – Hydrogen safety

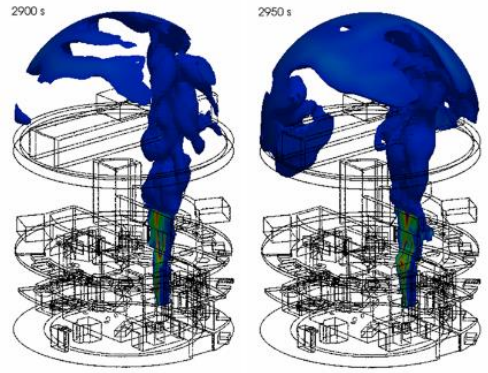
- **Development of technology to evaluate accident management strategy for containment hydrogen mitigation**
  - Experiment of hydrogen behavior and mitigation
  - Development and validation of multi-dimensional analysis code
  - Evaluation of accident management strategy for hydrogen mitigation



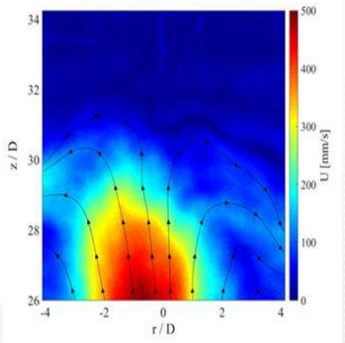
SPARC facility

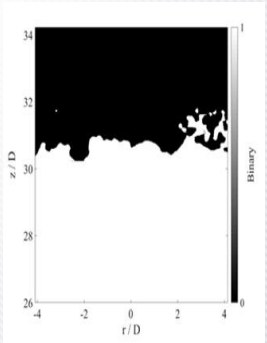


Code structure



Code evaluation of hydrogen distribution





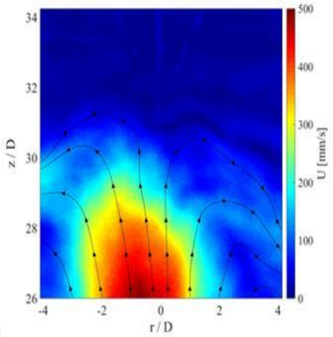
Visualization of hydrogen mixing

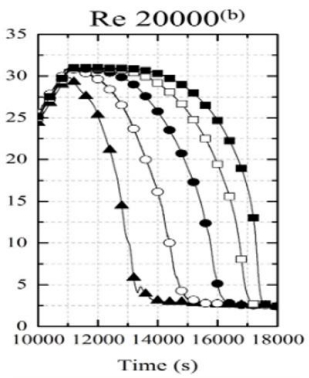
On-Going Research (2) – Hydrogen safety

Experimental research

- Test for mixing of a stratified hydrogen

- The purpose is to evaluate mixing behaviors depending jet velocity of air/steam

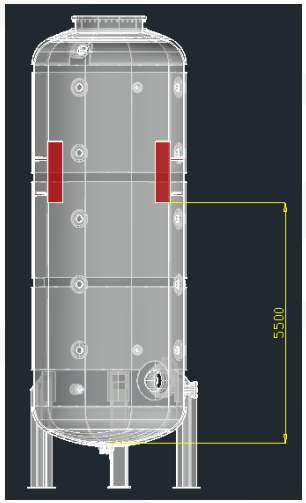




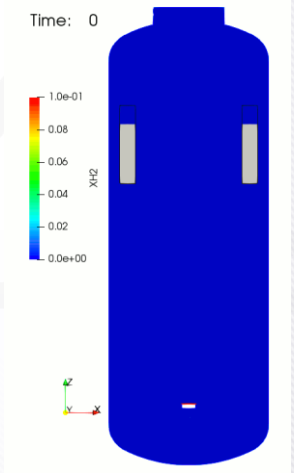
This experiment is underway

- Test for hydrogen stratification induced by PAR

- The purpose is to experimentally simulate PAR-induced hydrogen stratification and produce exp. data for analytical model validation



Test facility



Pre-test analysis

These experiments are planned

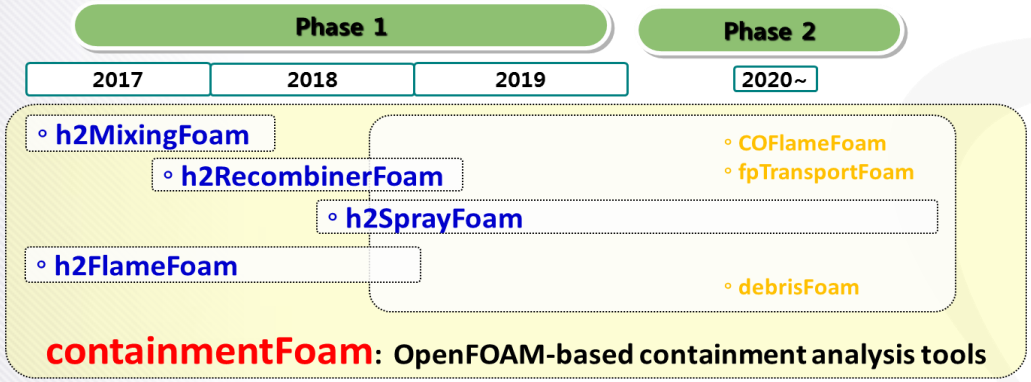
- Test for spray effect on hydrogen behaviors

- Test for hydrogen behaviors during cooling and depressurization

On-Going Research (2) – Hydrogen safety

Analytical research

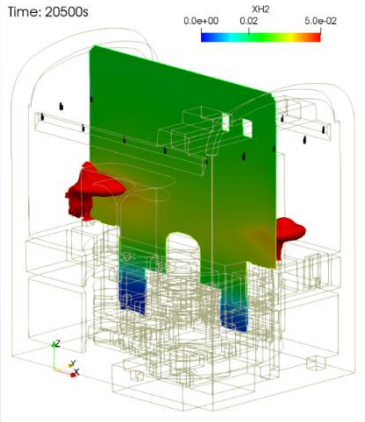
- Implementation of multi-dimensional analysis methodology to hydrogen safety evaluation in a NPP containment
  - ContainmentFOAM is under development to simulate combustible, non-combustible gas, and aerosol behaviors in containment by 2021.Containment integrity by hydrogen mitigation system such as PAR, ignitor, spray is going to be evaluated by using ContainmentFOAM

