Status and future plan of safety research of the BA-DDA

Makoto Nakamura
JAEA

“Japan-US Workshop on Fusion Power Plants and Related Advanced Technologies with participations from China and Korea”, Kyoto U., Feb. 26, 2013.

Why DDA Safety Research ?

Motivations

- After the decision of the ITER site, fusion safety study in Japan got stagnant.
- After the Fukushima Dai-ichi accident, we (the JA Team) have recognized necessity of reconfirming safety of fusion energy.

Asahi Newspaper, 2011/03/21.

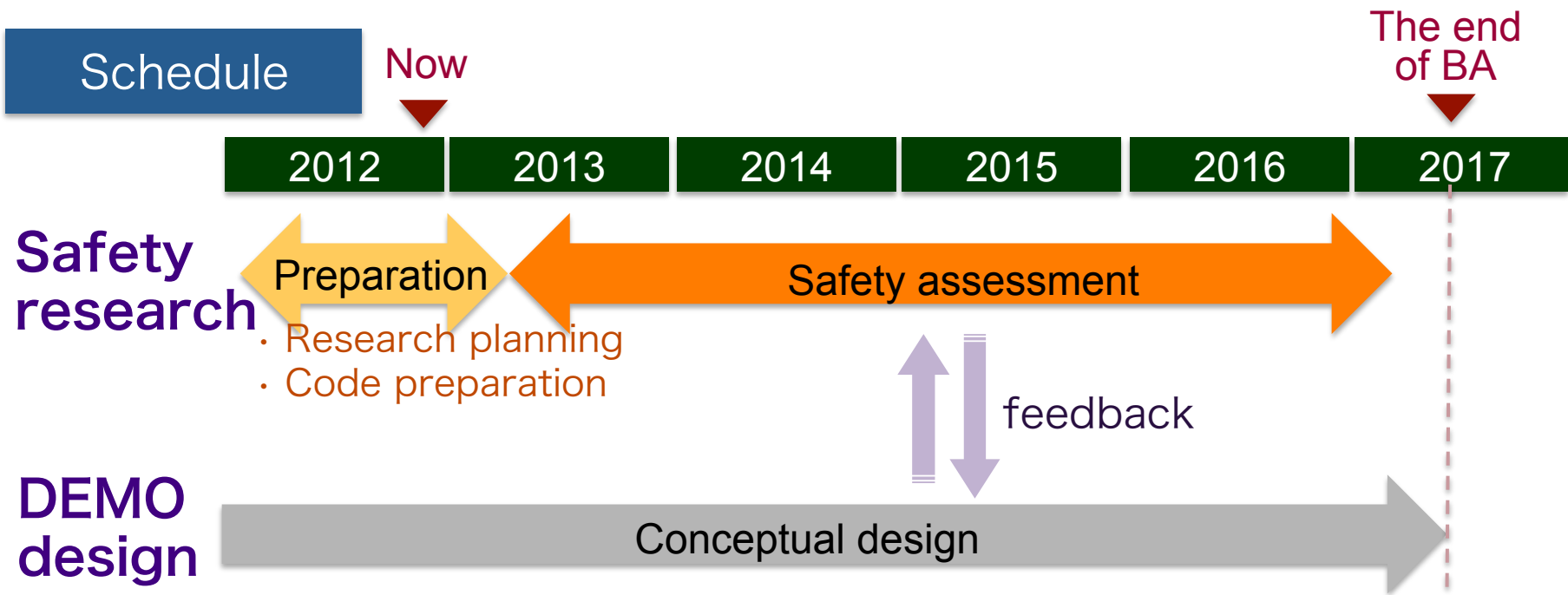
Fusion safety research has been kicked off in the BA-DDA

Scope of the DDA Safety Research

Objectives

- ❖ Analyze accident sequences potentially anticipated in DEMO as radiological risks
- ❖ Develop possible projections of the results to safety design for preventing and mitigating serious accidents
- ❖ Compile the safety design guidelines

Schedule



Implementation of the safety research

- The DDA Safety Research is implemented mostly by the JA Home Team.
- The JA side have frequent discussions with the safety expert of the EU side, Dr. Werner Gulden.
- The next JA-EU joint meeting is to be held this March.

Meeting w/ Dr. W. Gulden at Rokkasho
19-25 April 2012

Meeting w/ Dr. W. Gulden at Munich
Oct 1 2012

Structure of JA-HT for Safety Research

Coordination

Kenji TOBITA (JA-PM)

Makoto NAKAMURA

Yoshiteru SAKAMOTO

Consultation

Taisuke YONOMOTO — *Fission safety, licencing*

Takumi HAYASHI — *Tritium safety, ITER safety assessment in JA*

Safety assessment

Accidental sequences

Makoto NAKAMURA — *Physics & fission PSA*

Akira SATO — *Fission Safety, thermo-hydro*

Hisashi TANIGAWA — *Safety of ITER-TBM*

Yoshiteru SAKAMOTO — *Plasma Physics*

Activation/dose

Youji SOMEYA — *Activation, decay heat*

Safety design

Hiroyasu UTOH — *Safety System*

Youji SOMEYA

Kenji TOBITA

Industry

TOSHIBA Leading Innovation >>>

MITSUBISHI HEAVY INDUSTRIES, LTD. Our Technologies, Your Tomorrow

MNEC

Kawasaki

JGC

Software company

CTC Challenging Tomorrow's Changes

IX Knowledge Inc.

