NIFS-FERC

Materials Development and Design Effort for V/Li Blanket in Japan

T. Muroga

Fusion Engineering Research Center,

National Institute for Fusion Science, Japan

US/Japan Workshop on Power Plant Studies and
Related Advanced Technologies
Oct. 9 and 10, UCSD

V/Li Research in Japan

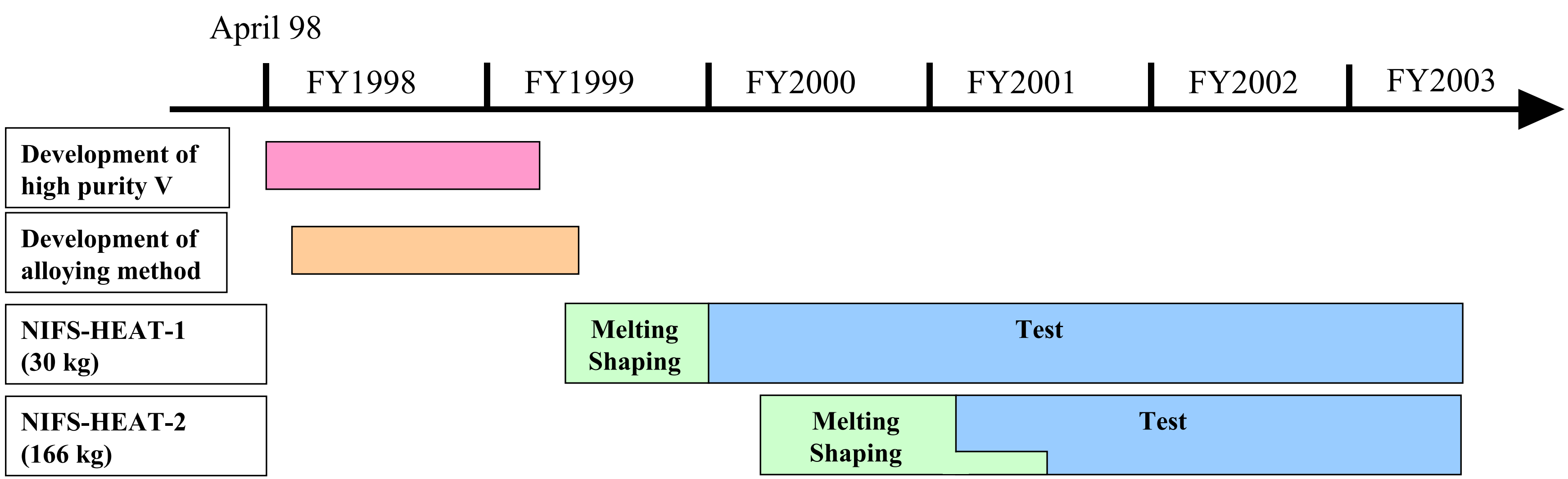
NIFS-FERC

- Collaboration by Materials, Blanket and Design people is increasing on V/Li system in Japan
  - Progress in the development of vanadium alloys by NIFS/Universities
  - Enhanced development of Li technology in relation to IFMIF-Key Technology Development
  - Enhanced participation to ITER-TBM by NIFS/ Universities, presently V/Li is the candidate being examined by NIFS/Universities
  - MHD coating development needs collaboration with design group and the collaboration is being enhanced

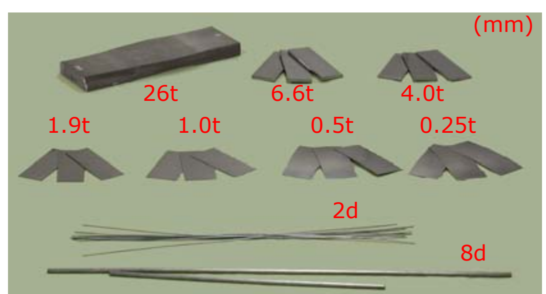
Production and Characterization of High Purity V-4Cr-4Ti (NIFS-HEATs)

NIFS-FERC

- NIFS-HEAT-1 has been tested by Japanese Universities
- NIFS-HEAT-2 was distributed for international collaboration



NIFS-HEAT-2 ingots



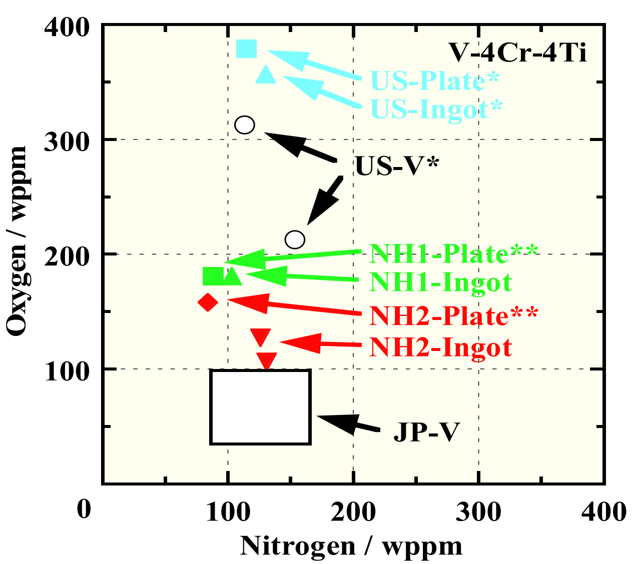
Products

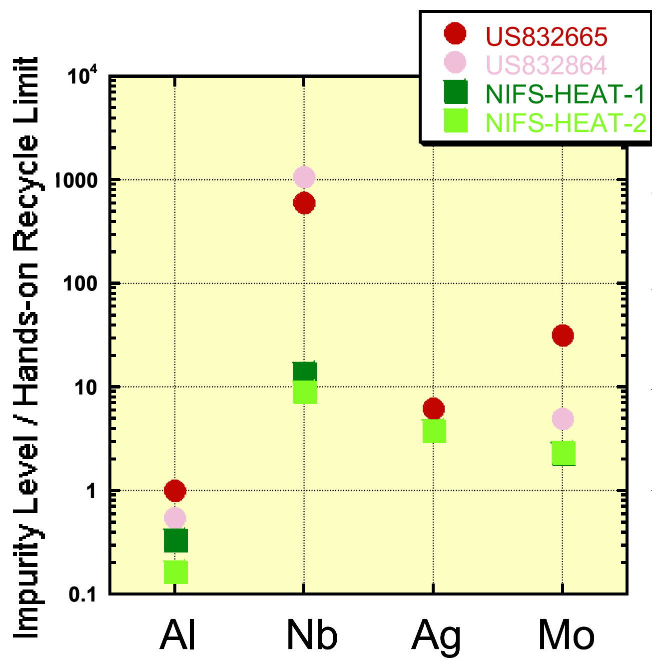

Specimens distributed

Merit of Purification

NIFS-FERC

- Some properties (welding, working, radiation response (in limited cases)) were improved by reduction of O and N
- Feasibility of economical recycling was demonstrated by reducing Al, Nb, Ag, Mo





Dolan, 1994

Remote Recycle limit (remote-control reprocessing)

Quasi-Remote Recycle limit

Quasi-Hands-on Recycle limit (contact reprocessing with some radiation control)

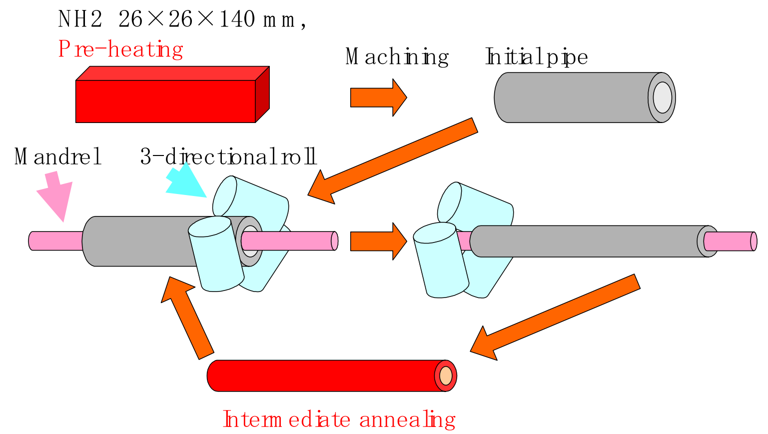
Hands-on Recycle limit

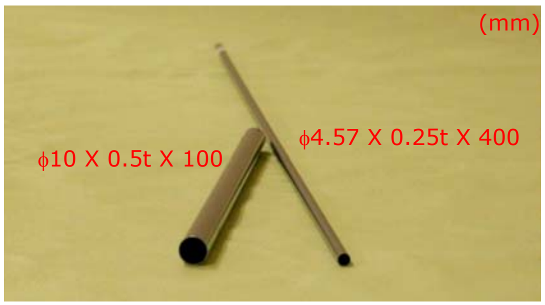
Element	Al	Nb	Ag	Mo
Hand-on Limit (wppm)	353	0.1	0.013	10

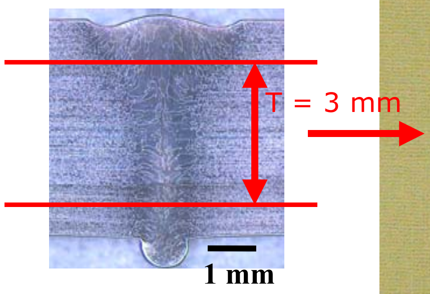
Fabrication Technology （Tubing, welding）

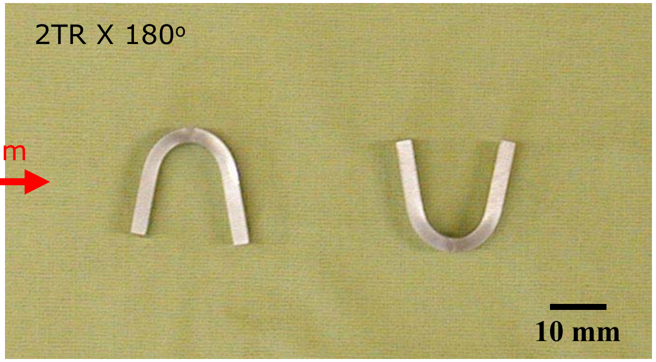
NIFS-FERC

- Plates, wires, tubes were successfully fabricated
- Good property of laser-weldment

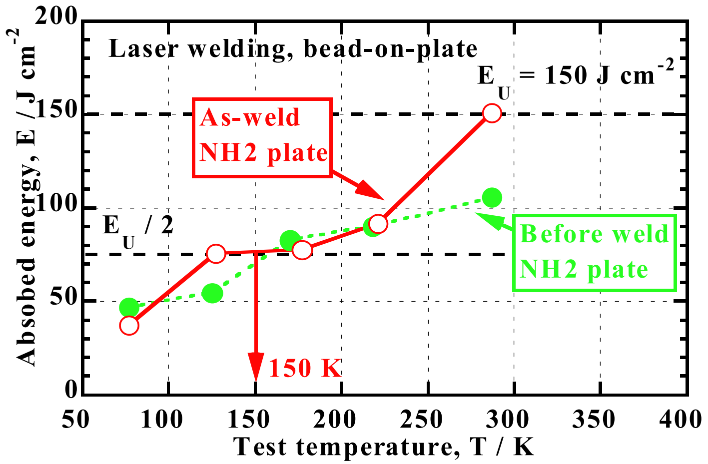








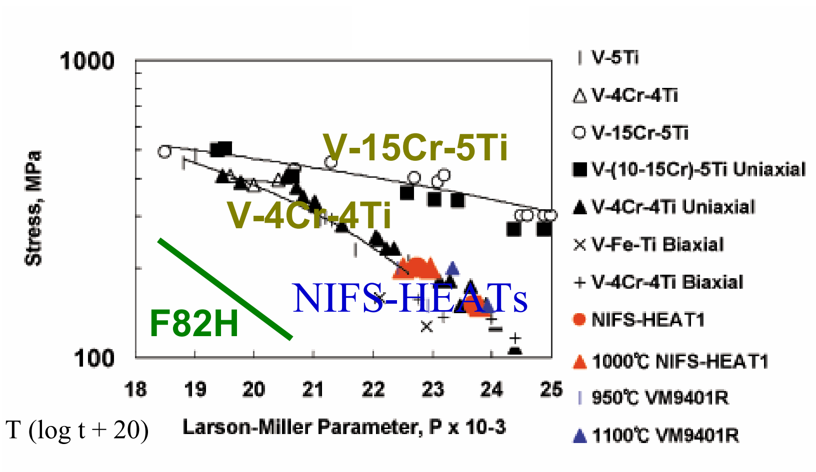
Specimen: 50 X 8 X 3 mm



Creep Properties of NIFS-HEAT

NIFS-FERC

- One of the concerns by the purification was the creep strength
- Creep strength of NIFS-HEATs was similar to other V-4Cr-4Ti