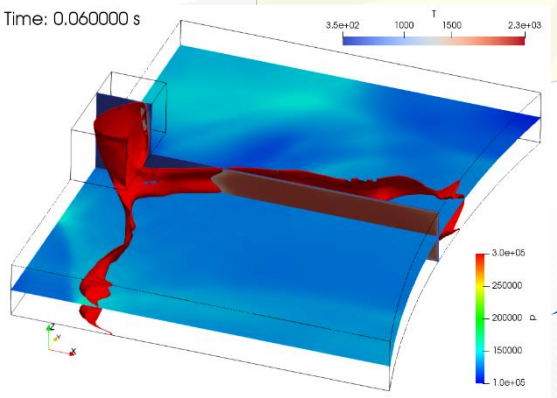


containmentFoam: OpenFOAM-based containment analysis tools

- *h2MixingFoam*: turbulent mixing of hydrogen with steam condensation
- *h2RecombinerFoam*: h2MixingFoam + PAR module
- *h2FlameFoam*: turbulent hydrogen combustion
- h2SprayFoam: condensation/evaporation by spray droplets
- *COFlameFoam*: turbulent CO combustion
- *fpTransprotFoam*: fission product transport
- *debrisFoam*: debris cooling

Hydrogen distribution in a containment





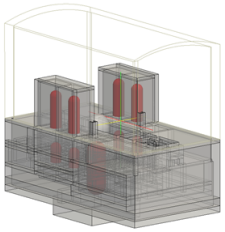
Hydrogen flame in a compartment

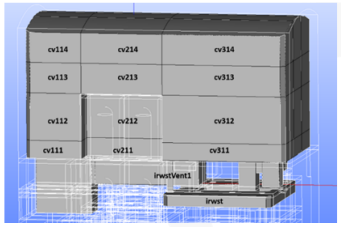
On-Going Research (2) – Hydrogen safety

Analytical research

- Development of tools to support best-estimate analysis of hydrogen behaviors in a containment using lumped-parameter code MELCOR/CINEMA
  - CAD-based containment nodalization for an LP code: A computer program is developed to generate geometric data of volumes and junctions in a containment.

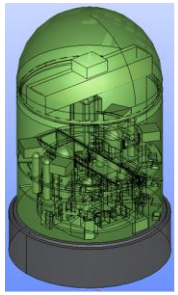
SMART containment nodalization

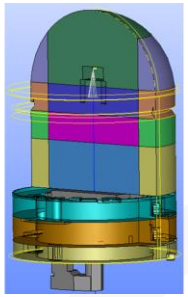


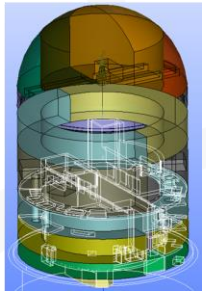


CV0	CV1	area	length	Dh
cv111	cv121	305.576	9.457	15.399
cv111	cv211	28.256	33.522	2.885
cv111	cv112	281.75	19.786	14.944
cv211	cv221	241.426	12.069	9.669
cv211	cv212	522.875	17.562	19.028
cv121	cv221	28.256	32.974	2.885
cv121	cv122	281.75	19.786	14.944
cv221	cv222	522.875	17.031	19.028
cv112	cv122	616.5	14.486	24.709
cv112	cv212	335.307	31.592	16.059
cv212	cv222	1048.05	14.817	31.928
cv212	IRWSTvent0	1.2	22.031	1.091
cv122	cv222	335.307	31.592	16.059
cv222	IRWSTvent1	1.2	22.031	1.091

OPR1000 containment nodalization







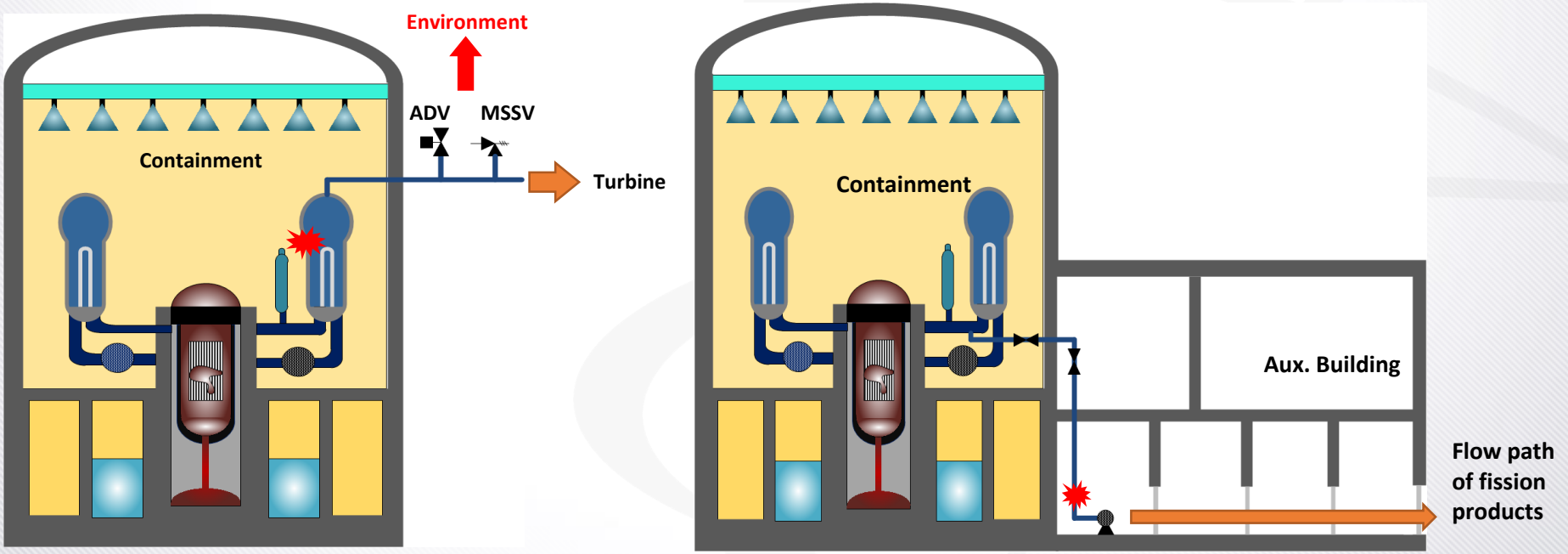
CV	vol	minZ	maxZ	xc	yc	zc	wall
annular1	2842.077	24.689	30.48	0.084	-0.372	28.273	2153.992
annular2	4326.454	30.48	37.186	-0.863	-0.498	33.771	2180.777
annular3	3625.182	37.186	43.282	-0.521	-0.265	39.948	2728.909
outerSouth1	4461.401	43.282	56.388	0.026	-11.807	49.908	1674.273
outerSouth2	2721.214	56.388	63.906	0	-12.135	60.147	518.35
outerSouth3	2498.643	63.906	71.482	0	-11.815	67.775	934.095
outerSouth4	3131.267	71.482	85.284	0	-11.618	76.629	1030.67

- A field visualization tool for data from LP code is going to be developed to support evaluation of hydrogen distribution in a containment.