ERI Inc.

V.I.C. Visible Information Center, Inc.

Y-S-E YAMATO SYSTEM ENGINEER

University/Institute

Ryoji HIWATARI — *Fusion design and fission safety*

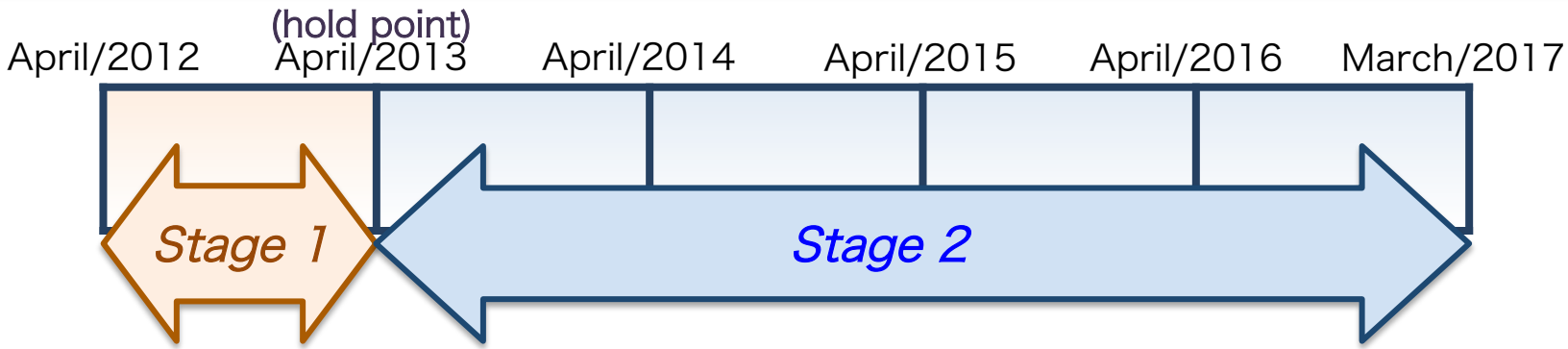
Toshiaki KUNUGI — *Thermo-hydraulic analysis*

Takehiko YOKOMINE — *Thermo-hydraulic analysis*

Ryuta KASADA — *Tritium behavior In environment*

Contribution by universities and institutes will be encouraged in coming years.

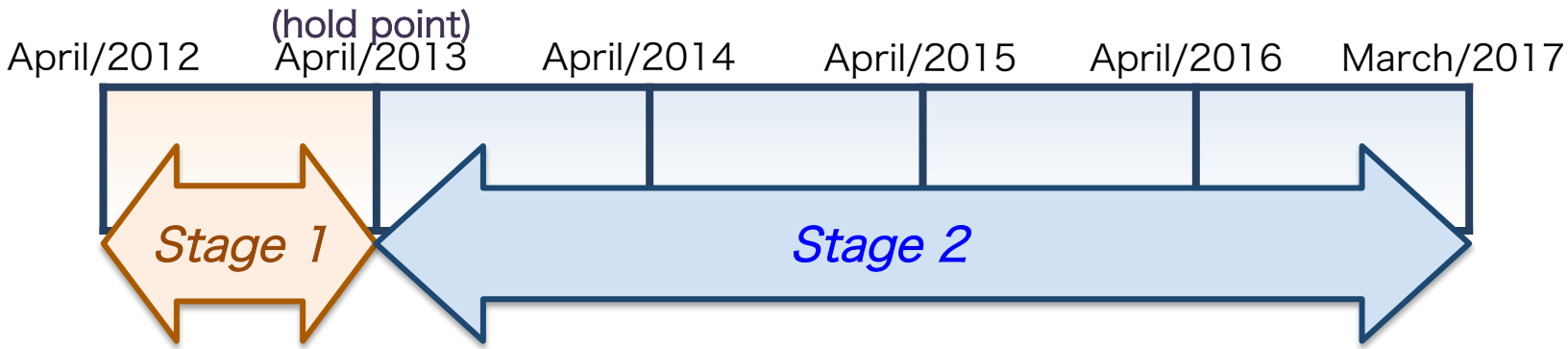
What type of DEMO ?



- The DDA Safety Research is implemented mostly by the JA Home Team.