Creep Rupture

Fukumoto (ICFRM-10)

- Significant progress was made in developing vanadium alloys with improved engineering maturity and feasibility for economical recycling

Status of V-Alloy Development

NIFS-FERC

<u>Key-Issues</u>

- Massive production
  - high purity
  - low activation
- Fabrication tech.
- Welding
- MHD coating
- Radiation effects (He)

Feasibility almost demonstrated

Progress being made but further efforts necessary for feasibility

Systematic efforts necessary

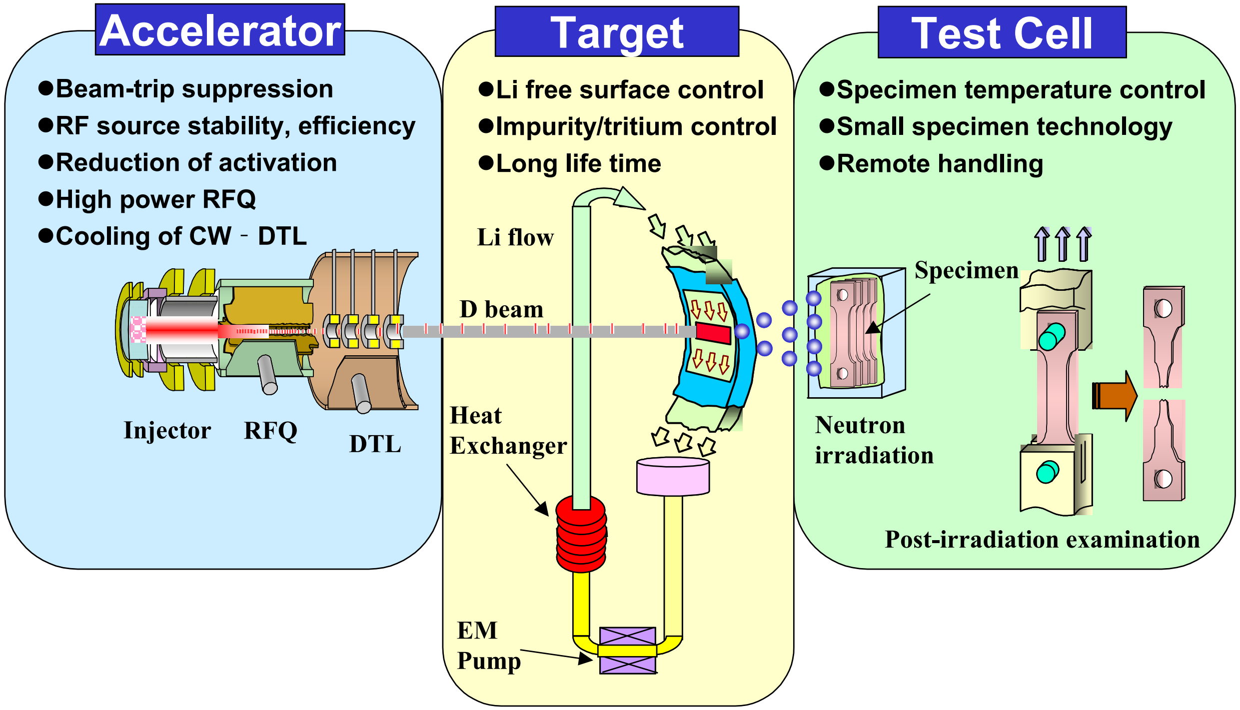
IFMIF Key Technology Verification

NIFS-FERC

- IFMIF Key Technology Verification studies were carried out in Japan in FY 2000~2002, sharing responsibility by JAERI and NIFS/Universities
- Li related Target research was carried out mainly NIFS/Universities

<u>IFMIF Schedule</u>

Key Element Technology Phase (KEP)	2000-2002
Transition	2003-2004
Engineering Validation and Engineering Design Activity (EVEDA)	2005-2009
Construction	2010~2016
Operation	2017~

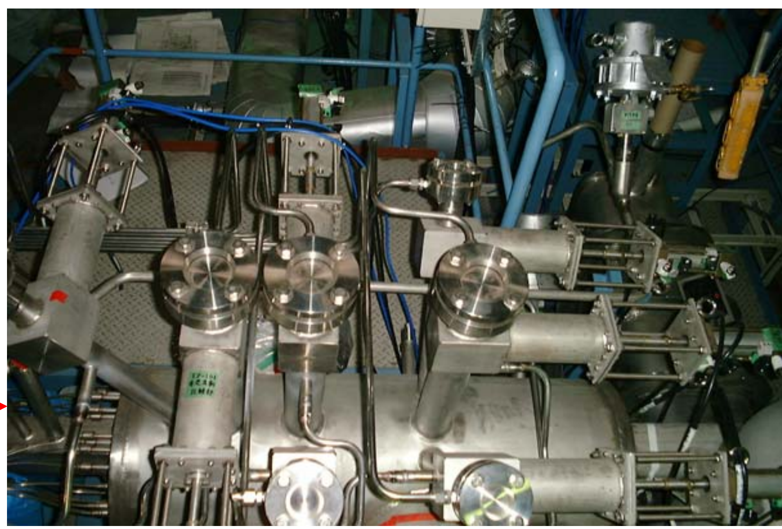


Li Target Test (Osaka University)

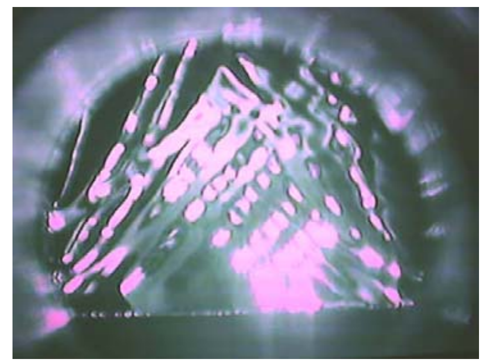
NIFS-FERC

- A test station was installed to 200L Li loop of Osaka Univ. for Target test
- Free surface test successfully carried out in FY2002
- Li and relating device technologies were enhanced

Li



Experiment Station



1 m/ s

Li

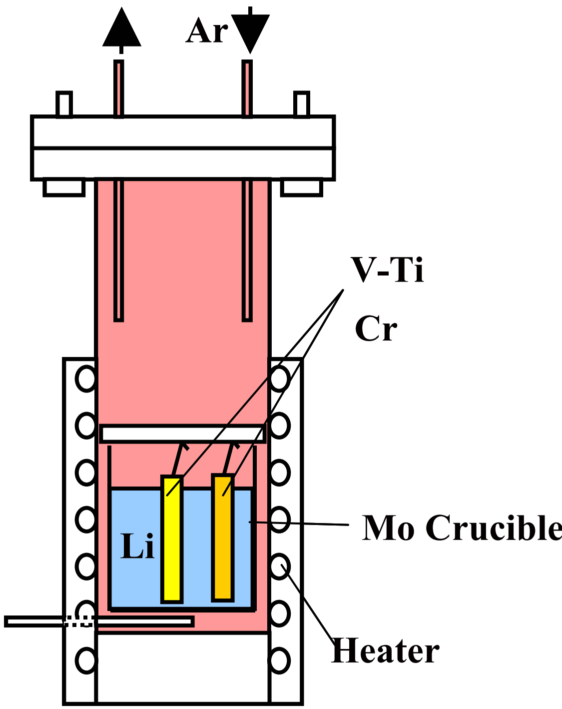
14 m/ s

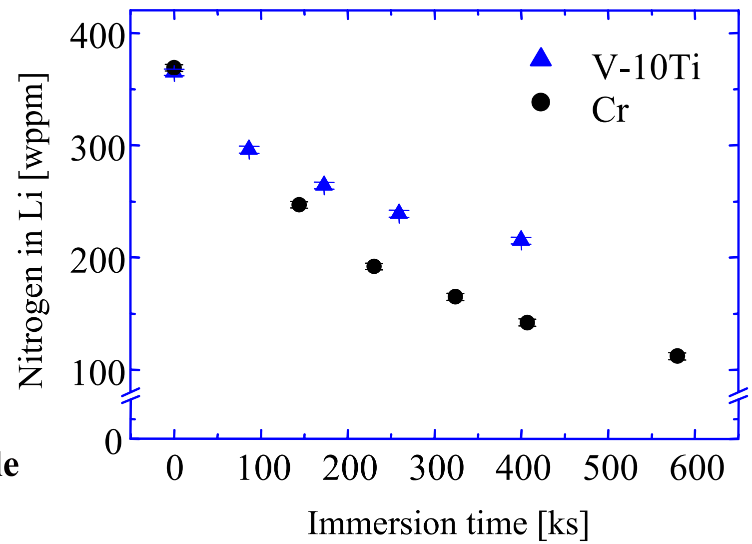
Horiike 2002

Li Impurity Control (U. Tokyo)

NIFS-FERC

- V-10Ti and Cr were shown to be effective getter material for hot N trap
- Control of N is essential for T recovery with Y
- T recovery study with Y in progress (U. Tokyo, Kyushu U.)





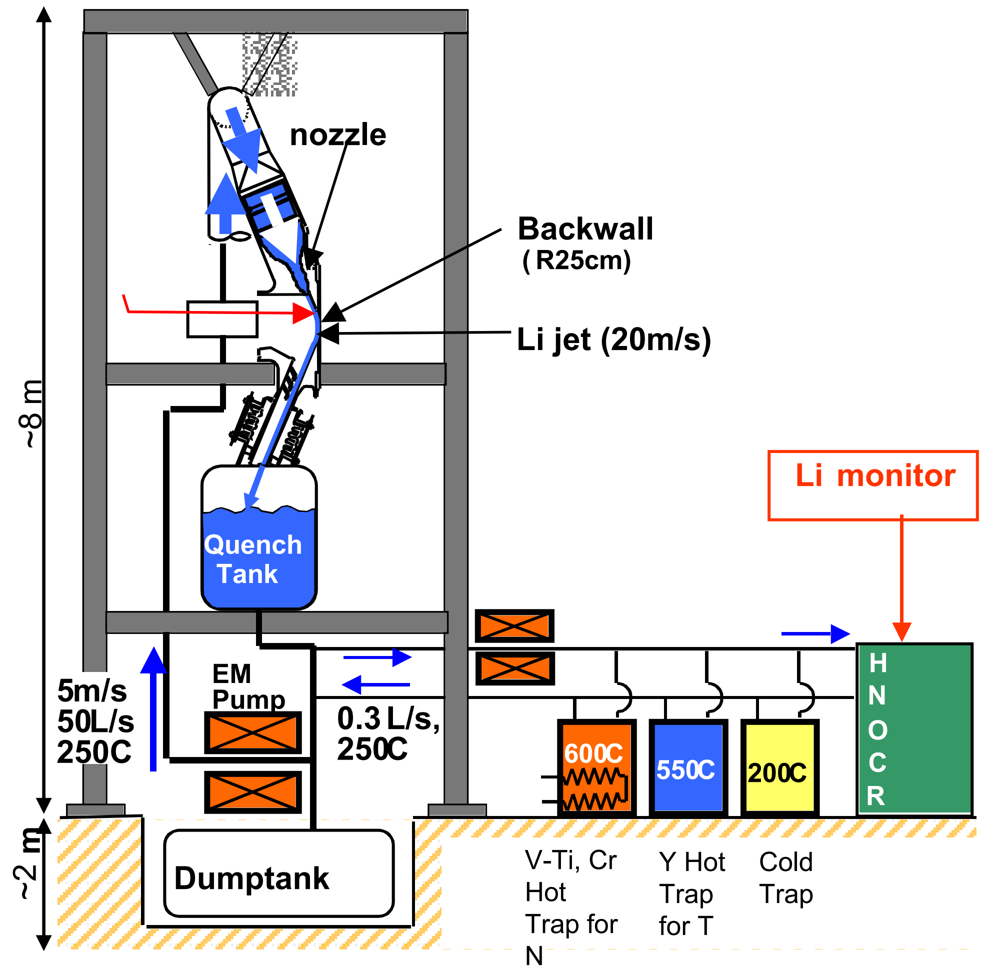
Nitrogen level in Li with Immersion Time at 823K