On-Going Research (3) – Containment bypass

Containment bypass scenarios

- C-SGTR (Consequential Steam Generator Tube Rupture)
  - SGTR + Severe Accident : Direct release of fission products to environment via SG
- Inter-System Loss of Coolant Accident (ISLOCA)
  - LOCA at the piping system connected to the primary cooling loop
  - Direct path of primary coolant to environment bypassing the containment
  - Severe accident : Large release of fission products.



On-Going Research (3) - Containment bypass

Mitigation system for FP reduction under containment bypass accident

- **Improve of severe accident management strategy**
- **Design and verification of mitigation system under SGTR and ISLOCA**

Evaluation of fission product behaviors under containment bypass accident

- **Scenario analysis for SGTR, ISLOCA**
- **Experiments of aerosol and iodine decontamination in SG and Aux. Building**
- **Model development of fission product retention in SG and Aux. Building**

Fission product behavior in SG

- Dry secondary side
  - In-tube deposition: Inertia impaction, turbulent deposition, particle re-suspension
  - In-bundle deposition: Vicinity of the tube break, Support plate, Bundle far-field
  - Deposition on separators and dryers
- Flooded secondary side

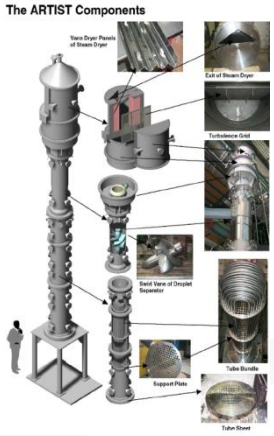
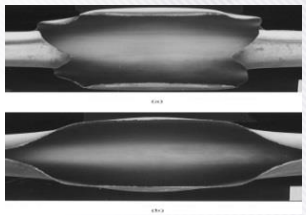
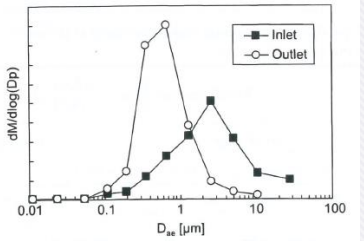
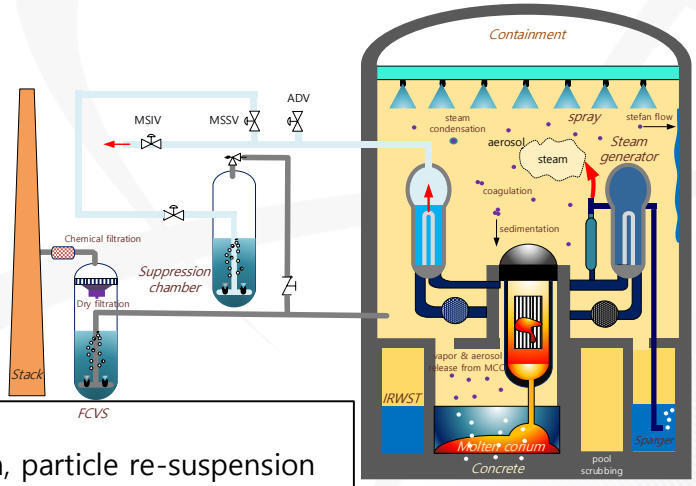


Fig. 3. Overall picture of the ARTIST bundle after the test



De-agglomeration of aerosol

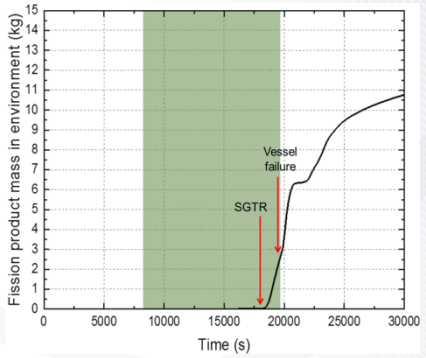




On-Going Research (3) - Containment bypass

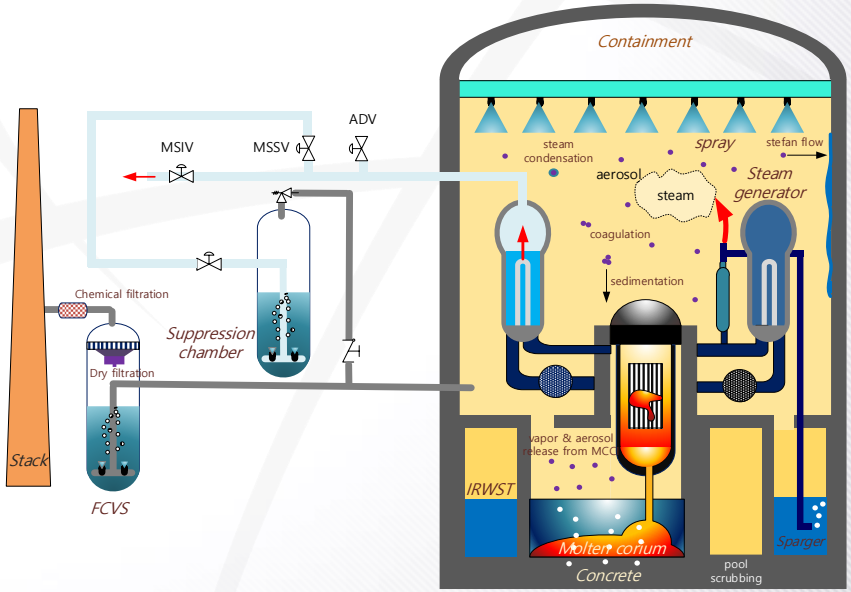
What to do for Mitigation of Containment Bypass Accident?