- A DEMO with a water-cooled solid breeding blanket (but with $Be_{12}Ti$) will be the main target.
- The initial analysis will start with moderate design parameters (e.g., fusion output of ~2 GW) and a generic system configuration.
- They are subject to change in line with the progress of safety analysis.

Overall schedule of the safety research



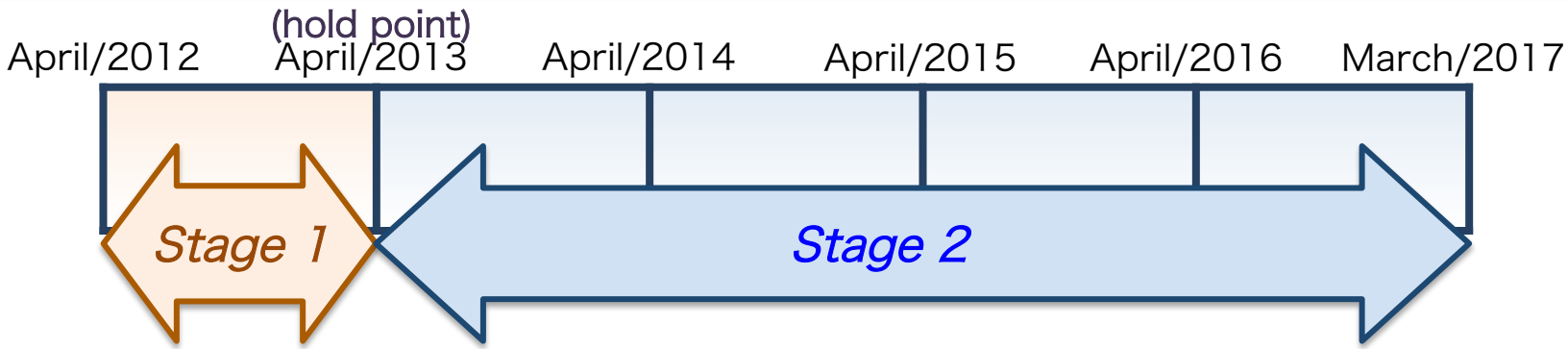
- **Stage 1:** Preparation & definition of SR targets (2012/04～2013/03)

  - Definition of safety requirements
  - Definition of source terms
  - Identification of reference events
  - Preparation of computer codes

- **Stage 2:** Assessment based on reference events(2013/04～2017/04)

  - Development of computer codes
  - Analysis of reference event sequences
  - Definition and analysis of beyond design basis events (BDBEs)
  - Projections to DEMO safety design
  - Compilation of safety design guidelines

Overall schedule of the safety research



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Stage 1-1:

Definition of safety requirements

【 ITER 】

1. Terminate reactions

- Fusion reactions are not "chain" reactions.
- Termination of fueling lead to termination of reactions.

2. Cool the reactor

- In-vessel components can be cooled passively

3. Confine radioactive materials

- In-vessel components can be cooled passively
- Defense-in-depth

【DEMO】

➔ Similar to ITER

➔ Not similar to ITER

➔ Not similar to ITER

Source terms and energies should be quantified.

Stage 1-1:

Definition of safety requirements

- How to define safety requirements for DEMO ?

  - In Japan, the safety requirements for ITER were established for invitation of ITER.
    - These might not be applicable to DEMO since these are based on passive safety natures of ITER.
  - PPCS safety design guidelines and DOE Standards can be applicable to DEMO.
    - P. Karditsas and the PPCS Team, PPCS/TW4-TRP-003/ UKAEA, (2004).
    - DOE-STD-6002-96, DOE-STD-6003-96 (1996).
  - We are now discussing the DEMO safety requirements based on these previous documents.

Stage 1-2:

Definition of source terms

Radioactive source terms

Tritium

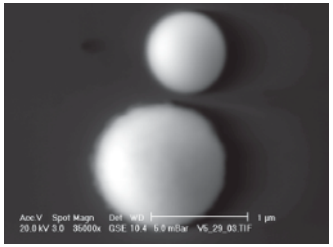
- T-inventory could be of the order of kg.

The inventory and distribution are dependent on DEMO design

W dust

- Mechanisms and a amount of W dust production have not been clarified yet.

The upper value of the amount of the W dust should be set as planned in (≤100 kg)



W dust observed in ASDEX-U

Stage 1-2:

Definition of source terms (cont.)