S. Tanaka 2002

Li Loop Experiment Planned in EVEDA

NIFS-FERC

- Full-size test loop will be constructed for validation of continuous operation
- Impurity control system will be installed based on KEP results
- The technology will be applied to Li blanket



ITER-TBM Past Proposals

NIFS-FERC

- From Japan, only solid breeders were proposed to ITER via JAERI
- A NIFS-collaboration activity started in 2002, in which liquid blanket test module is explored

Party	Proposed TBM-type
JAPAN	Solid - Water
	Solid - Helium
EU	Solid - Helium
	Li-Pb - Water
Russia	Solid - Helium
	Lithium
US	Solid - He
	Lithium

1995

Party	Proposed TBM-type
JAPAN	Solid - Water
	Solid - Helium
EU	Solid - Helium
	Li-Pb - Water
Russia	Solid - Helium
	Lithium

2001

NIFS Collaboration Activity for ITER-TBM

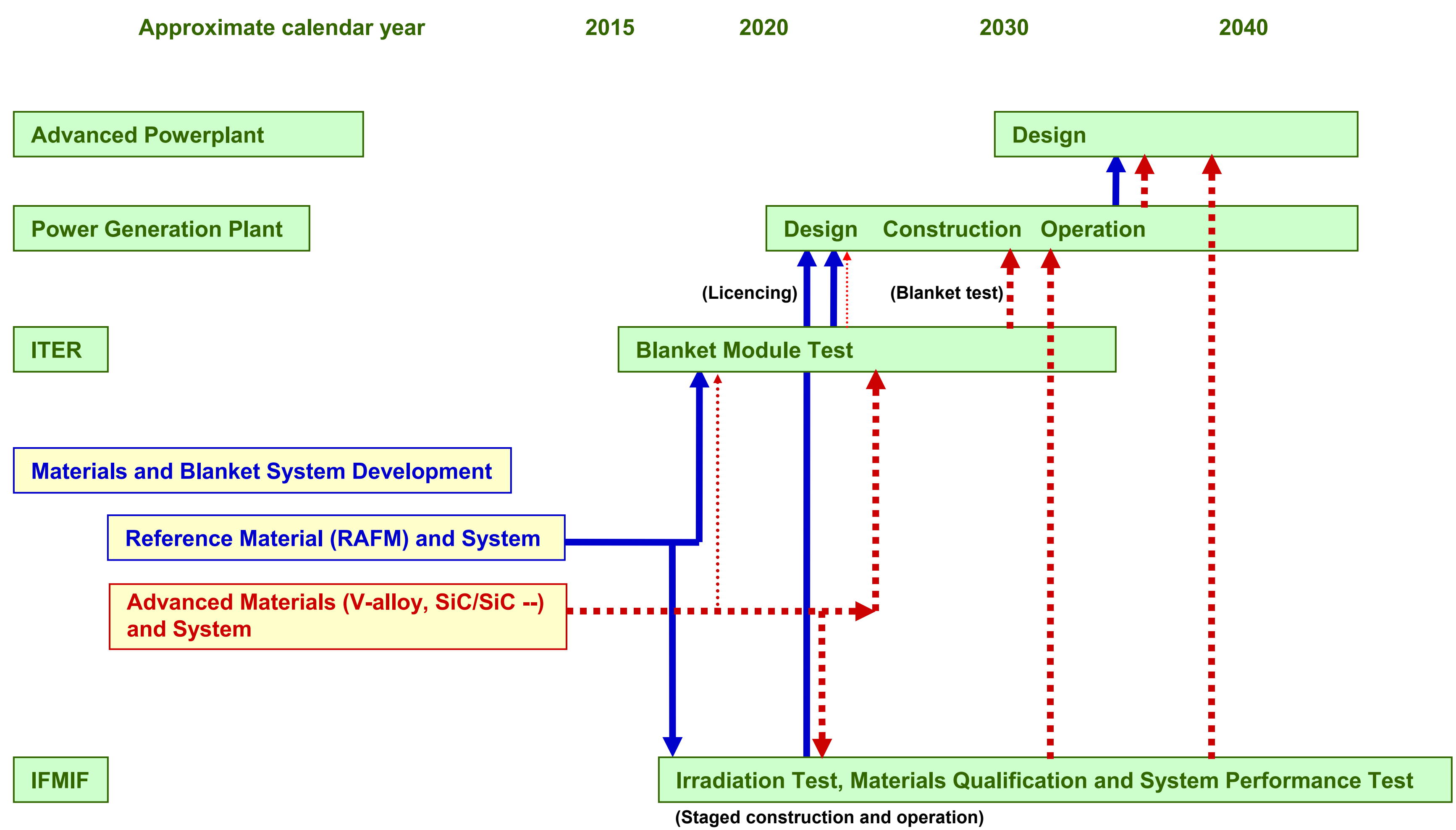
NIFS-FERC

- Li/V as a reference and Flibe as a back-up
- Support from JAERI
- First output expected in 2004

Subject	University	NIFS	Initial Activity
Thermal-structural Analysis	Hashizume Horiike Takahashi	Imagawa Nagasaka	Thermal-structural analysis MHD-reduction
Neutronics	Iguchi	T. Tanaka	T-production Nuclear Heat, After Heat, Activation
T-recovery	S. Tanaka Fukada	Suzuki	Hot trap Cold trap
Materials	Matsui Abe	Nagasaka	Design data
Flibe-module concept	Terai	Sagara	Concept exploration
Design Integration	Matui JAERI	Muroga Sagara	Reporting

Roadmap for Materials and Blanket Development in Japan (Fast Option)

NIFS-FERC



Fast Power Generation Option (Mostly JAERI responsibility)

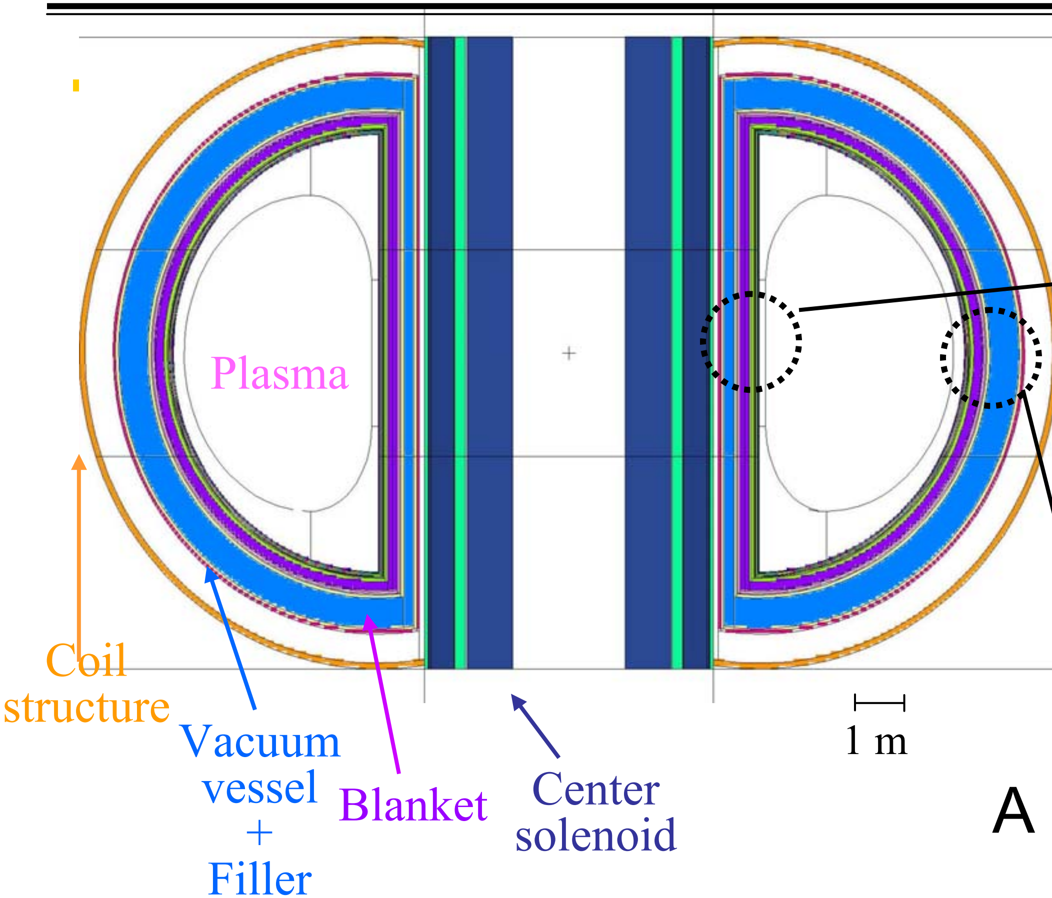
Advanced Option (Mostly NIFS/University responsibility)

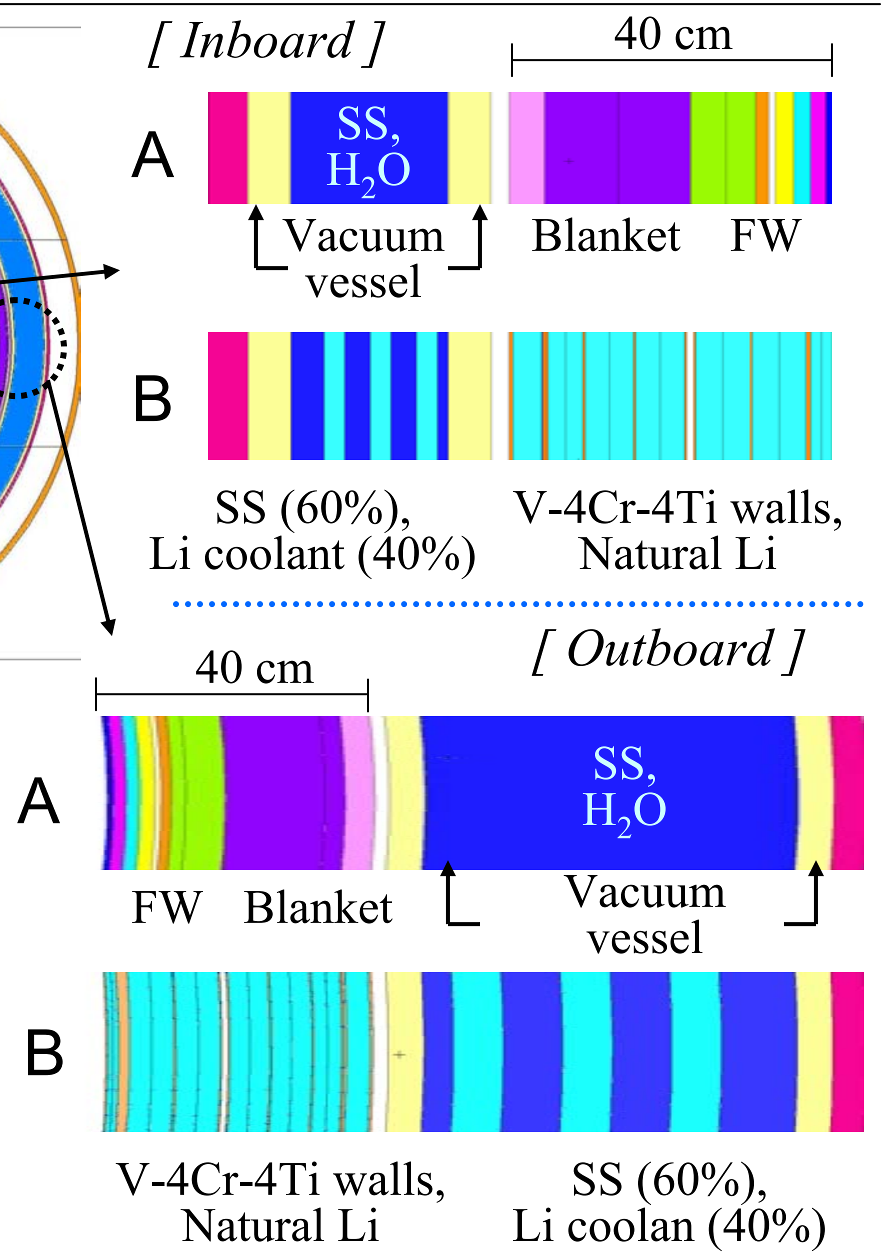
Purpose of Li/V ITER-TBM (current discussion in NIFS collaboration)