- Development of PIRT
- Scenario Analyses using MELCOR code
  - Target plants: OPR1000, APR1400
  - Scenario: SGTR, ISLOCA
- Experiments and model developments
  - In-tube aerosol behavior in SG
  - Aerosol break-up and deposition on tube
  - Aerosol scrubbing in pool including high velocity gas injection
  - Iodine scrubbing in wet SG and Aux. building
- Development of mitigation system
  - Design of mitigation system
  - Setup mockup
  - Performance test



FP mass in environment at SGTR

SGTR Experiment Facility



On-Going Research (3) - Conta

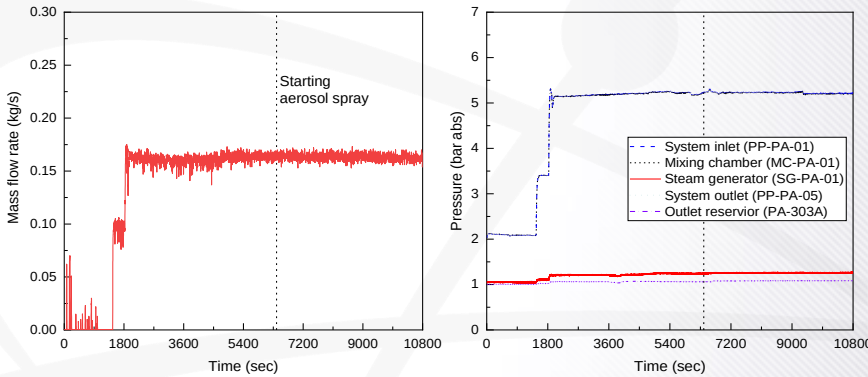
Experimental Facility on SGTR accident

- **Component**:
  - SG vessel
  - Steam/Air supply system
  - Aerosol generation/sampling system
  - Sensor, controller, etc.

- **Thermal hydraulic test:**
  - Obtain aerosol experimental test conditions
  - P: 5 bar, 0.17 kg/s Air, 150°C

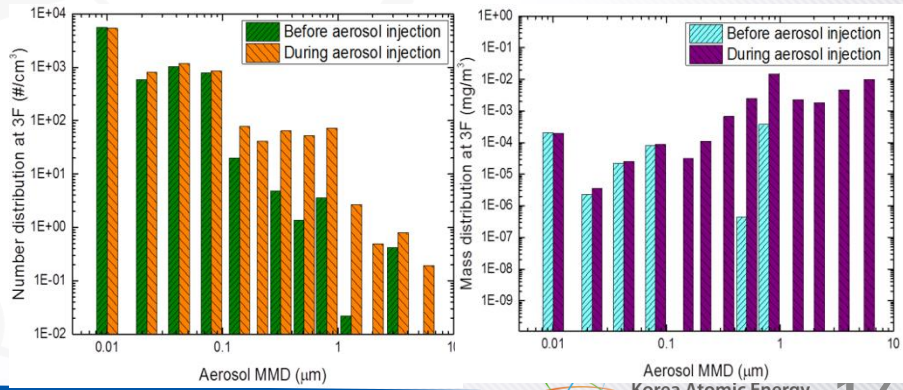
- **Aerosol test:**
  - Obtain DF with filter, ELPI

SGTR Experiment Facility



Thermal hydraulic test results (mass flow rate, pressure)

Filter test result



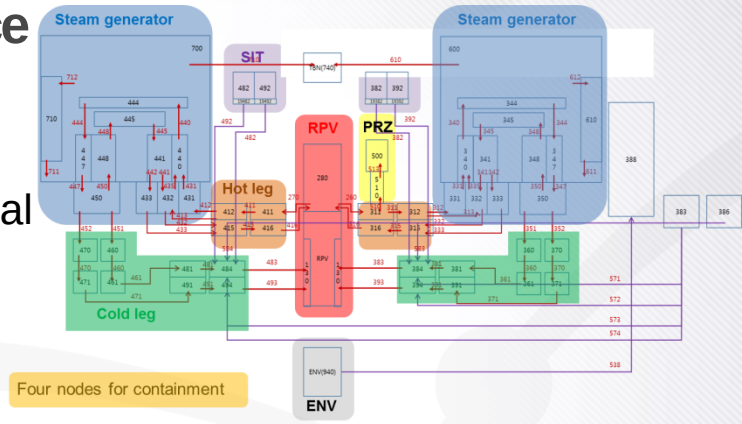
ELPI test result (number, mass)

On-Going Research (3) - Containment bypass

MELCOR analysis on SGTR accident sequence

- **Modeling of OPR1000 plant**
  - It consists of RPV, SG, HL, CL, PRZ, CNT, ENV.
  - SG and HL divided into two node for simulating natural circulation

- **Accident scenario:**
  - Initial accident was SBO and SGTR was induced



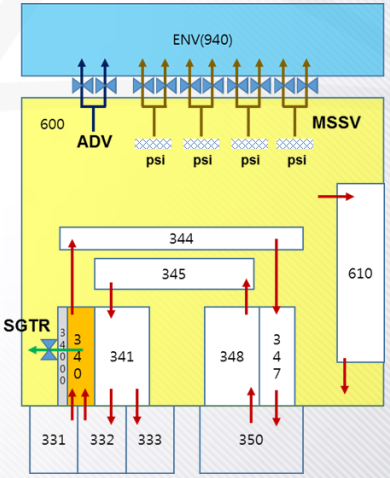
Nodalization of OPR1000 plant

TH and Aerosol conditions with the number of ruptured tube

At time = 19,000 sec								
The number of tube rupture	Gas mass flow rate (kg/s)	Gas velocity (m/s)	Broken area (m2)	Gas volume flow rate (m3/s)	Primary pressure (MPa)	Secondary pressure (MPa)	Primary gas temperature (K)	Aerosol mass concentration (g/m3)
0.5	1.335	584.5	0.000112314	0.065648	16.169	0.115	1148	0.37
1	2.570	555.6	0.000224629	0.124804	14.842	0.133	1122	0.35
2	5.634	512.3	0.000449257	0.230154	15.037	0.187	1067	0.33
3	7.295	521.9	0.000673886	0.351701	13.192	0.238	1057	0.67
4	8.913	503.1	0.000898514	0.452042	11.697	0.281	1048	0.38
5	10.050	495.0	0.001123143	0.555956	10.407	0.313	1047	0.25

Accident scenario

Time (s)	Events
0.0	SBO, Reactor trip
0.001	MSIV close
16.32	Reactor coolant pump trip
5400.0	Steam generator(SG1) MSSV stuck open
5495.6	Steam generator(SG1) secondary dryout (water mass < 1000kg)
6000.0	Steam generator(SG2) secondary dryout (water mass < 1000kg)
8401.2	SRV operation start
14072.8	Fuel rod gap release
17814.8	Material candling start
17910.6	First core support structure failure (ring 1, level 10)
18262.5	Steam generator(SG1) tube creep rupture → SGTR
19854.7	Lower head penetration failure → Vessel failure
19854.7	Debris injection to cavity
19876.5	SIT injection start
30000.0	End of calculation



