Materials for spallation sources
-topics from IWSMT-

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(October 20, 2009)

A short pulse spallation neutron source in mercury target

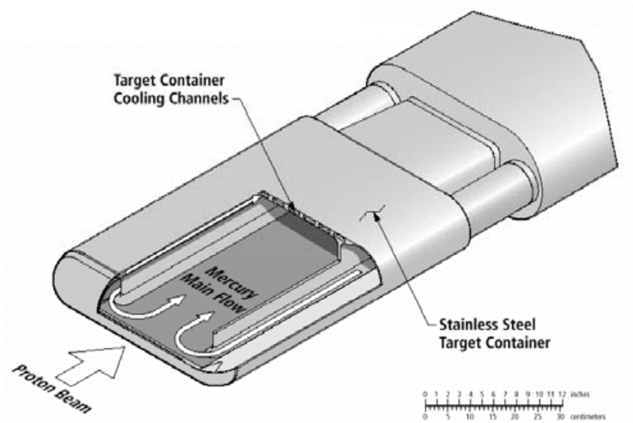
- ASTE[ORNL,JAERI,ESS,LANL]
- Exp. at AGS/BNL, pressure wave and particle transport in 1997.
- Pressure wave exp. at WNR/LANL in 2001.
- US-SNS operating from 2006/4月, now 1MW.
- J-PARC MLF operating from 2008/12, now 0.02 MW
- ESS canceled in 2004, and revises mercury or rotating W target in 5MW/2mA.

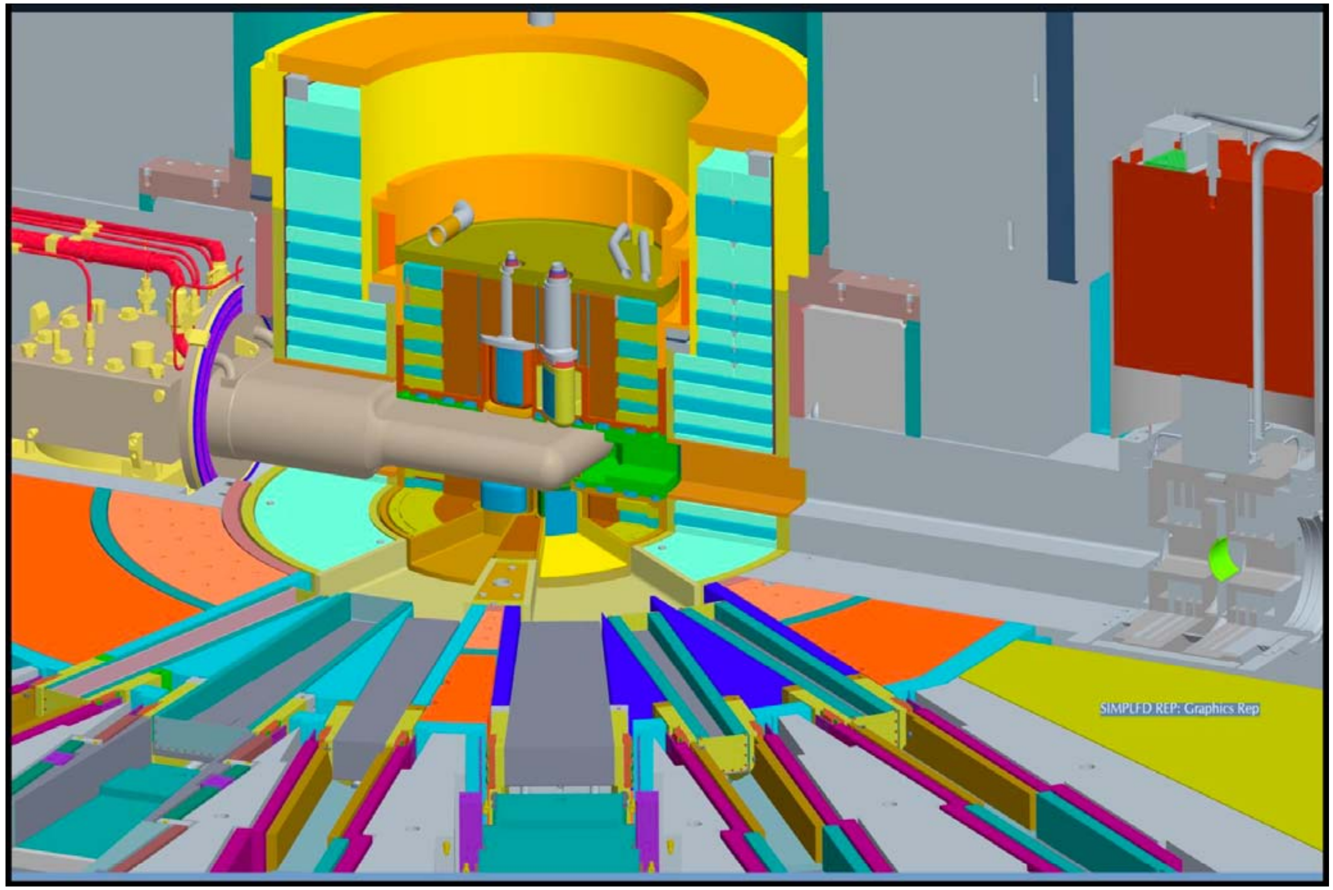
Liquid Metal Targets: Candidate Materials