NIFS-FERC

- Feasibility of no-Be and natural Li blanket
  - Use of ^{7}Li reaction for enhancing TBR in contrast to Russian Be+^{6}Li enriched TBM
- Validation of neutronics prediction
- Technology integration for V-alloy, Li and T

ITER with Li/V self-cooled blanket - *MCNP calculation by T. Tanaka (NIFS)* -





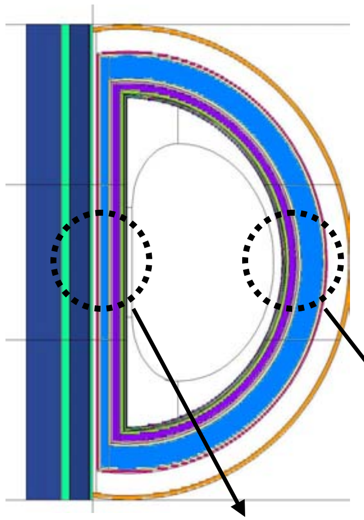
A : Standard ITEF-FEAT blanket

B : ITER with V/Li full blanket

Input geometry for MCNP calculation *

(*Dimensions from ITER Nuclear Analysis Report)

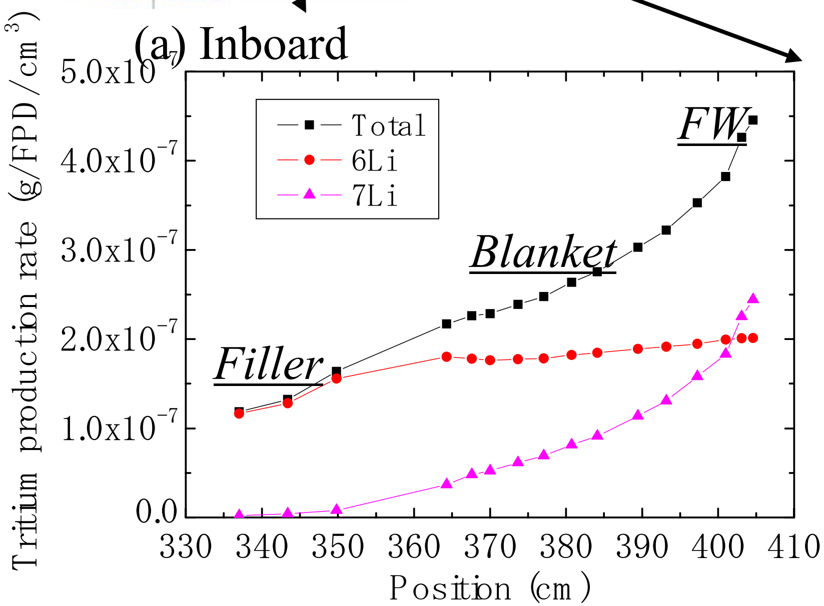
ITER with Li/V self-cooled blanket - *Local TBR* -

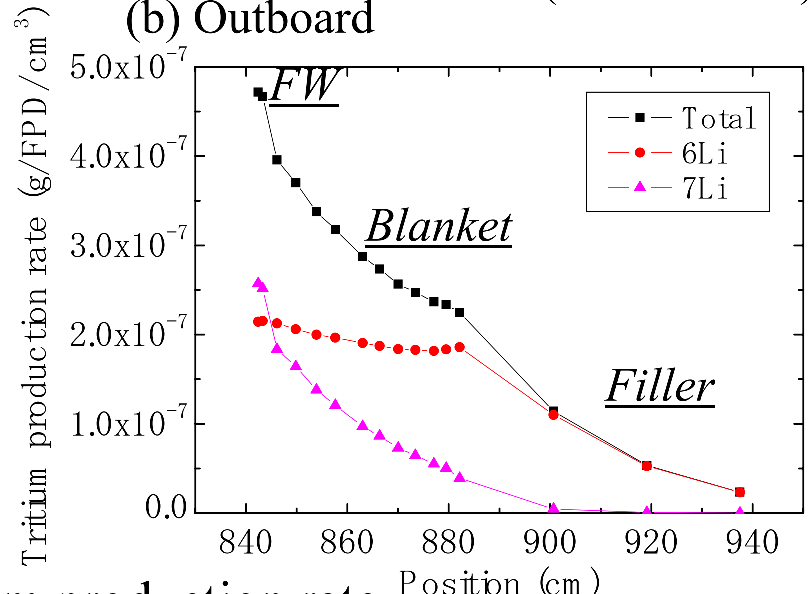


Local TBR (Full Coverage)*

	Inboard	Outboard	Total	Contribution of ^{7}Li (%)
Li/V blanket	0.30	0.92	1.22	33
Coolant in filler	0.029	0.15	0.18	2.6
Total	0.33	1.1	***1.4***	---

(* JENDL 3.2)

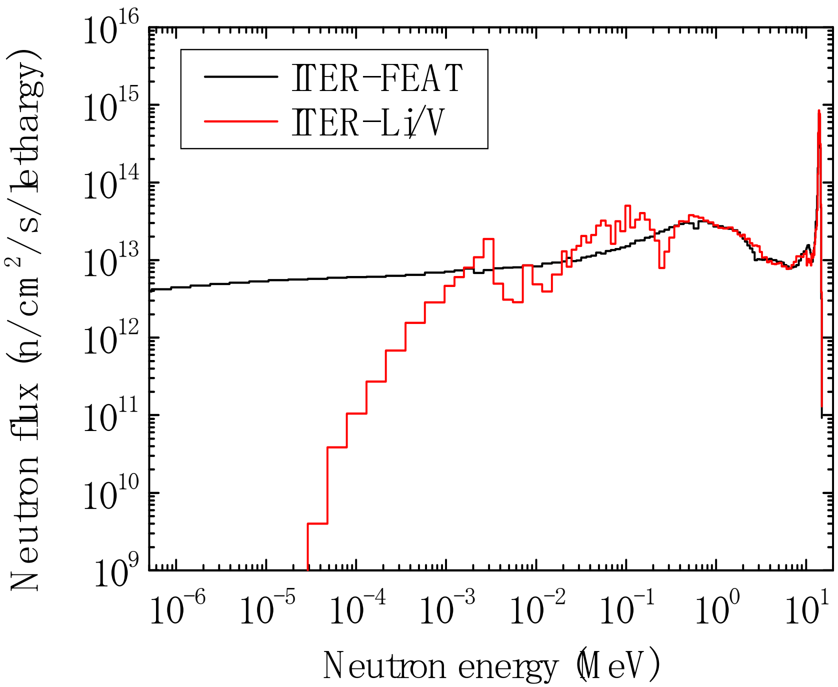




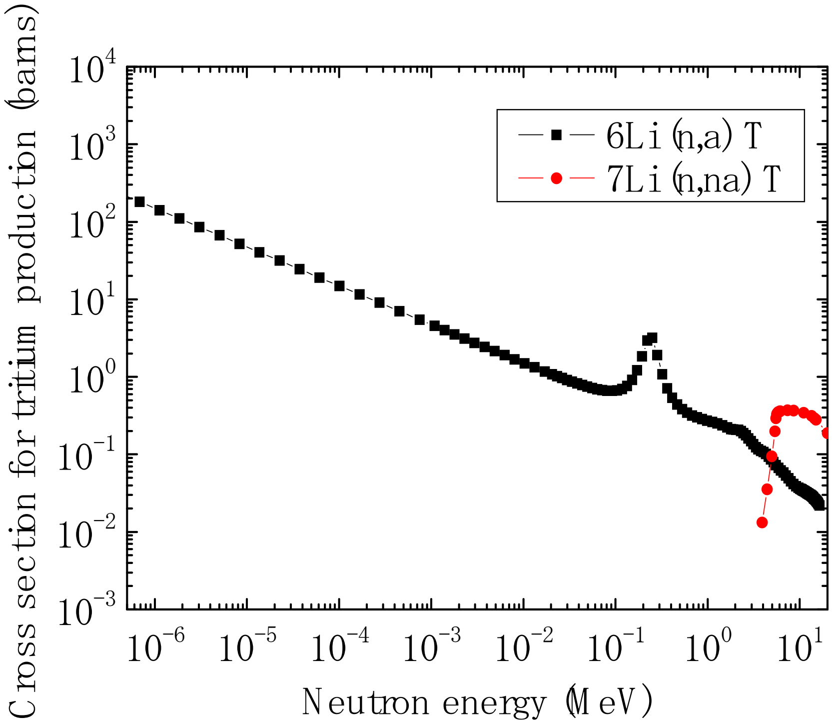
Distribution of tritium production rate

- Significant contribution of ^{7}Li to TBR

Neutron spectrum at first wall of Standard and V/Li Blanket



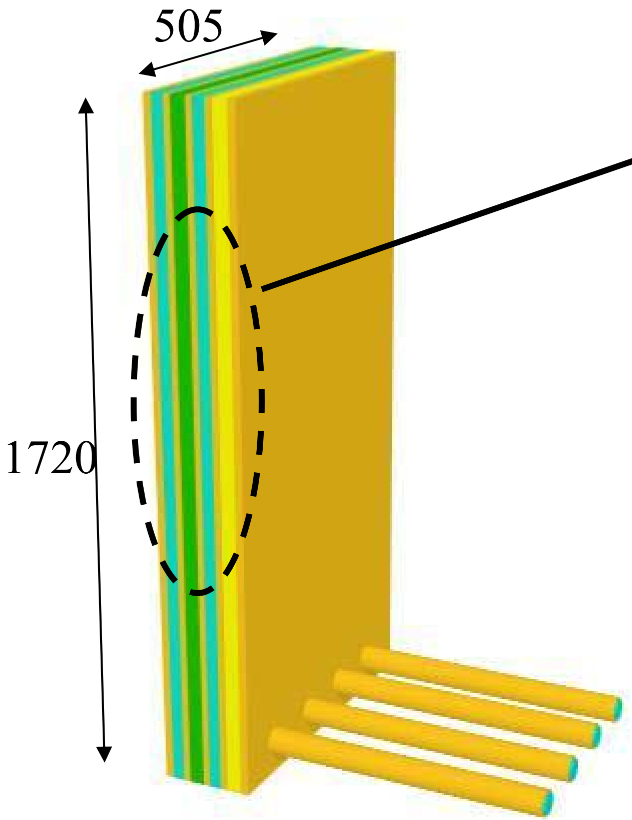
Comparison of Neutron Flux
at Outboard First Wall