Stored Energies

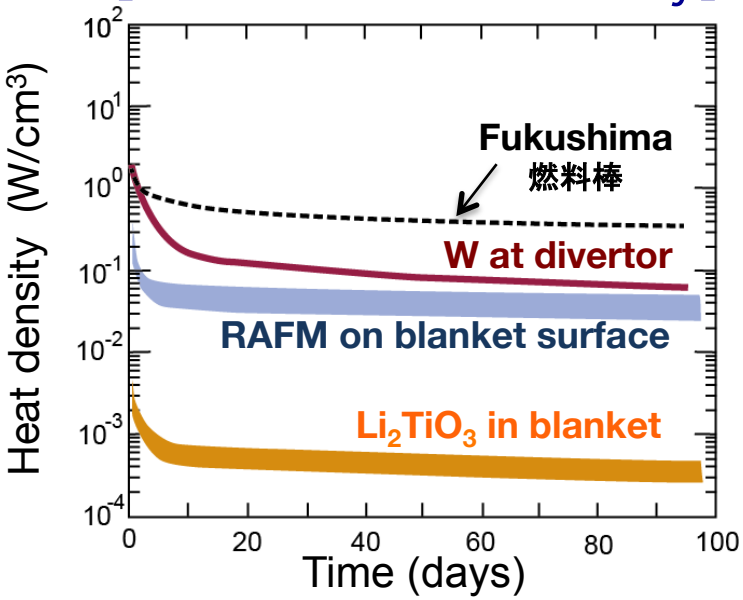
potentially mobilizing the radioactive materials

Residual heat

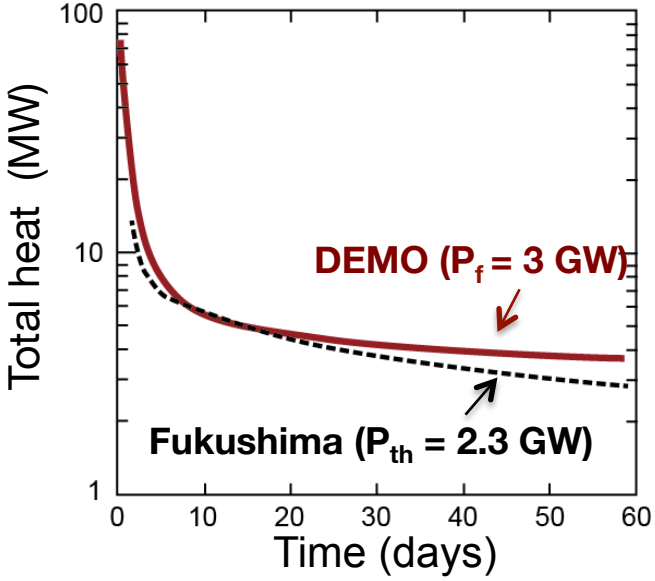
- **One order larger than ITER !**

	0	1 day	1 month
ITER	10 MW	1 MW	～0.1 MW
DEMO 3GW	54 MW	11 MW	3.1 MW

【Residual heat density】



【Total residual heat】



Evaluated by Youji Someya (JAEA)

Stage 1-2:

Definition of source terms (cont.)

Stored Energies

potentially mobilizing the radioactive materials

Magnetic energy Stored in TF coils

- Could be 2-3 times larger than ITER

  ITER: 41 GJ

  DEMO: 100-130 GJ

Chemical energies

- Hydrogen explosion

  $Be + H_2O \rightarrow BeO + H_2$

  metal (W) + $H_2O \rightarrow H_2$

- Dust explosion

  W dust w/ spark

Plasma stored energy

- α-heating & thermal energies: several times larger than ITER

  VDE, disruption or any failures of control

  ➡ Damages to divertors

Internal energy of coolant

- Coolant water pressure could be several times larger than ITER

  Could be crucial for LOCA & LOVA

	ITER	DEMO
Blanket	**ITER-shielding blk ~100°C, 2.6 MPa**	**~300°C, 15.5 Mpa ~200 m³/loop**
Divertor	**~150°C, 4.2 MPa**	**~300°C, 15.5 MPa**

Stage 1-3:

Identification of reference events

Event Sequences

Revisit accidental sequences in the previous designs;

- SEAFP
- PPCS
- ITER

Source terms

Consideration on the differences in

- Radioactive source terms
- Stored Energy
- Decay heat

Identification of the most critical event sequences

- The JA Team have had a research contract with the engineering company.
- We have a collaborative work for this task.
  - To be presented at ISFNT 2013.

Stage 1-4:

Preparation of computer codes

	Code (developer)	Status (A= available)	Functions
Neutronics	**THIDA-3** (JAEA)	A	• Versatile neutronics calculation code. • n, γ transport, dpa, W/cm^3, Bq/cm^3, TBR, etc. • Multiple reaction included.
	MCNP (LANL)	A	• n, γ transport, mainly for 3D cal.
Thermo-hydrolics	**MELCOR-FUS** (INL/SNL)	A	• Severe accident code based on compartment model. • Capable of dealing with chemical reactions
	TRAC (LANL)	In progress	• Thermo-hydrodynamics • Best estimate code based on precise 3Dmodel Now, TRACE (TRAC/RELAP advanced computational engine)
Plasma operation	**SAFALY** (JAEA)	A	• Transient events in tokamak
	AINA (U. Catalunya)	A	• Engineering parts of SAFALY, upgraded
Tritium / Dust	**TMAP-4** (INL)	A	• Tritium transport in materials
	ACUTRI/ ACUTAP (JAEA)	In progress	• Dose due to T/dust release to the environment (plume model)
	UFOTRI (KIT)	A	• Dose due to dust release to the environment
Heat trans.	**ANSYS**	A	• Residual heat analysis using the output of neutronics codes
	PHOENICS	A	• Heat and CFD analysis