Property		Pb	Bi	LME *	LBE**	Hg
Composition		elem.	elem.	Pb 97.5% Mg 2.5%	Pb 45% Bi 55%	elem.
Atomic mass A (g/mole)		207.2	209	202.6	208.2	200.6
Linear coefficient of thermal expansion (10^{-5} K^{-1})	solid	2.91	1.75			
	liqu. (400°C)	4		4		6.1
Volume change upon solidification (%)		3.32	-3.35	3.3	0	
Melting point (°C)		327.5	271.3	250	125	-38.87
Boiling point at 1 atm (°C)		1740	1560			356.58
Specific heat (J/gK)		0.14	0.15	0.15	0.15	0.12
Th. neutron absorpt. (barn)		0.17	0.034	0.17	0.11	389

* Lead magnesium eutectic ** Lead bismuth eutectic

SNS Hg target, 1GeV, up to 2WM / ORNL





SS316L.. the liquid mercury target vessel and water-cooled shroud

McManamy, ORNL

SNS Hg target, 3GeV / J-PARC

SS316L:Target & Helium vessels

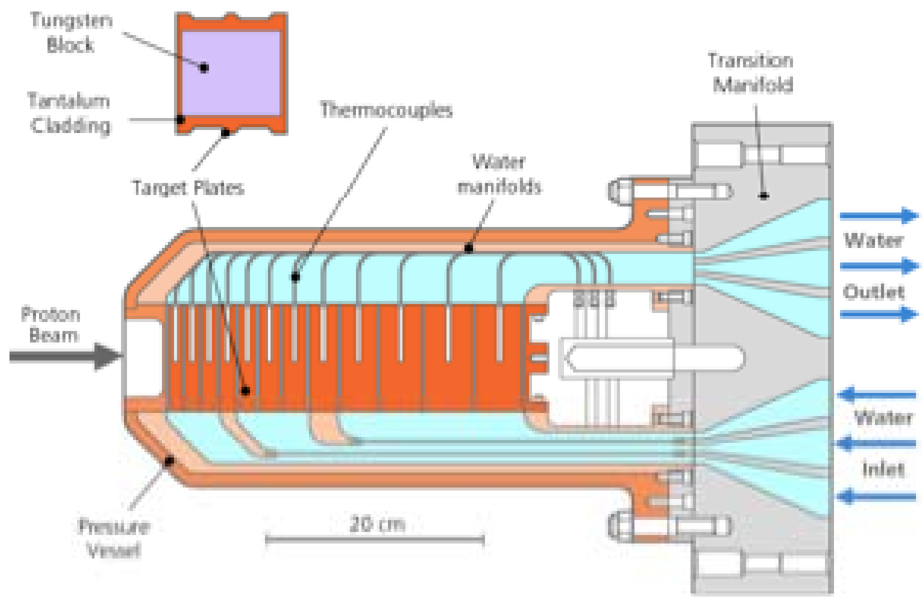
Oyama, J-PARC

Solid target

- U high neutron yield but difficult to handle
- W erosion under high speed water flow
- Ta decay heat, brittle or ductile?
- Au ?
- Pt ?