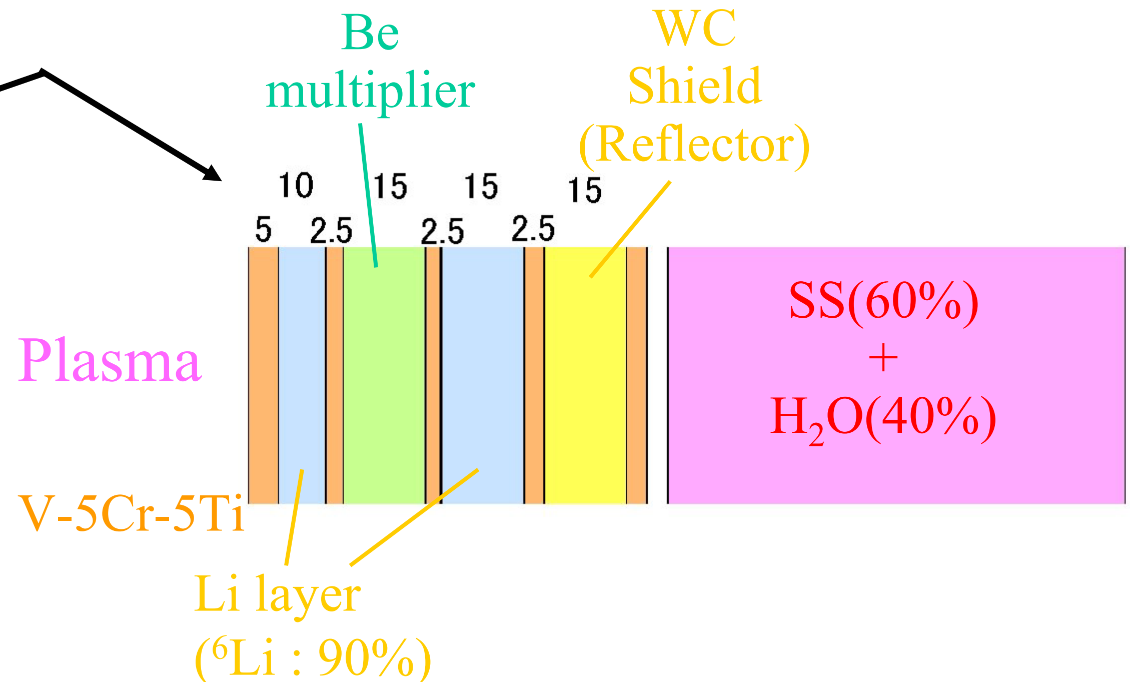
Cross Section for Tritium Production
(JENDL 3.2)

- Significant difference between thermal neutron component in ITER-FEAT and ITER-Li/V
- Thermal neutron should be shielded in the TBM area of ITER-FEAT for the purpose of simulating V/Li blanket condition

Russian Li/V self-cooled test blanket module *- Structure -*



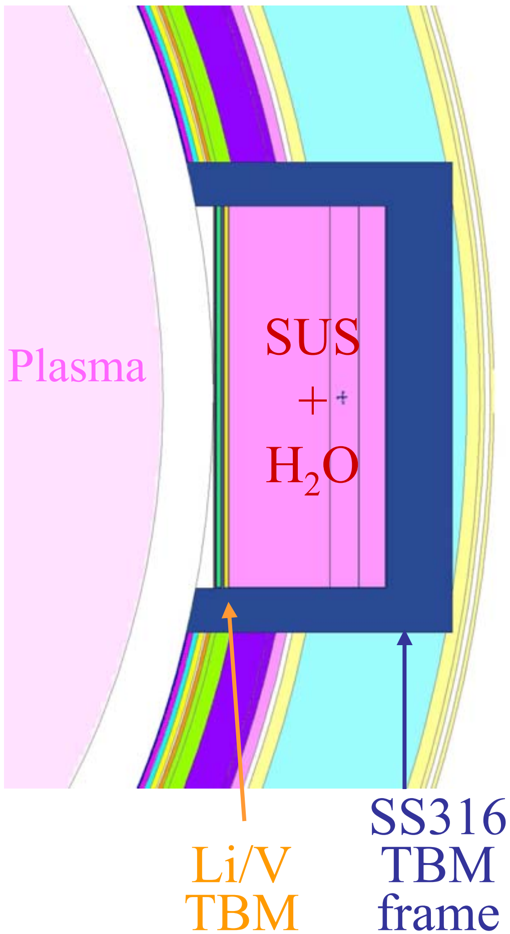
(Unit : mm)

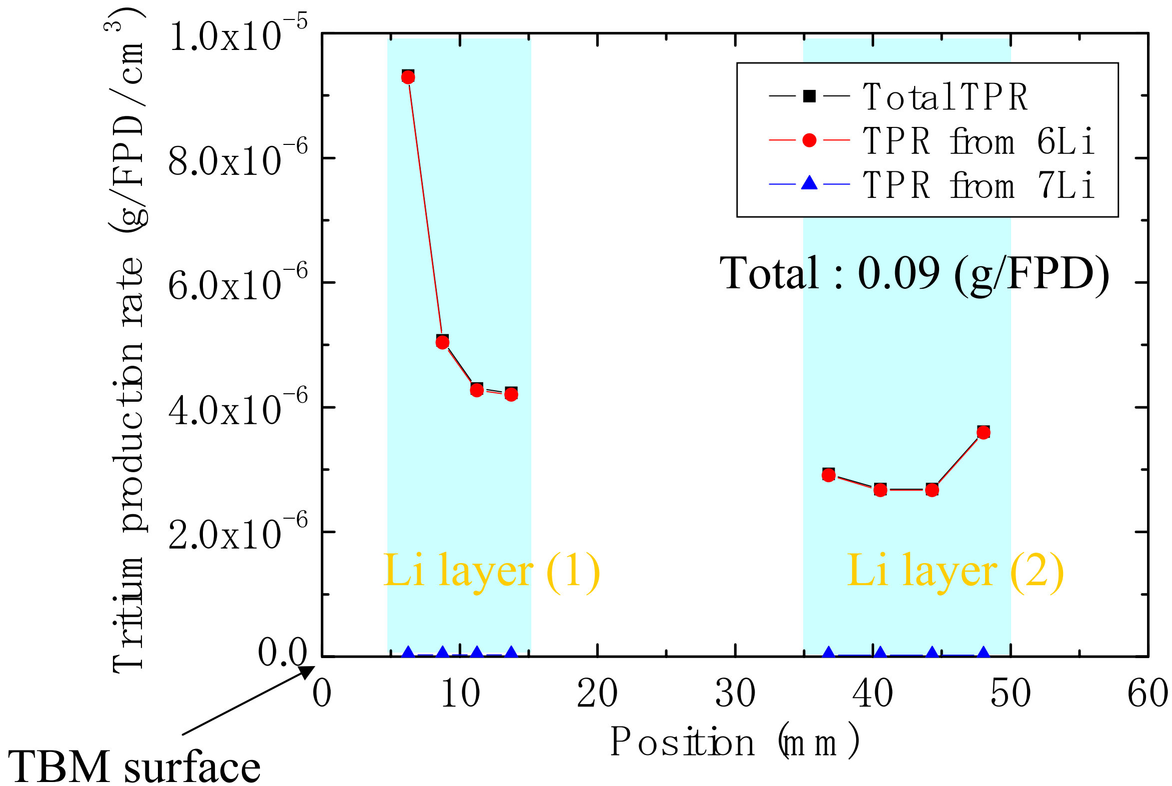


Structure of Russian Li/V TBM

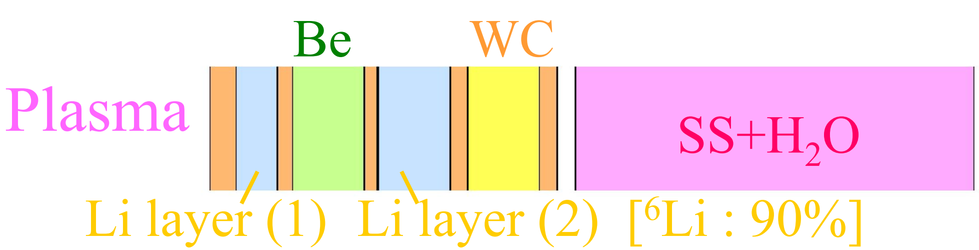
- ^{6}Li enriched coolant (7.5 % ==> 90%)
- Li layer x 2, Be multiplier ==> ^{6}Li (n, α) T
- Maximize the ^{6}Li reaction to demonstrate DEMO reactor breeding tritium by ^{6}Li

Russian Li/V self-cooled test blanket module *- Tritium production -*

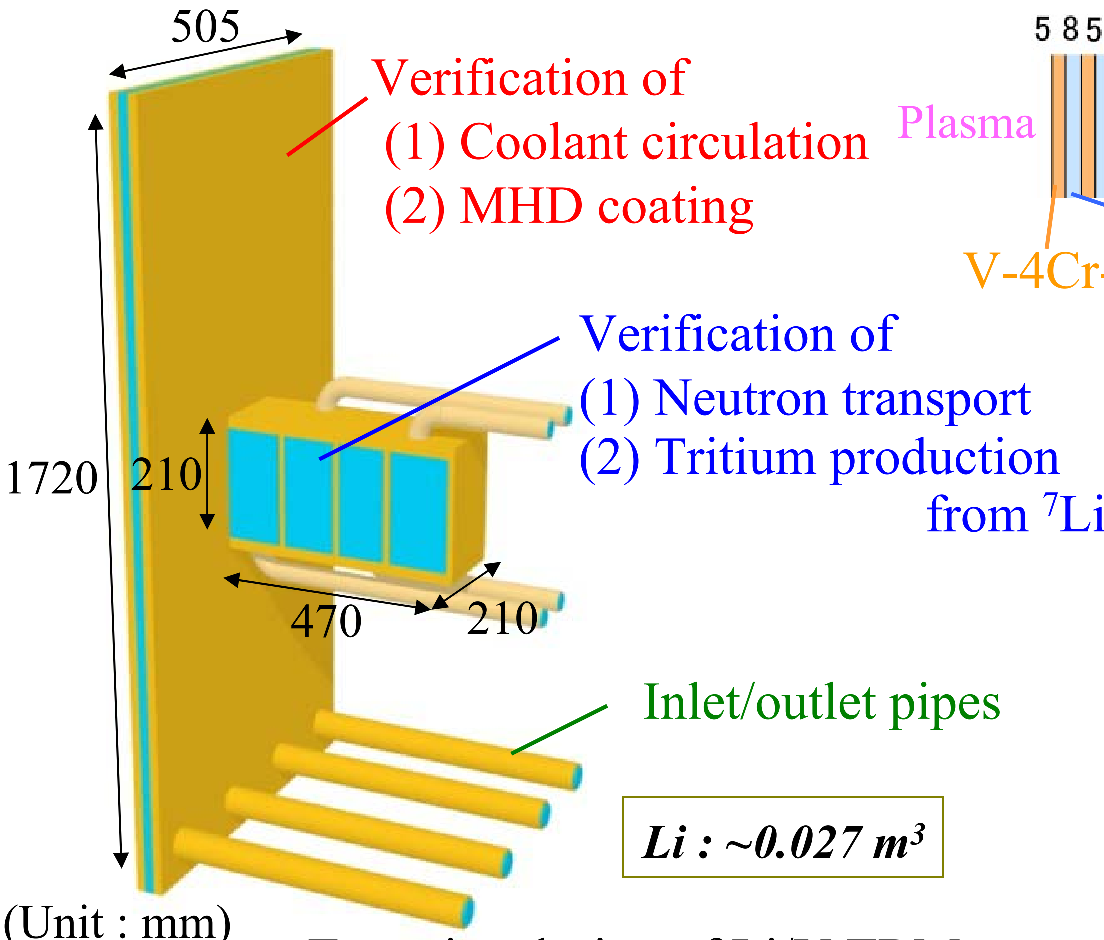




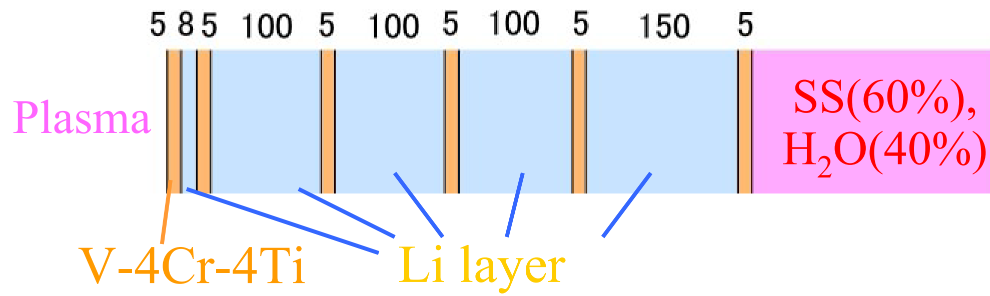
Tritium production rate in Li layers and contribution of ^{6}Li and ^{7}Li