Getting MELCOR-fus

20-26/04/2012, Rokkasho

Werner Gulden's advise

- that we should use MELCOR for thermo-hydraulic accident analysis from the viewpoint of quality assurance

- JAEA completed the non-disclosure agreement with INL and US-NRC for getting MELCOR-fus.
- Tobita-san and I visited INL for implementing MELCOR-fus for the DDA safety research from 28th October to 11th November.

11/11/2012, Idaho Natl. Lab.

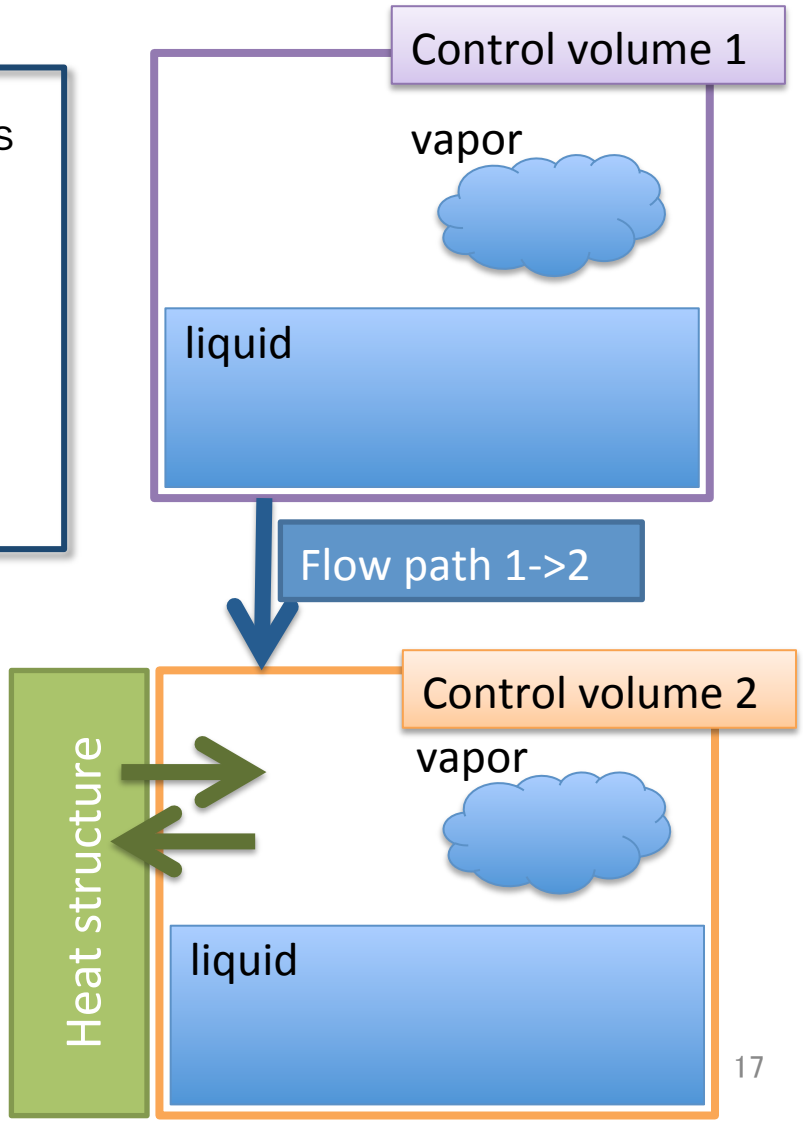
Basic structure of MELCOR

Basic equations

- Mass and energy conservation equations
  - for each control volume (CV)
  - for both liquid and vapor states
- Momentum conservation equation
  - for each flow path
- Heat transfer equation
  - for each solid structure