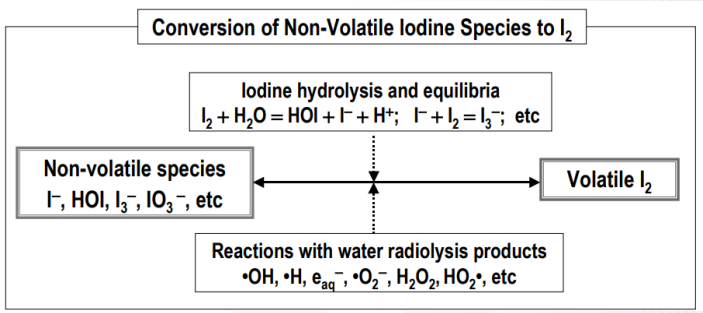
SG nodalization

On-Going Research (3) - Containment bypass

Iodine code development

- **Iodine behavior in pool(Semi empirical method)**
  - Radiolysis products generation in high dose condition
  - The products turned into volatile species (I_2)

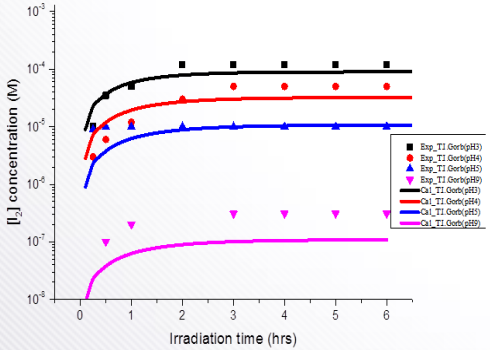
- **Previous work:**
  - There are difference between experimental data and code result in low pH condition



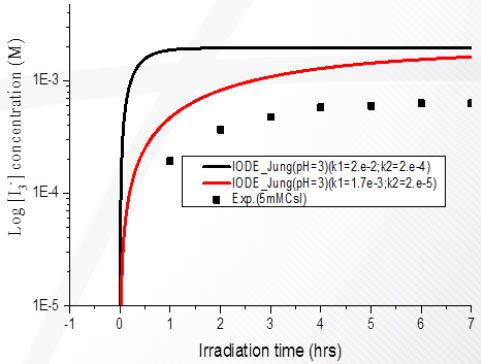
Concept of volatile iodine generation

- **Correlation development with pH variation in low pH condition:**

$$\frac{d[I_2]}{dt} = 0.63[I^-]D[H^+]^{0.5} - 0.82[I_2]$$



Experimental data comparison with KAERI code

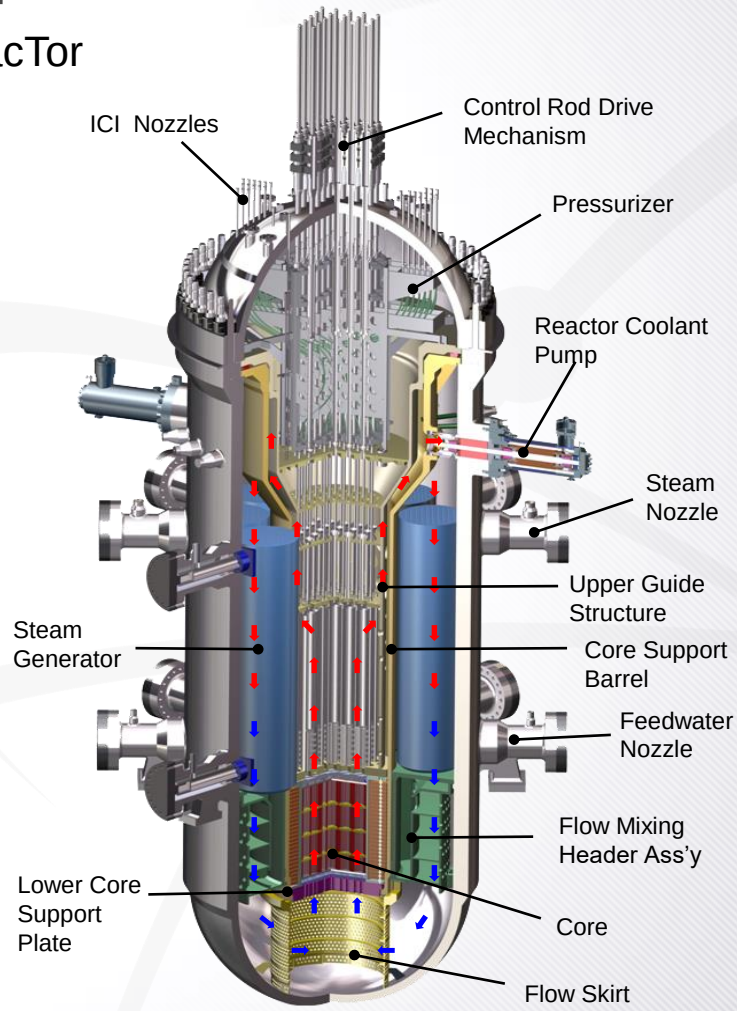


Experimental data comparison with code results

On-Going Research (4) - SMART

Severe accident evaluation of SMART reactor

- SMART: System-integrated Modular Advanced ReacTor
  - Water cooled small integral reactor in Korea
- Thermal power: 365 MWth
- Passive system: PRHR, PSIS, etc
- Design characteristics
  - 4 RCPs, 8 Steam Generators
  - Design: 17.0 MPa, 360 ºC
- Severe accident mitigation
  - In-Vessel Depressurization
  - IVR-ERVC
  - Hydrogen Mitigation System: PARs
- SMART PPE(Pre-Project Engineering)
  - Started on Dec.1 2015 to November 2018 (with K.A.CARE in Saudi Arabia)



Schematic Diagram of SMART

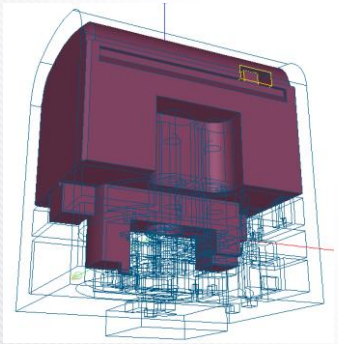
On-Going Research (4) - SMART

Code development of CINEMA-SMART

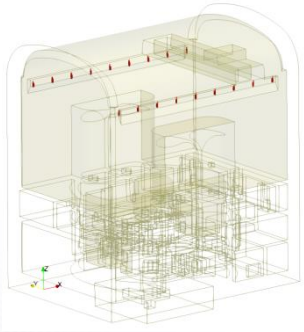
- Computer code for severe accident sequence analysis in SMART
- Based on CINEMA-APR1400
- Results of merging the COMPASS (In-vessel melt progression, KAERI), the SPACE (RCS Thermal hydraulic behavior, KAERI et al.), the SACAP (Severe accident in containment, FNC), and the SIRIUS (FP behavior, KAERI)
- Contents
  - Module development for helical S/G, CPRSS, and so on
  - Severe accident sequence analysis with in-vessel depressurization: TLFW, SBLOCA