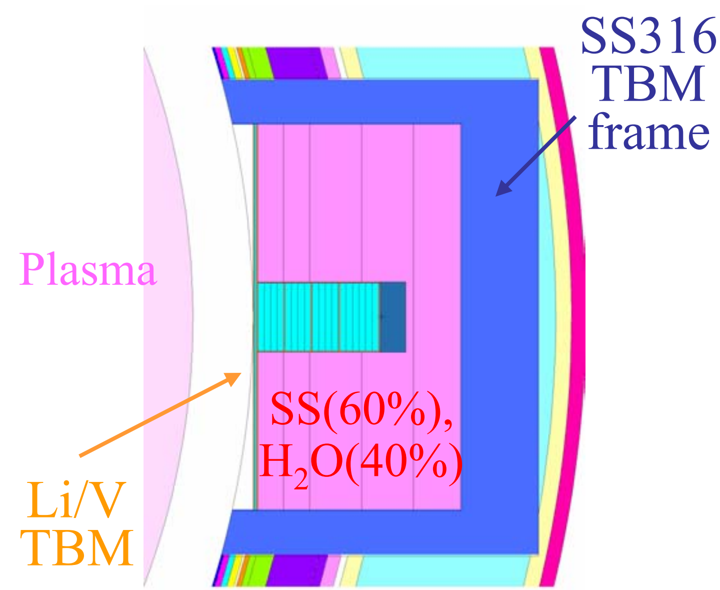


Tentative design of Li/V self-cooled TBM by NIFS/Universities



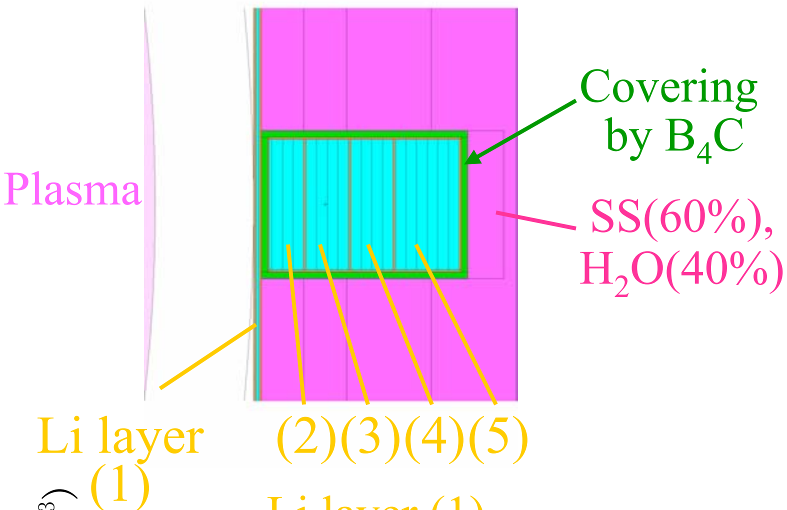
Tentative design of Li/V TBM



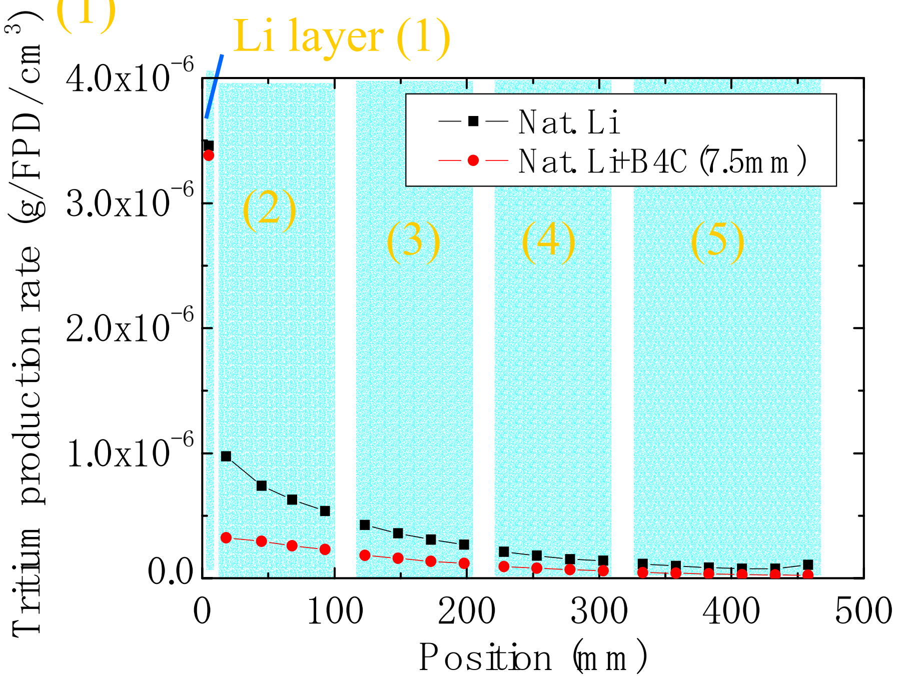


- Verification of TPR for ^{7}Li
- Thick Li tanks for verification of neutron transport

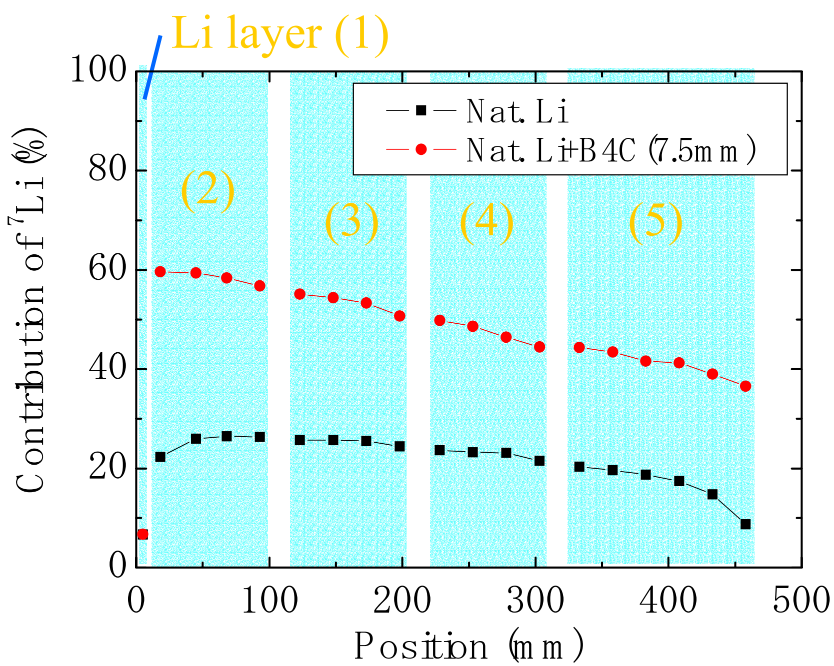
Tentative design of Li/V self-cooled TBM *- Tritium production -*



- For verification of tritium production from ^7Li (n, nα)T reaction
  - Reduction of thermal neutrons by B_4C shielding

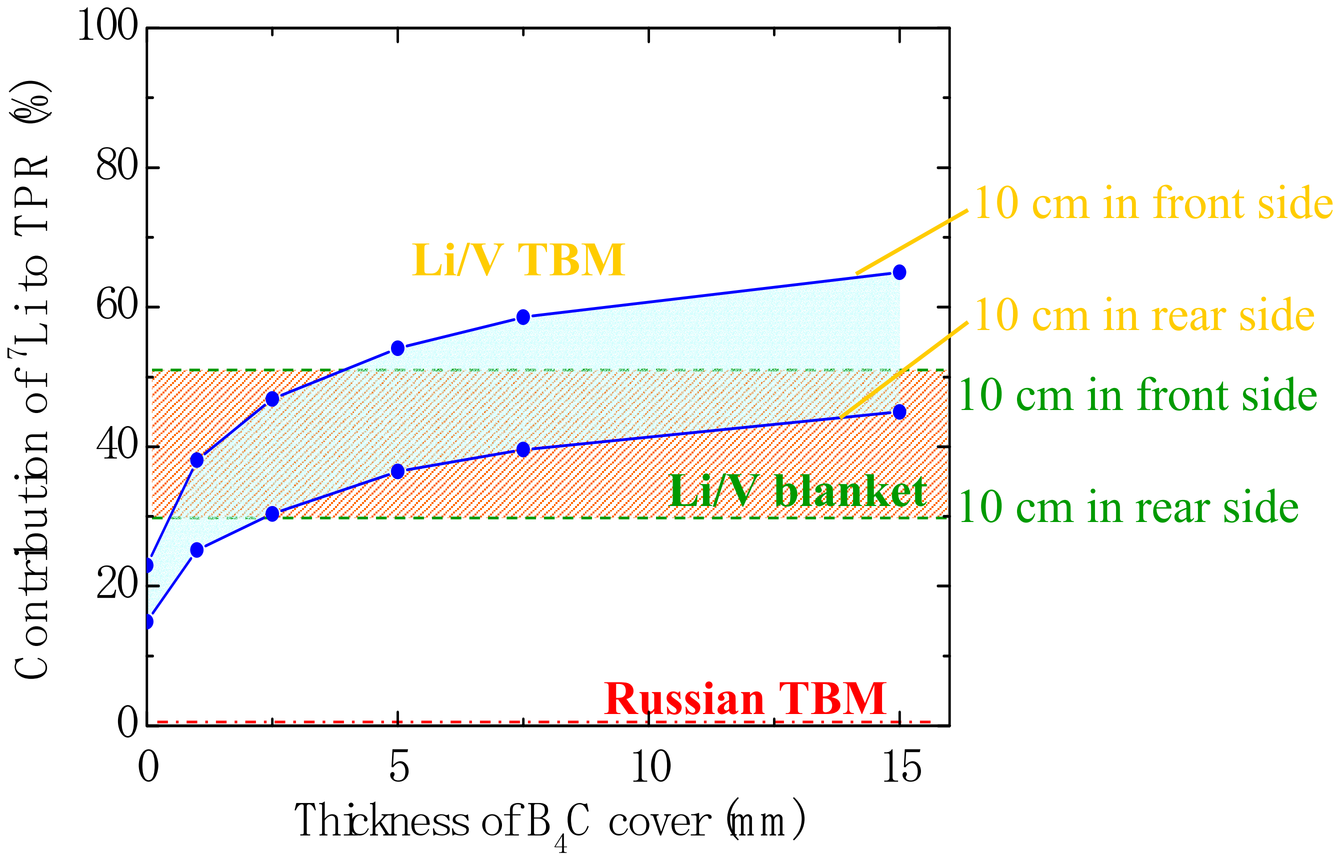


Tritium production rate in Li layers



Contribution of ^7Li to tritium production

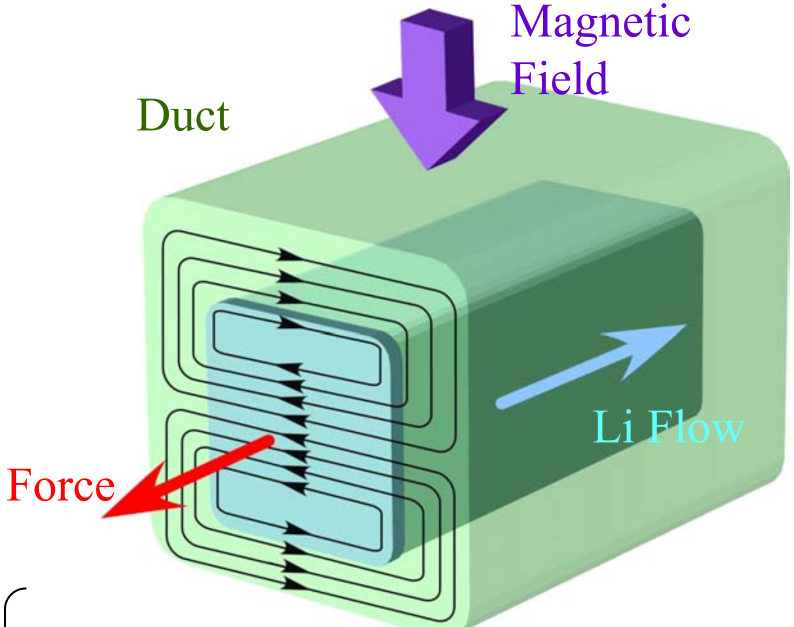
Experimental parameter for Li/V TBM *- Adjustment by B_4C shield -*