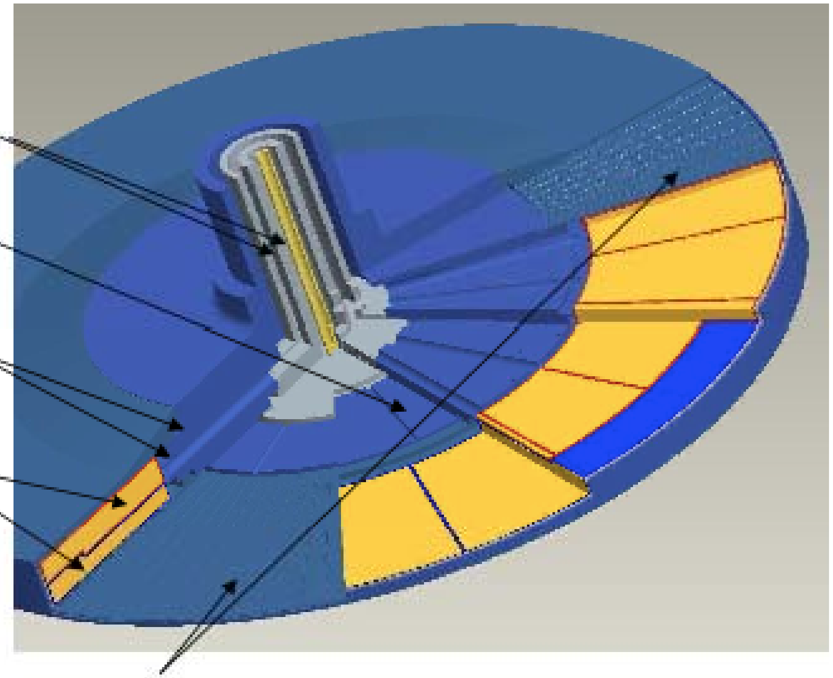
ISIS, Rutherford Appleton Laboratory

- Design for 800 MeV, 200μA
- Target types
  - Zircalloy-2 clad U-238
  - Tantalum
  - Tantalum clad W
- In operation since 1984
- Have highly developed remote handling capability



www.isis.rl.ac.uk/accelerator-2006

Target Module



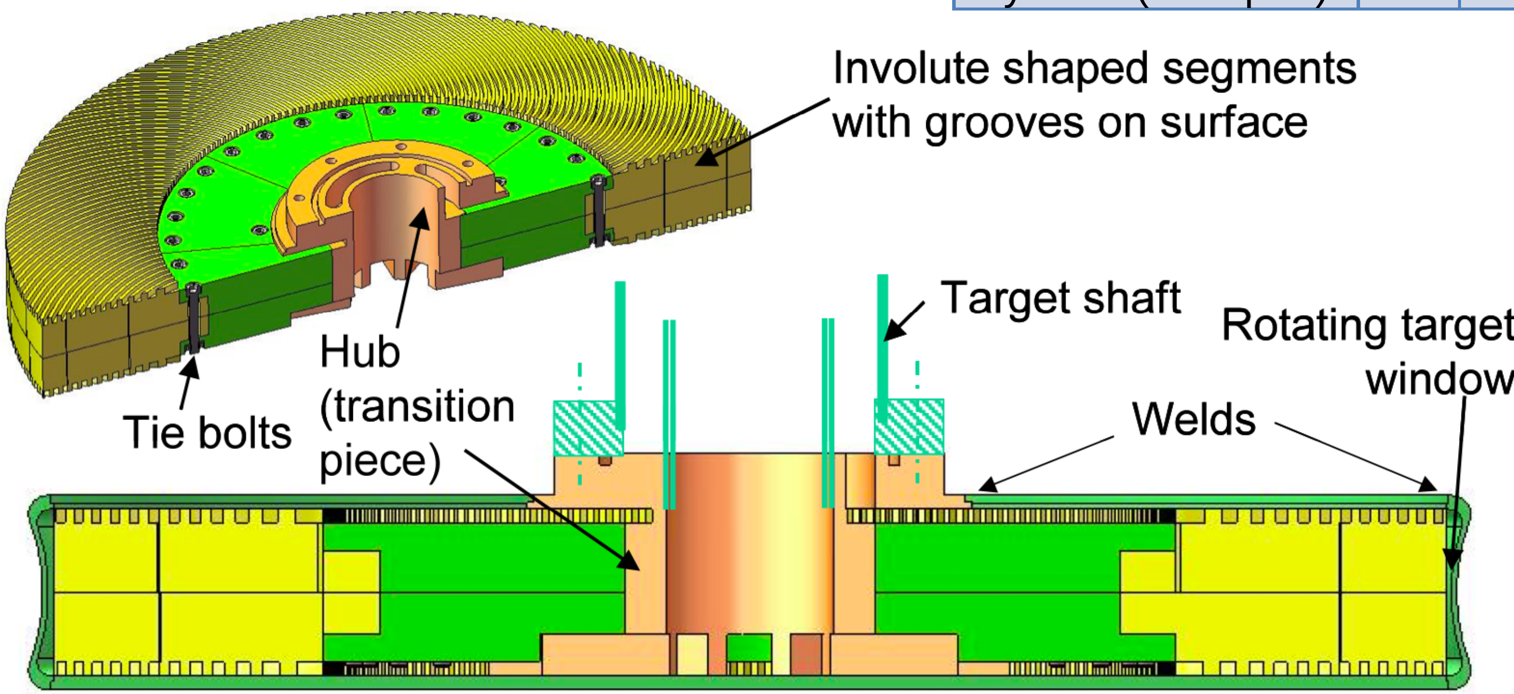
- **The target module includes the clad segments, shroud and axle.**
- **The joint between the target and drive modules must be very precise. This joint also includes a significant water seal assembly.**
- **Concentric pipes inside the axle will require differential thermal expansion capability.**