Evaluation of severe accident issues

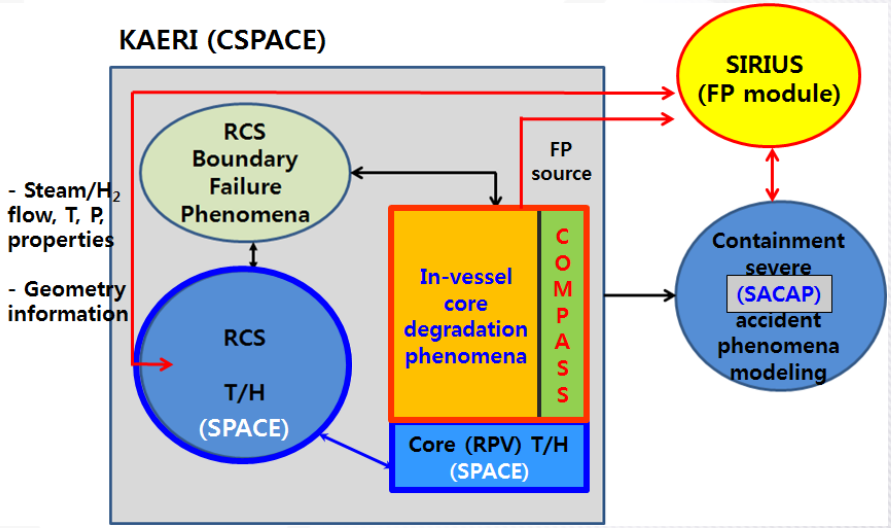
- IVR-ERVC
- Hydrogen control



Without PAR



With PAR



CINEMA-SMART structure

중대사고 연구현황 – KINS(1)

- 지난 5년간의 중대사고 연구 현황 및 결과
  - 규제 평가방법론 개발에 치중함.
    - ✓ 외벽냉각 (Ex-vessel Cooling)
    - ✓ 증기폭발 (Steam Explosion)
    - ✓ 증기폭발 조건에서 격납건물 구조적 건전성 (Containment Structural Integrity under Steam Explosion conditions)
    - ✓ 격납건물 여과배기 계통 (Containment Filtered Venting)
    - ✓ 수소 현안 (연소, 농도, PAR...)
    - ✓ 사고관리 평가방법론 개발
  - 연구에 사용/개발된 전산코드
    - ✓ APR1400 Analysis of Ex-vessel Cooling : MELCOR
    - ✓ Develop in-house code for Ex-vessel Cooling (AIR-2Layer, AIR-3Layer)
    - ✓ Steam Explosion Assessment using TROI : TEXAS-V
    - ✓ APR1400 Containment Structure Analysis : LS-DYNA, Civil-FEM
    - ✓ Pool Scrubbing Assessment using Experiments : MELCOR
    - ✓ Hydrogen Behavior Assessment using Experiments : MELCOR, CFD

조용진, KINS 중대사고 연구현황 및 리스크 평가 연계방안, 2018 중대사고연구회, 포스코 국제관, 2018. 7. 5 – 6

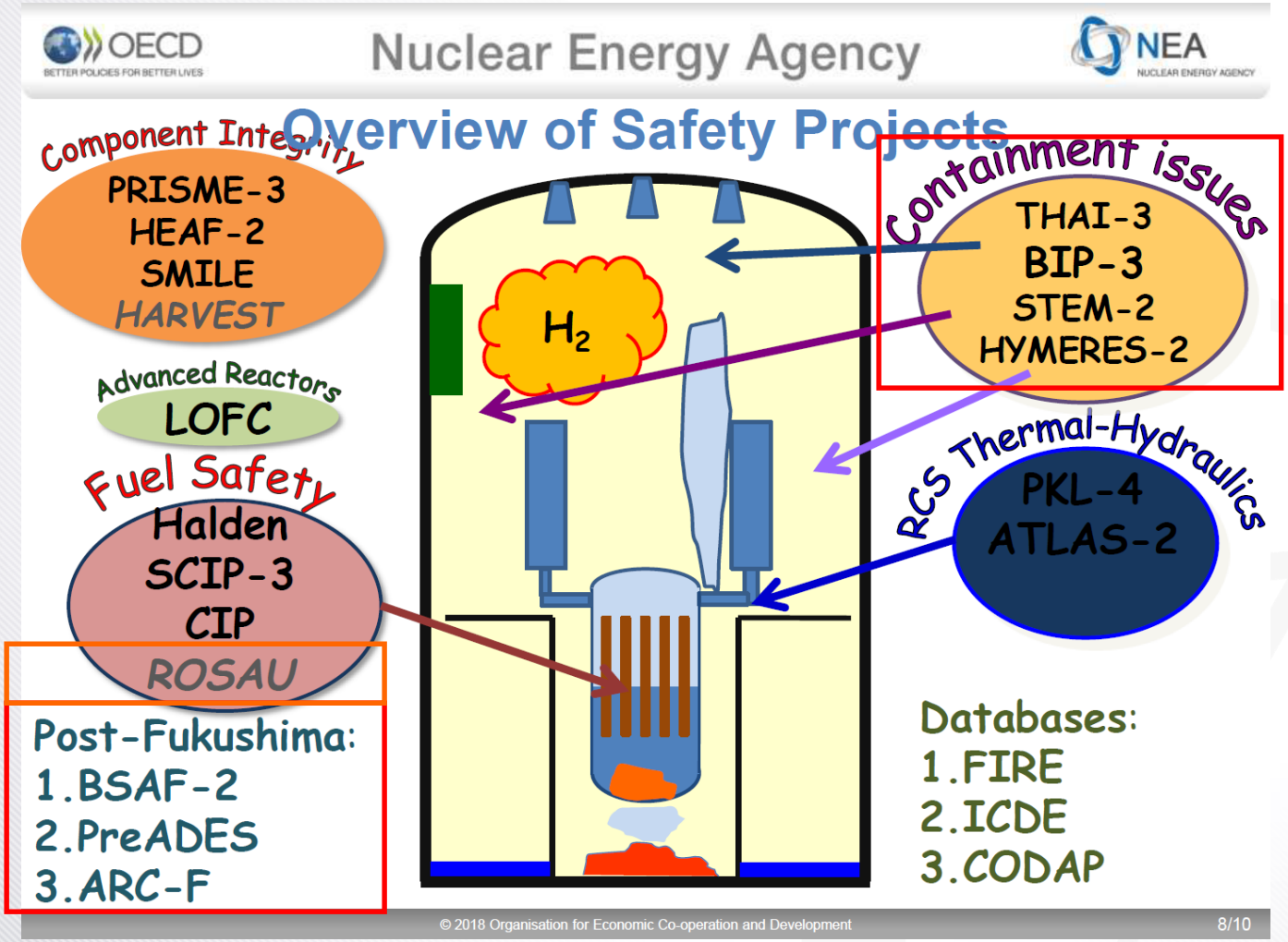
중대사고 연구현황 – KINS(2)