Changes in contribution of ^{7}Li by B_4C covering

- Contribution of ^{7}Li to TPR can be adjusted by thickness of B_4C shield

MHD Coating – Necessity–



Pressure Drop： proportional to

Flow length、Velocity、B^2、Duct thickness、Conductivity of Li and Duct

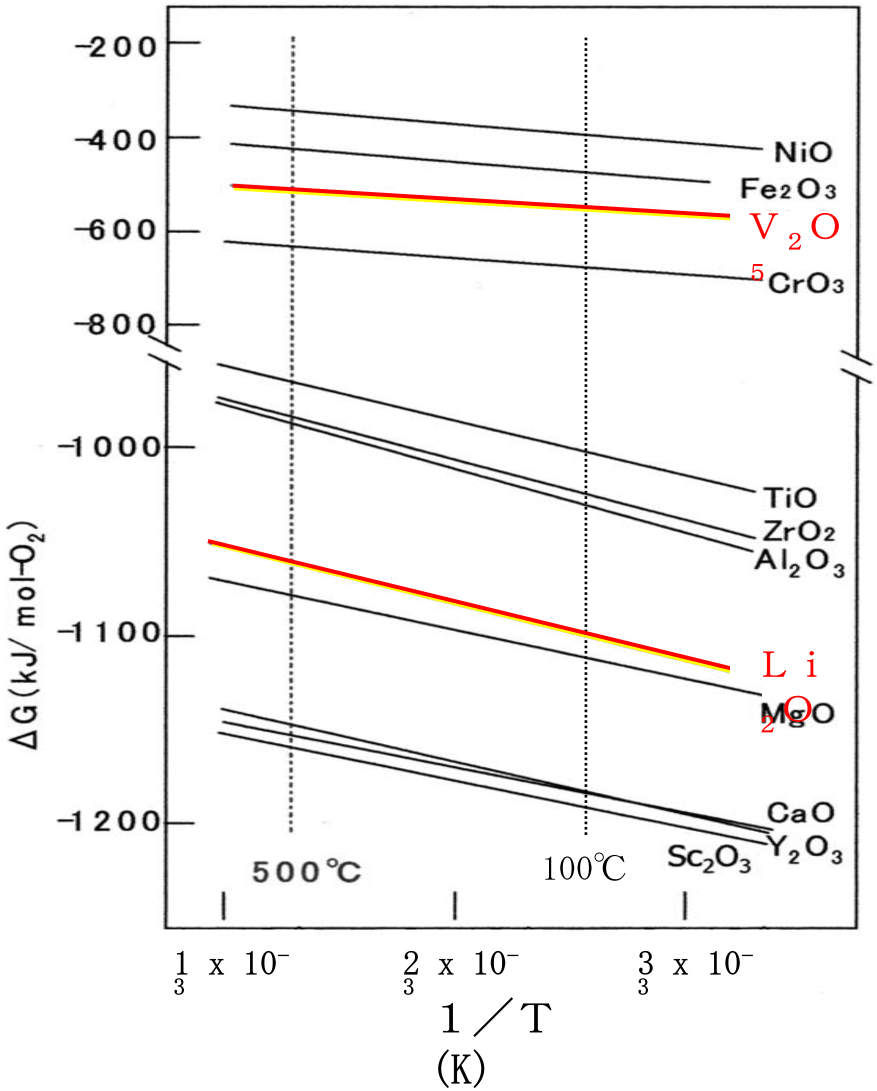
MHD Pressure Drop

・Load to pumping system

・Force to structures

Insulator coating inside the ducts a possible solution

MHD Coating Candidates (1)–Free Energy



Stable ceramics in a quite reducing condition

↓

Selection from the free energy data

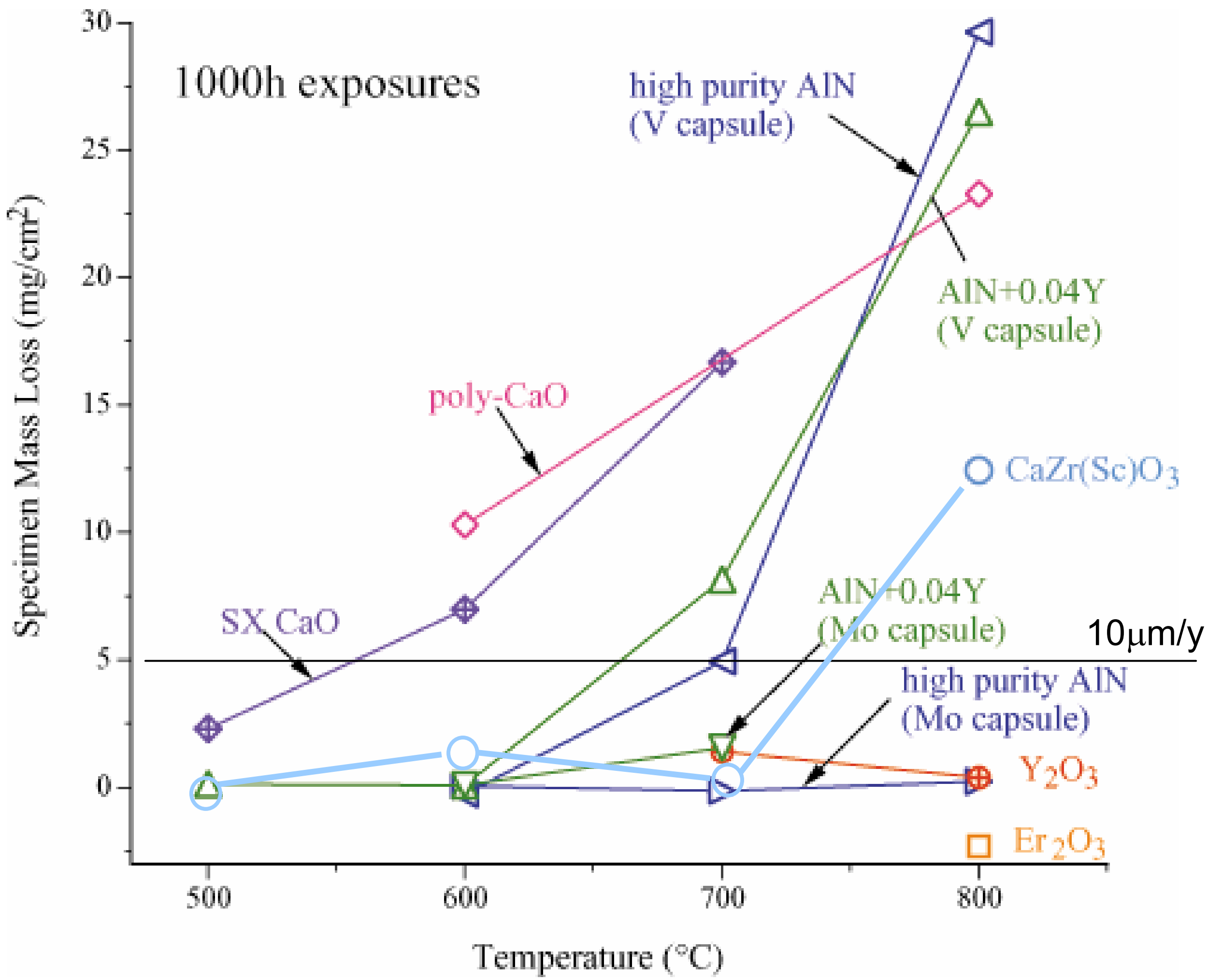
CaO、Y_2O_3、Er_2O_3、

CaZr(Sc)O_3、

AlN、BN

MHD Coating Candidates (2)– Bulk Compatibility

- Potential candidates
  - Y_2O_3
  - Er_2O_3
  - AlN with N control
  - $CaZr(Sc)O_3$ (~700C)
  - others

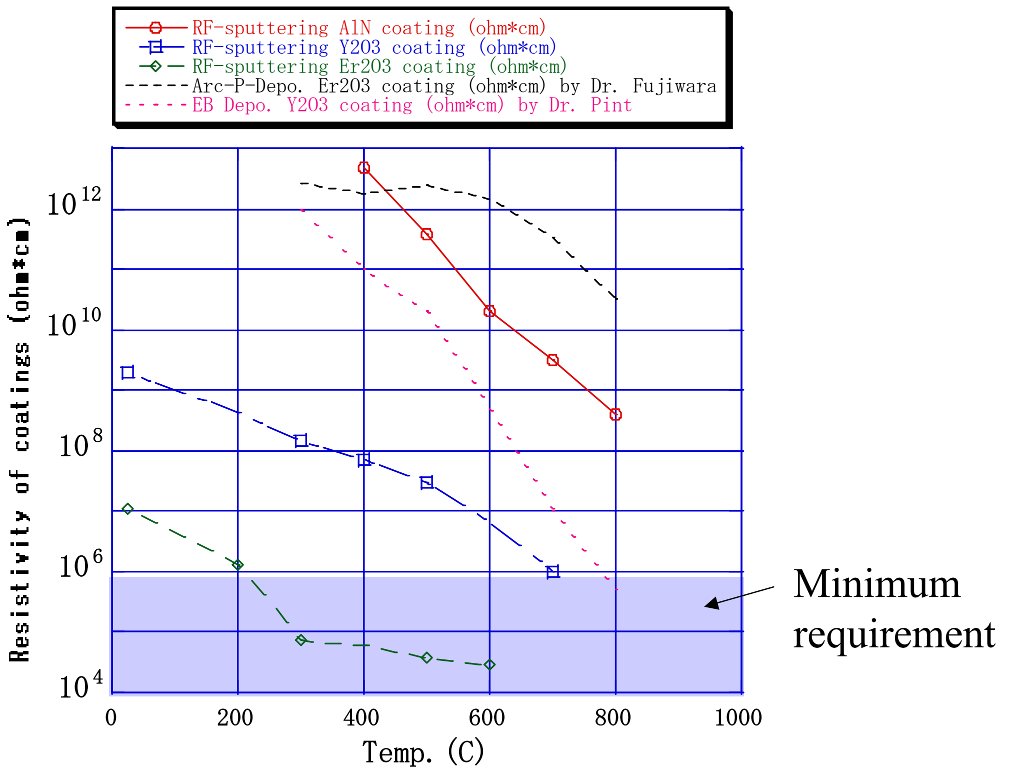


Japan-US JUPITER-II Collaboration (Pint, Suzuki et al. 2002)