Assumptions

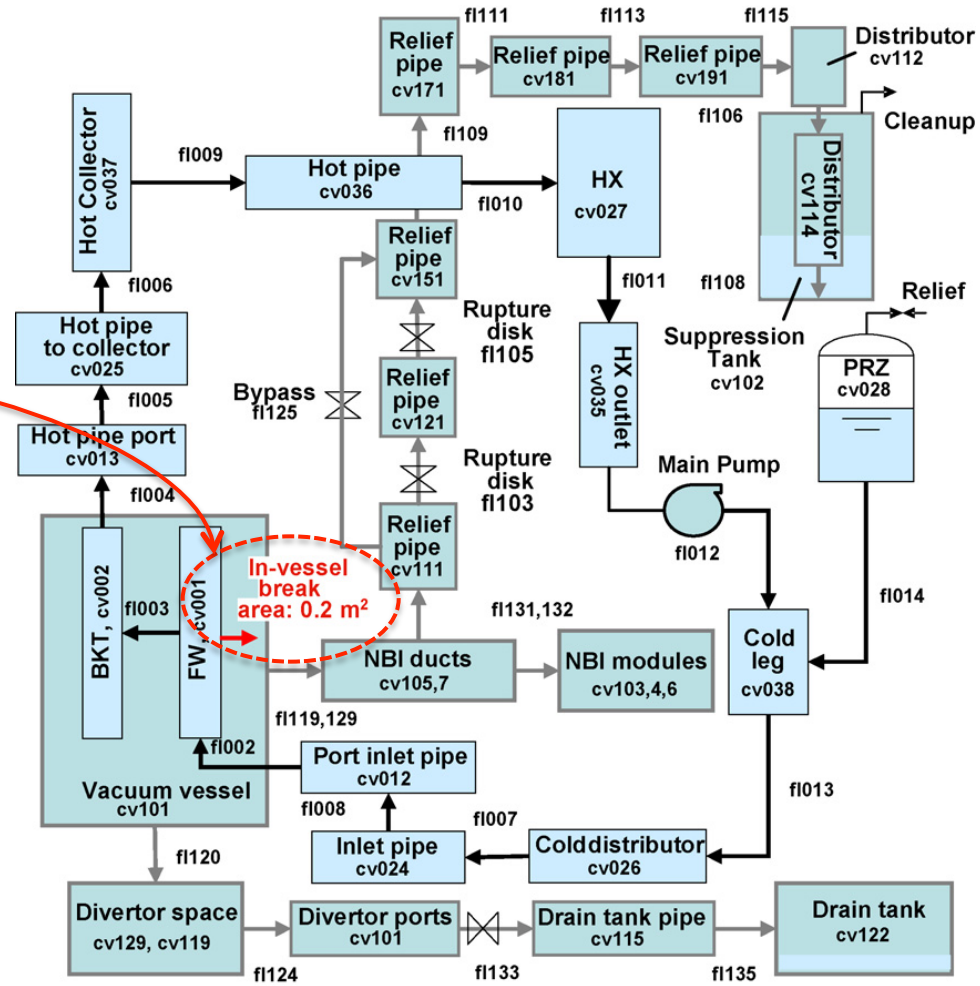
- Each component is represented by one or a small number of control volumes,
- Each flow path is represented by a one-dimensional flow



Simulation of accident in MELCOR

Breaks of pipes or structures are simulated by

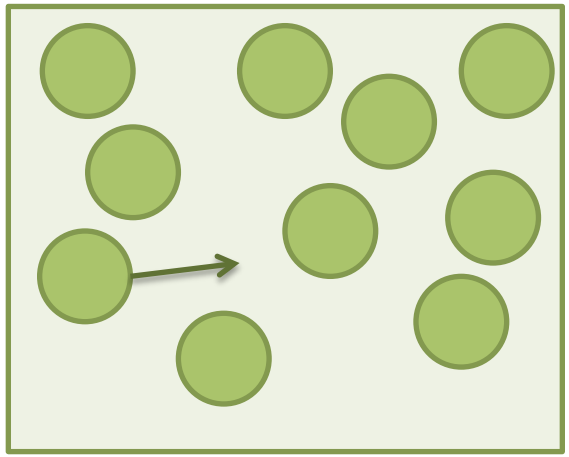
- ✓ pipes
- ✓ valves
- ✓ control logics

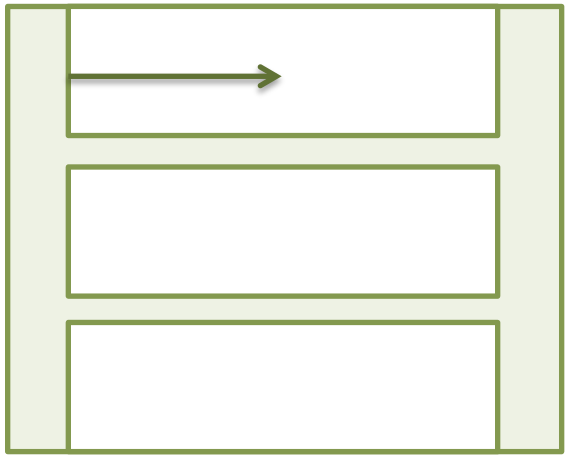


MELCOR-fus inputs for an ITER in-vessel multiple first wall pipe break event,
Merrill et al., FED 85, 1479 (2010).