- 향후 5년간의 연구는 지난 연구의 미진한 부분과 새로운 연구주제로 나누어짐.
  - 중대사고 분야
    - ✓ **Reactor Pressure Vessel Integrity under ERVC conditions**
    - ✓ **Containment Bypass (temperature Induced SGTR)**
    - ✓ **Explosive Load in containment**
    - ✓ **Ex-vessel Corium Debris Coolability**
    - ✓ **Recriticallity Evaluation under Severe Accident Conditions**
    - ✓ **Fission Product behavior Models Development / Improvement**

조용진, KINS 중대사고 연구현황 및 리스크 평가 연계방안, 2018 중대사고연구회, 포스코 국제관, 2018. 7. 5 – 6

On-Going Research (8)

International Collaborations



NUGENIA

IVMR

IPRESCA

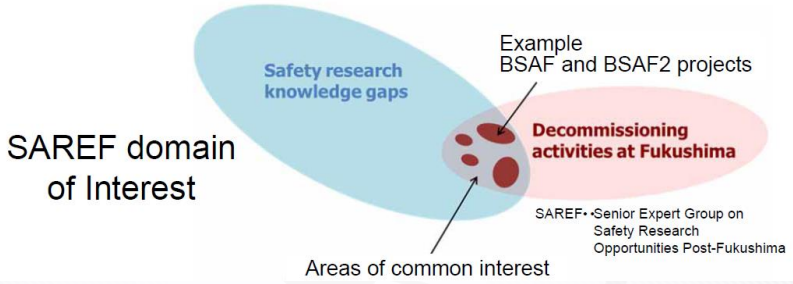
OECD/NEA Projects

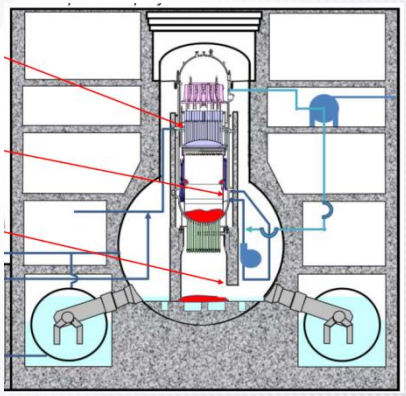
BSAF-2

- To provide information and analysis results on the SA progression, FP behavior, source term estimation within the first 3 weeks of the Fukushima Daiichi Accident in March 2011 including a comparison to measured plant data, to support safe and timely decommissioning of the Fukushima Daiichi NPS
- To contribute to the improvement of methods and models of the SA codes applied by each participating organization, in order to reduce uncertainties in SA analysis and to validate SA analysis codes using data measured through the decommissioning process at the Fukushima Daiichi NPS.

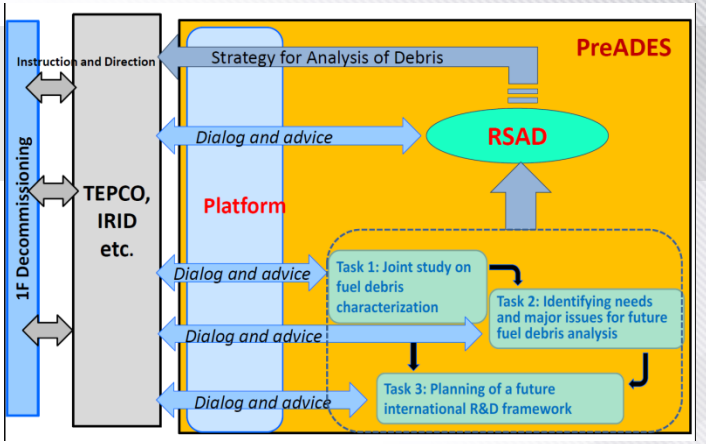
ARC-F

- Task 1 : Refinement of analysis for accident scenarios and associated FP transportation and dispersion (taking over the BSAF2)
- Task 2 : Compilation and management of data and information
  - Inclusion of JAEA own activities with technical and financial supports by the Nuclear Regulation Authority (NRA) of Japan
- Task 3 : Discussion for future long-term project
  - One of major objectives of the SAREF near-term projects.





OECD/NEA Projects



PreADES

- Task 1: Joint study on fuel debris characterization
  - (1-1) Fuel debris properties characterization method
  - (1-2) Estimated properties of fuel debris
- Task 2: Identifying needs and major issues for future fuel debris analysis
  - (2-1) Needs for fuel debris analysis
  - (2-2) Experimental/analytical techniques and demands in hot-testing facilities
  - (2-3) Study for major issues on future debris analysis
- Task 3: Planning of a future international R&D framework
  - (3-1) Develop a plan of a future R&D framework using actual fuel debris sampled from Fukushima Daiichi NPPs

TCOFF

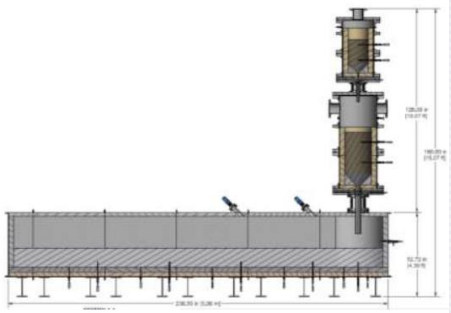
- Improve quality and/or inventory of thermodynamic databases with a reference to SA-progression analysis for FDNPS accident
- Conduct joint thermodynamic evaluations of SA-progression at in-vessel and ex-vessel phases of FDNPS unit-1,2, and 3.