MHD Coating Development
Present Efforts

NIFS-FERC

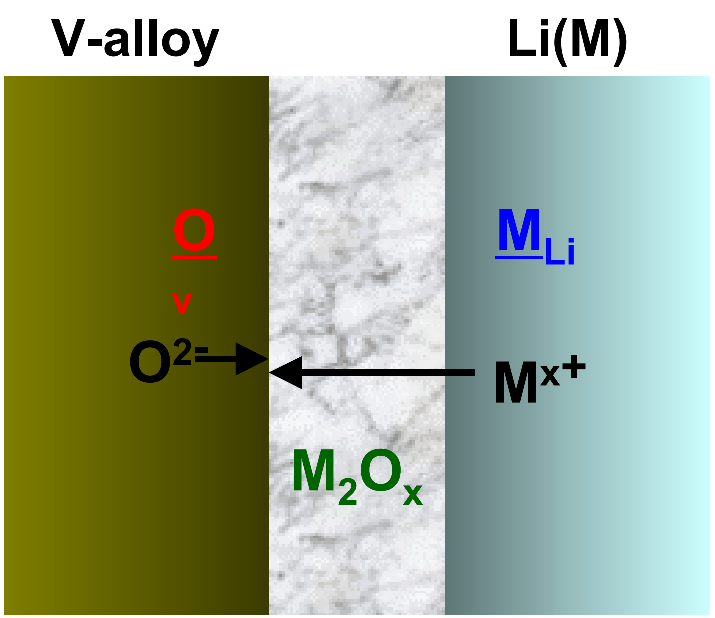
- Development of coating technology
  - RF-sputtering
  - EB-PVD
  - Arc Plasma Deposition
- Characterization of the coating
  - Resistivity
  - High temperature stability
  - Compatibility with Li
  - Radiation induced conductivity
- In-situ coating technology



Japan-US JUPITER-II Collaboration (Suzuki, Pint et al. 2003)

In-situ Coating

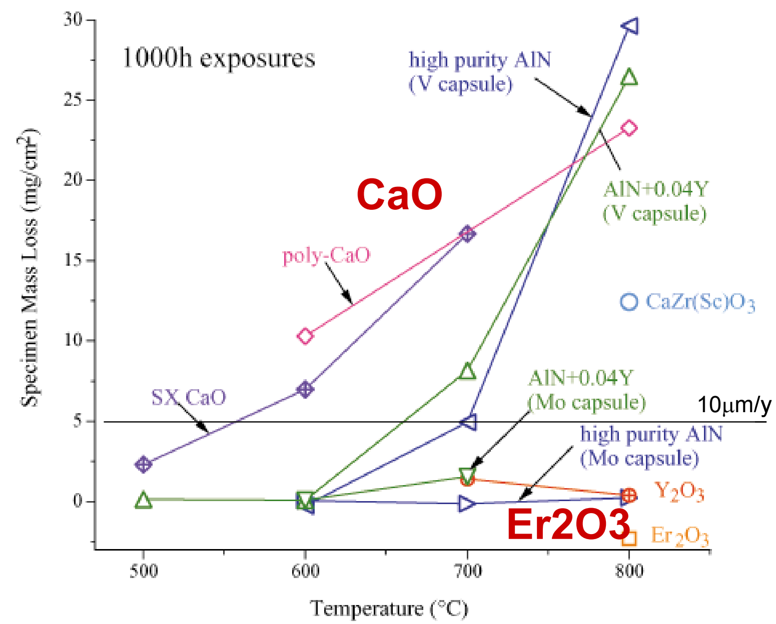
- The in-situ coating method has advantages as,
  - possibility of coating on the complex surface after fabrication of component
  - potentiality to heal the cracks without disassembling the component
  - CaO coating has been explored



Problems of the CaO Coating and New Effort on Er_2O_3

NIFS-FERC

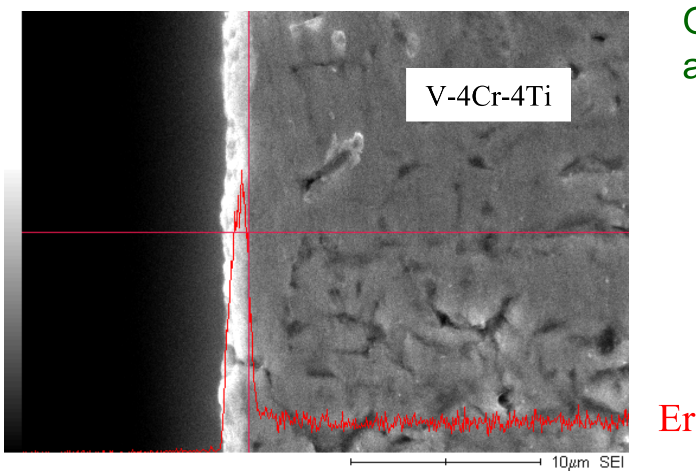
- It was found that the CaO coating, after formation, dissolved at high temperature (600, 700C)
  - CaO bulk is inherently not stable in pure Li at high temperature, continuous supply of oxygen is necessary to maintain the coating
- Er_2O_3 is much more stable at high temperature
  - It is expected Er_2O_3, once formed, be stable in Li for a long time
  - Er_2O_3 is stable in air, combination of dry-coating and in-situ coating is more feasible



In-situ Er_2O_3 Coating on V-4Cr-4Ti

NIFS-FERC

- Er_2O_3 layer was formed on V-4Cr-4Ti by oxidation, anneal and exposure to Li (Er) at 600C
- The coating was stable to 300 hrs
- The resistivity was ~10^{13} ohm-cm



Yao. 2003

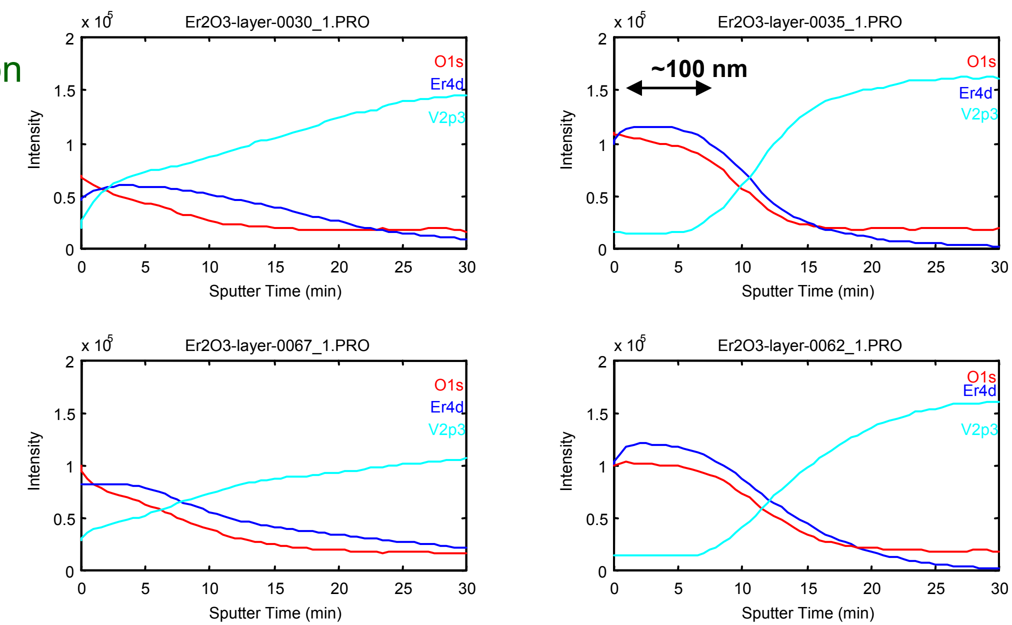
Oxidation at 700C

Oxidation only

Oxidation and anneal at 700C for 16 hr

6 hr

1 hr



XPS depth profile after exposure to Li (Er) at 600C for 100 hr

Need for Collaboration with Design People

NIFS-FERC

- Requirement to the coating performance depends strongly on the design
  - System design is necessary to quantify the requirement to the coating
  - Clever design would make the requirement lenient
- New idea of coating will be obtained by collaboration with design
  - Laminar coating structure, etc.

Meeting Summary for Crack Fraction Allowance for the MHD Coating (Sze Aug.03)

NIFS-FERC

- For a single pipe, with a perfect insulating coating, the allowable crack fraction was <u>≤10(-7)</u>
- For a real coating, 10(-2) is achievable, while 10(-4) might be achievable.
- If we start with a poor coating, the allowable fraction can be higher, maybe 10(-4), with a higher MHD pressure drop.
- There are other ways to increase the allowable crack fraction, such as change the aspect ratio of the channel, change the boundary conditions of the flow channel.
- The boundary condition of the flow channel, such as the contact resistance between the fluid and the wall, may have major impact on the crack fraction.
- The change of the designs may have major impact on the crack allowance.

Impact of Sze Summary on the Coating Development in Japan

NIFS-FERC

- Experimental examination of the resistance between the (flowing) Li and the wall covered with cracked coatings at high temperature is of high priority.
- The goal of the in-situ healing may be set to increase the resistivity of cracked area from complete conduction by <u>4 order of magnitude</u>

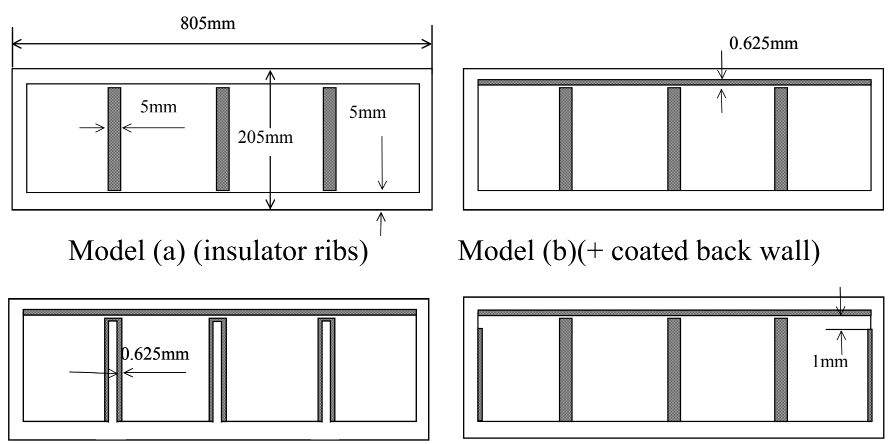
    Allowable crack fraction : 10(-7)

    Realistic crack fraction : 10(-3)
- Increased collaboration between materials and design people in Japan

Design Effort to Reduce Requirement to the Coating

NIFS-FERC

- Optimization of channel structure for reducing the requirement to the coating
  - Coating may be necessary only on limited flat surfaces
  - Insulator ribs may be inserted instead of coated ribs/walls
- Other suggestions on laminar coating structure, enhanced heat transfer, etc



Model (a) (insulator ribs)

Model (b)(+ coated back wall)

Model (c)
(coated ribs and back wall)

Model (d)
(+ coated end ribs)

(unit : kPa/m)

$\sigma_{insulator} / \sigma_{HT-9}$	1	10^{-3}	10^{-6}	10^{-9}
Ideal case of (c)	339	49.1	2.12	0.49
Model (a)	339	60.5	53.4	58.4
Model (b)	339	58.7	6.88	1.01
Model (c)	339	127	9.95	1.01
Model (d)	339	48.1	6.68	1.02

(Hashizume)

Summary

NIFS-FERC

- Collaboration by Materials, Blanket and Design people are increasing on V/Li system in Japan
  - Progress in developing vanadium alloys toward engineering maturity
  - Enhanced Li technology by IFMIF-KEP
  - Increased accessibility for the liquid blanket people to ITER-TBR
  - Collaboration on MHD-coating development by materials and design people
- One of the goals of the collaboration is to propose V/Li ITER-TBM
- The collaboration is enhancing research for other advanced blanket systems (Flibe --)
- The collaboration covering Material, Blanket and Design people in the US will accelerate the progress, and should be enhanced in the framework of JUPITER-II