McManamy, ORNL

Conceptual Solution for the CSNS Rotating Target Disk

Xeujun, CSNS

Parameter		Early operation	Upgrade option
General			
Proton energy	MeV	1600	1600
Beam power	kW	120	500
Power deposited in target	kW	50.00	210
Target			
Outer diameter of cylinder	cm	50.00	50
Full height of cylinder (solid part)	cm	5.00	5

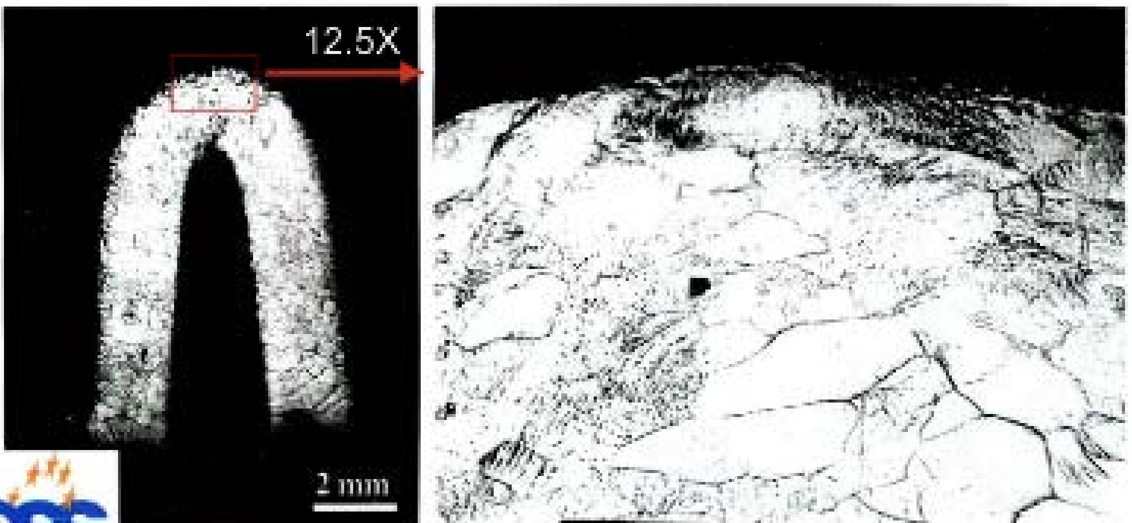


W

$AlMg_3$

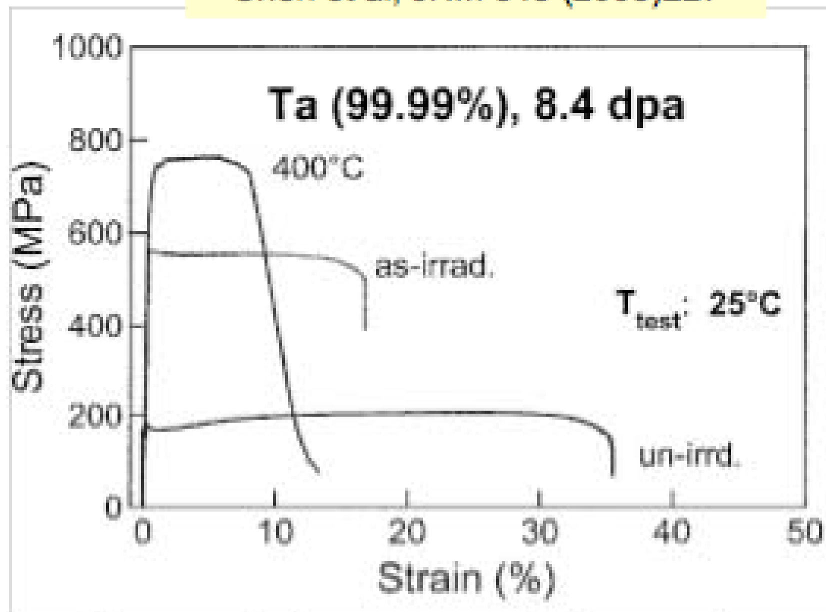
Spent ISIS Target: The Tantalum Puzzle

Side view of a bent Ta specimen from an ISIS target irradiated to 13 dpa with 800 MeV protons