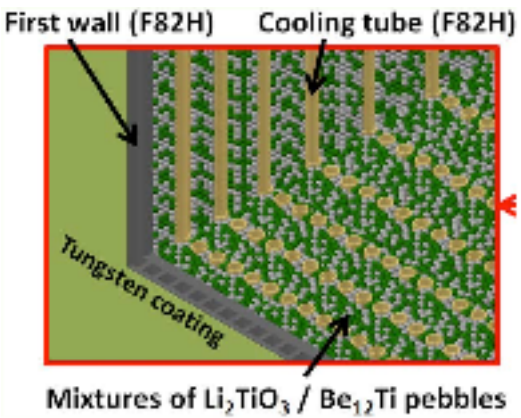
Modification for a fusion reactor

- Implementation of radiation heat transfer





Structure with libs

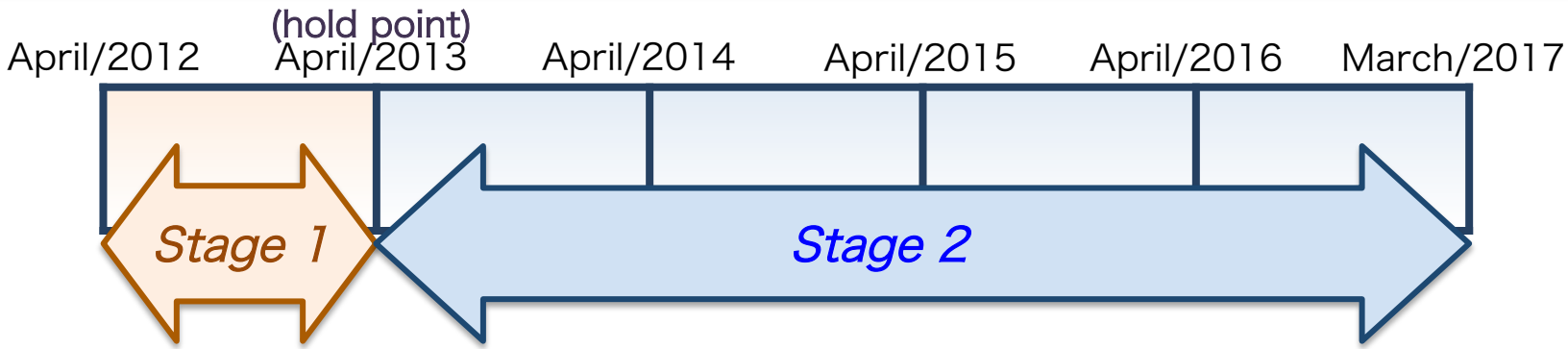


Solid pebble water cooled blanket for SlimCS
Someya et al, presented at IAEA-FEC (2012).

$$q = \delta \frac{\kappa}{\Delta x}\left(T_1 - T_2\right) + \left(1-\delta\right)\varepsilon\sigma\left(T_1^4 - T_2^4\right)$$

δ : the mass fraction of solid material

Overall schedule of the safety research



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Stage 2:

Assessment stage

2-1: Development of computer codes

Examples:

@ Steam-$Be_{12}Ti$ reaction for MELCOR & SAFALY

@ Interfaces for linking between the codes

@ Mesh convertor with CAD data

Reference Event

2-2: Analysis of reference event sequences

The analysis will cover

- ➔ In-vessel temperature after LOCA
- ➔ Temperature in VV after LOCA
- ➔ Transport of radioactive materials after LOVA
- ➔ Prevention or mitigation systems of tritium and RI dust

Stage 2:

Assessment stage (cont.)

2-3 Definition & analysis of beyond design basis events (BDBEs)

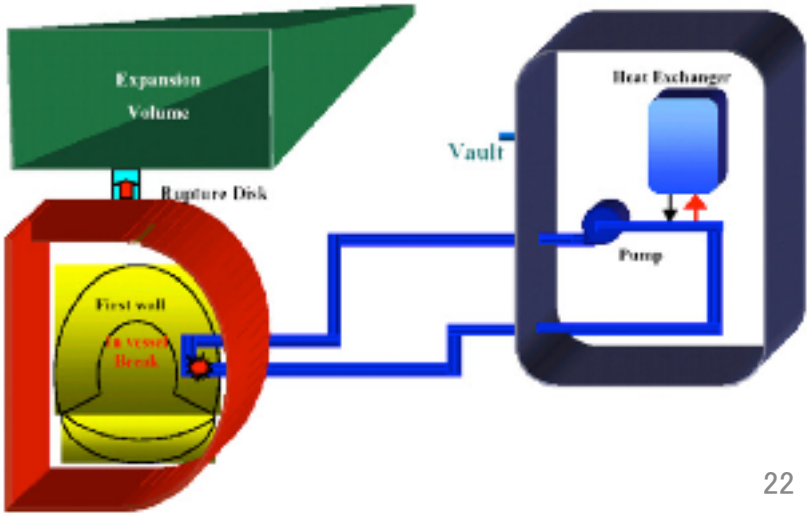
- Despite with extremely low probability, it is required to assure that no consequences resulting from the BDBEs lead to a cliff-edge.
- The following events would be considered as BDBE:
  - Total loss of on-site power for a long period (>72H ?)
  - Total loss of coolant from all loops for a long period (>72H ?)
  - Multiple failures sequentially or simultaneously