OECD/NEA Projects

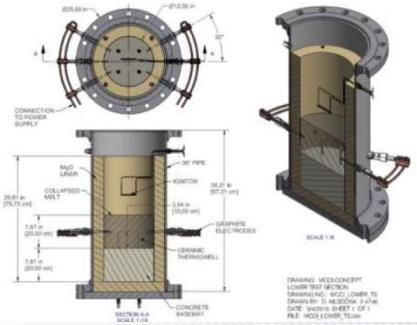
ROSAU

Cat.	Test Type	Objective & Rationale	Approach	Number and Schedule
1	Large-scale underwater melt spreading experiments	Produce underwater melt spreading data examining influence of melt composition, flowrate, and coolant subcooling on spreading behavior. Spreading is important as it influences long term coolability. Limited test data.	Produce and inject core melt into a 10º spreading sector up to 7.25 m long containing water. Melt masses up to ~300 kg; melt composition, flowrate, temperature, and water depth are potential parametric variations. Dry-test as possible baseline. Fission product simulants can be included	3 large scale tests in an initial 3 year program, or 6 large-scale tests in a 5 year program.
2	MCCI and debris coolability experiments	Provide reactor material data examining influence of metal content (including steel and unoxidized Zr) and potentially coolant purity on coolability and MCCI.	Produce ~100 kg core melts with up to 30% metal (steel/Zry) content. Metal concentration and coolant purity can be varied. Water top-flooding to study integral cooling behavior. Post-test strength measurements made on solidified corium ingot to measure crust fracture strength. Incorporate sustained decay heat simulant via Joule or inductive heating.	3 tests in an initial 3 year program, or 5 tests in a 5 year program

Melt spreading apparatus



Modified facility



OECD/NEA Projects

THAI-3

- Topic 1: PAR performance under counter-current flow conditions
- Topic 2: Hydrogen combustion and flame propagation in two-compartment system
- Topic 3: Fission product re-entrainment from water pool at elevated temperature
- Topic 4: Re-suspension of fission product deposits upon impact of a high-energetic event, e.g. hydrogen deflagration

BIP-3

- Methane/I_2 Irradiations, Iodine adsorption on surface, Methyl iodide(paint) production, Leaching tests

STEM-2

- Effect of paint ageing (in-service operation and pre-irradiation) on iodine trapping and release under irradiation
- Effect of irradiation on stability/destruction of iodine aerosols (iodine oxides as well as multi-components iodine aerosols)
- Ruthenium revaporisation processes with more oxidizing prototypic conditions (complement of already performed tests to develop predictive models for ST evaluations)

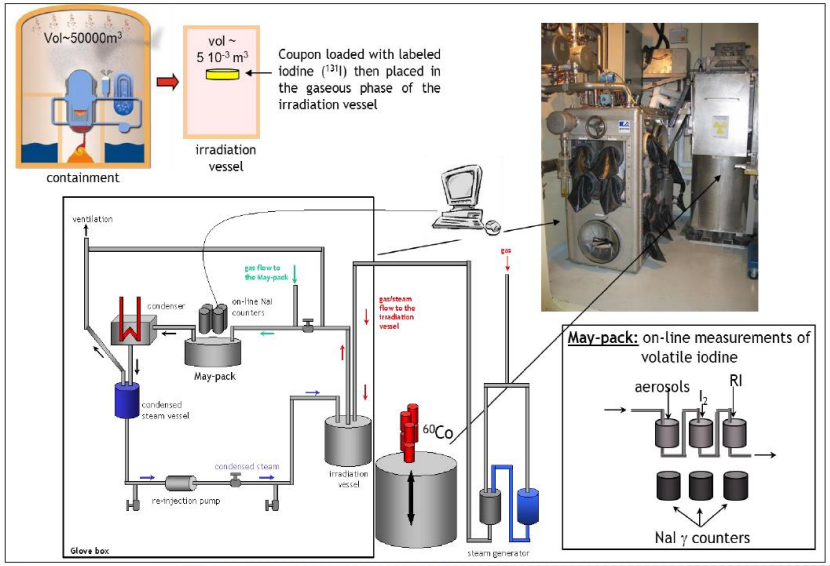
	THAI	PAD
Volume	60 m³	18m³
Height	9.2 m	9.8 m
Diameter	3.2 m	1.6 m

(PAD: Parallel Attachable Drum)

P/T: 1.4 MPa (180°C)
Stainless steel: 22 mm

- Configurable sub-compartments
- Pressure resistant for H_2 -deflagrations
- Licensed for use of radiotracer I^{123}

IODINE part : EPICUR Loop



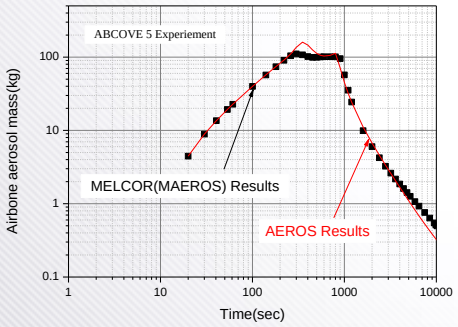
Future Research Milestone – Fission Product

Code & Methodology

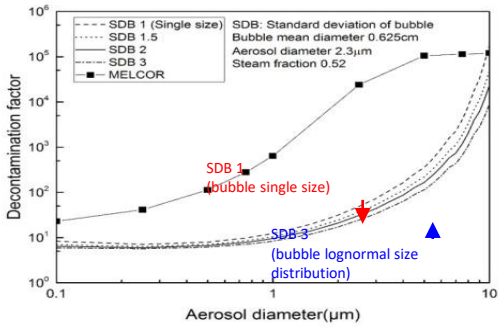
Experiments & Mitigation

2012 — 2017 — 2022 — 2027 — 2032

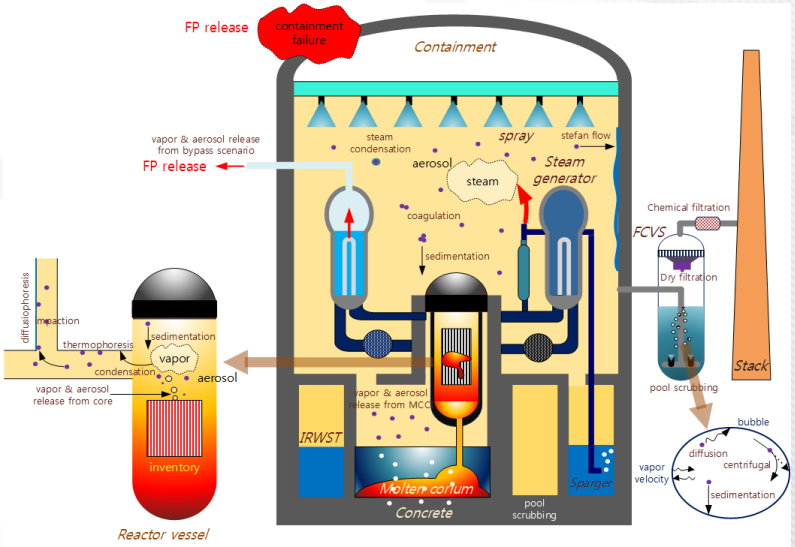
- AEROS
- PIAERO
- SIRIUS
- CINEMA -SMART
- CINEMA -BYPASS
- Update of CINEMA
- Realistic Source Term
- New regulation : Strengthen target of FP releasing amounts
- ARIEL
- FCVS
- ARIEL-BYP
- SGTR mitigation system
- FP release facility
- Mitigation for FP reduction



AEROS code :
aerosol mass in gas



PIAEROS code:
aerosol scrubbing in pool



THANK YOU