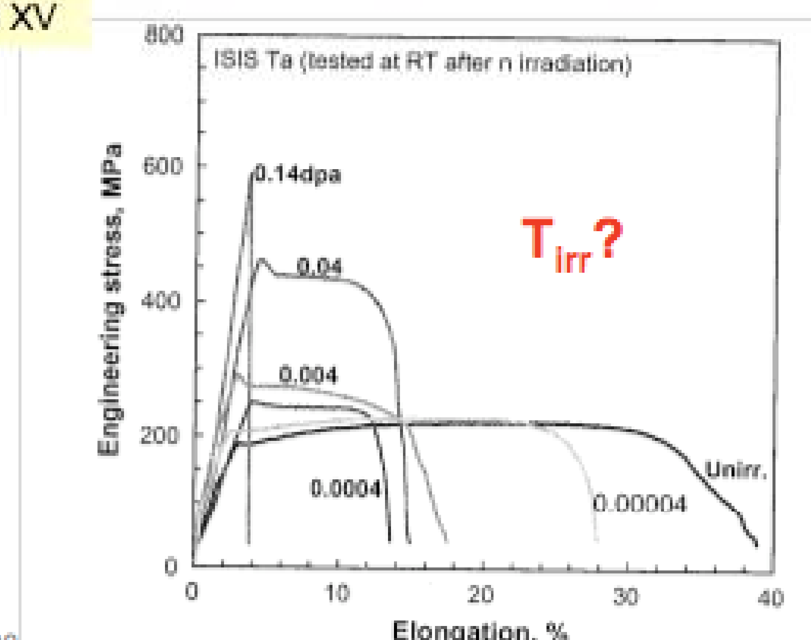


ICANS XV

Chen et al, JNM *343* (2005)227



Stress-strain curves of Ta specimens from an ISIS-target tested at a strain rate of 10^{-3}/s



Engineering stress-strain curves for ISIS Ta at room temperature after neutron irradiation

TS Byun and SA Maloy JNM *377* (2008) 72

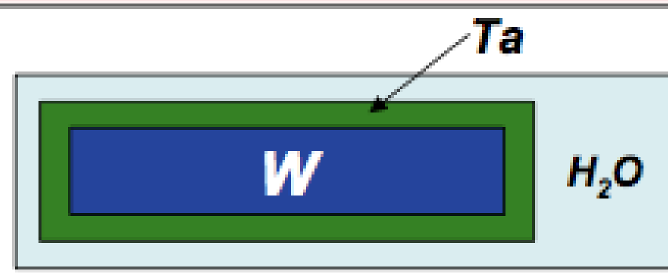
Cladding of LANSCE Tungsten Neutron Scattering Target with Tantalum

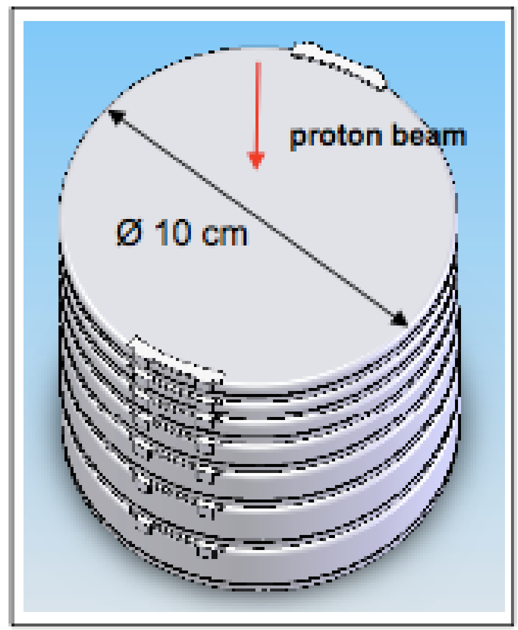
Manuel Lujan Jr.
Neutron Scattering Center
LANSCE