- Example of PPCS-B

(1) LOFA
+
(2) Failure in plasma shutdown

→ in-vessel LOCA

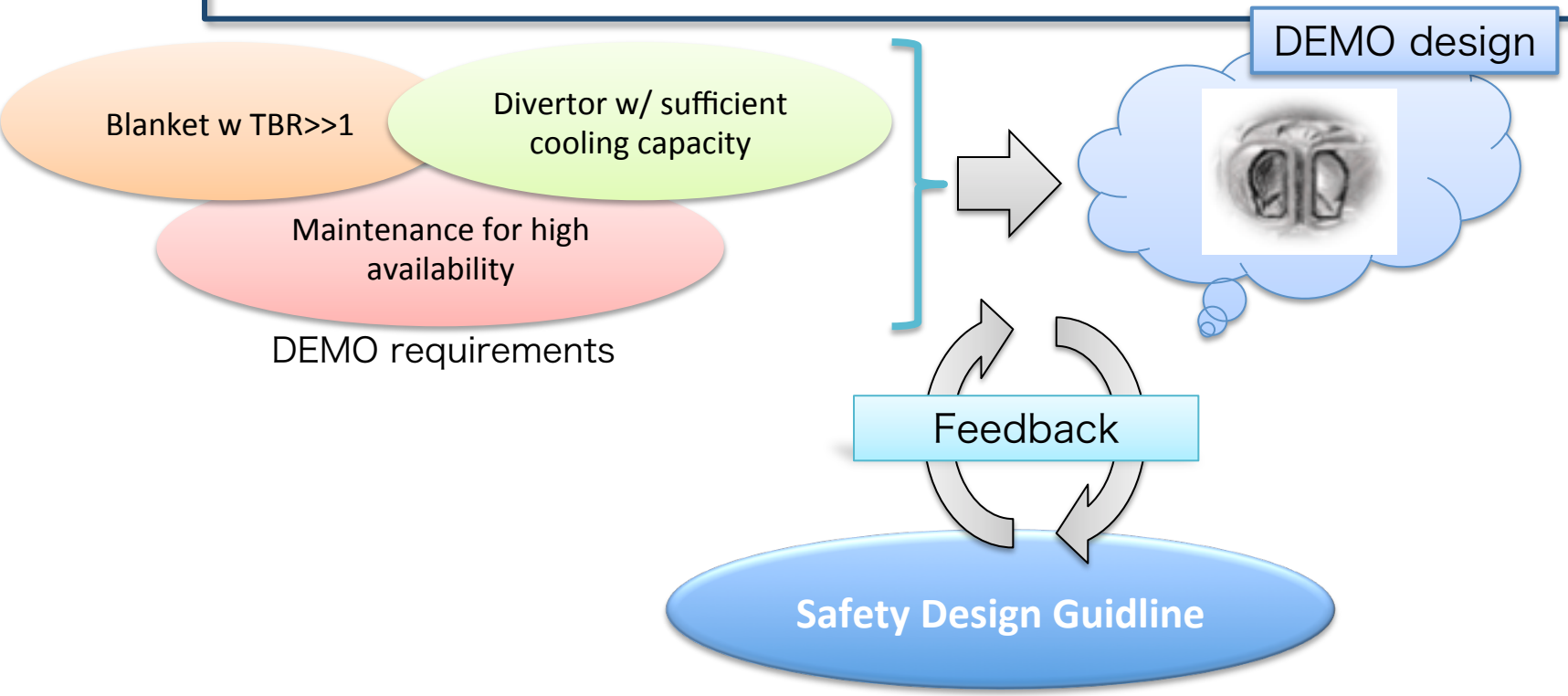
Gulden et al., NF (2007)



Stage 2: Assessment stage (cont.)

2-4: Projections to DEMO safety design

- The analysis results will lead to generic safety characteristics of DEMO.
- They should be fed back to the reference DEMO design so that the impacts of introducing various prevention and mitigation systems against abnormal events would be confirmed.



Summary

Fusion safety research has been kicked-of in BA-DDA

- The fiscal year 2012 is the preparation stage; quantitative assessment will be started in 2013.
- The DDA safety study is done in accordance with progress in the DEMO design. Findings in the safety research are to be reflected to the DEMO design, and vice versa.
- The safety requirements are now being prepared, prior to quantitative analysis.
- Many computational codes are being prepared. Particularly, implementation of MELCOR-fus is a key item for the DDA safety research.