- Tungsten target 'pucks'
- Light water coolant
- Tantalum cladding

Plans underway to Clad MLNSC Target with Ta

- Main reason is to reduce activity for the water cooling system
- Initial HIP bonding tests at 1500C were successful
- Plan to have new targets fabricated by March 2009





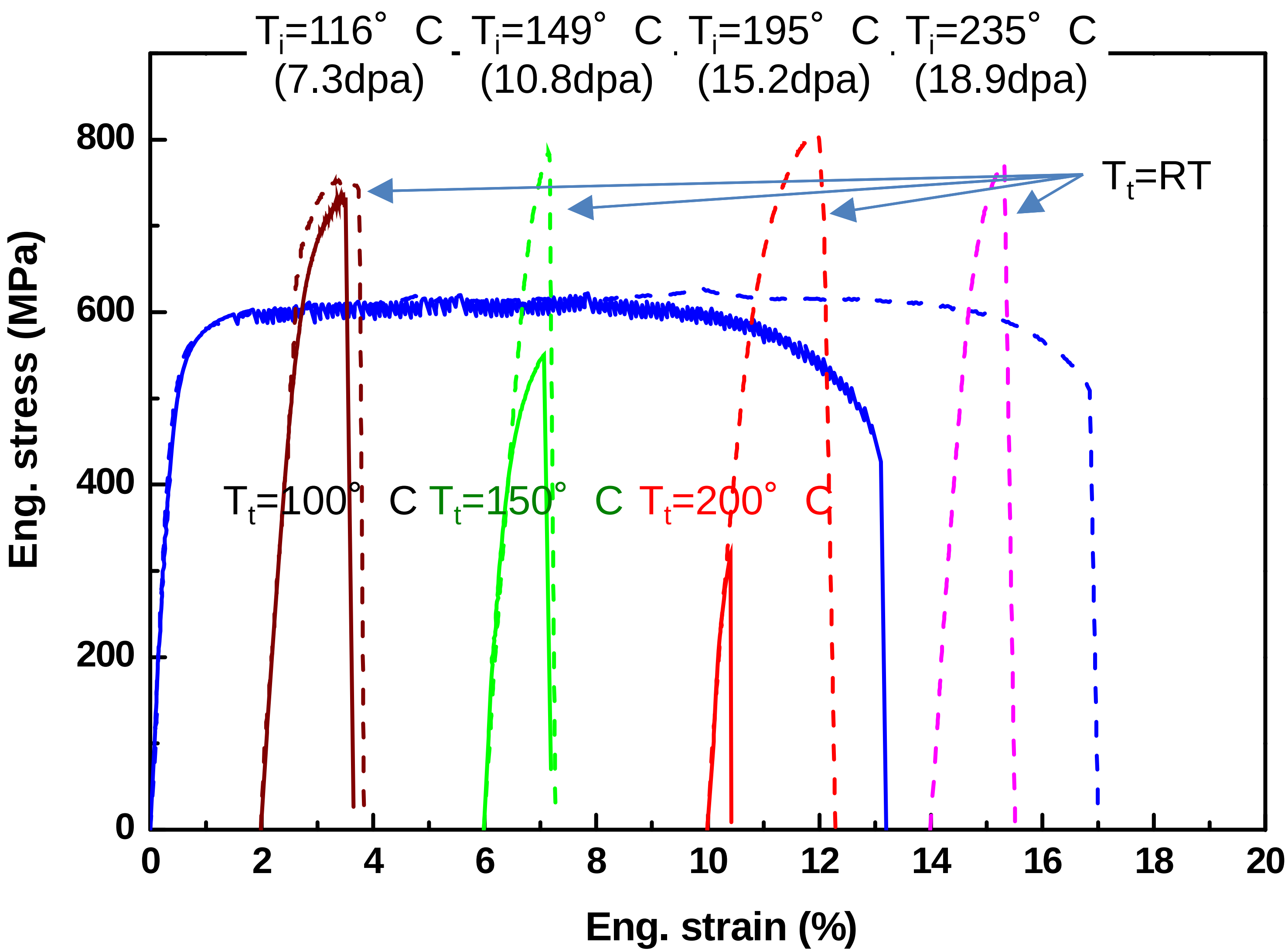
Maloy LANL

Los Alamos
NATIONAL LABORATORY
EST. 1943

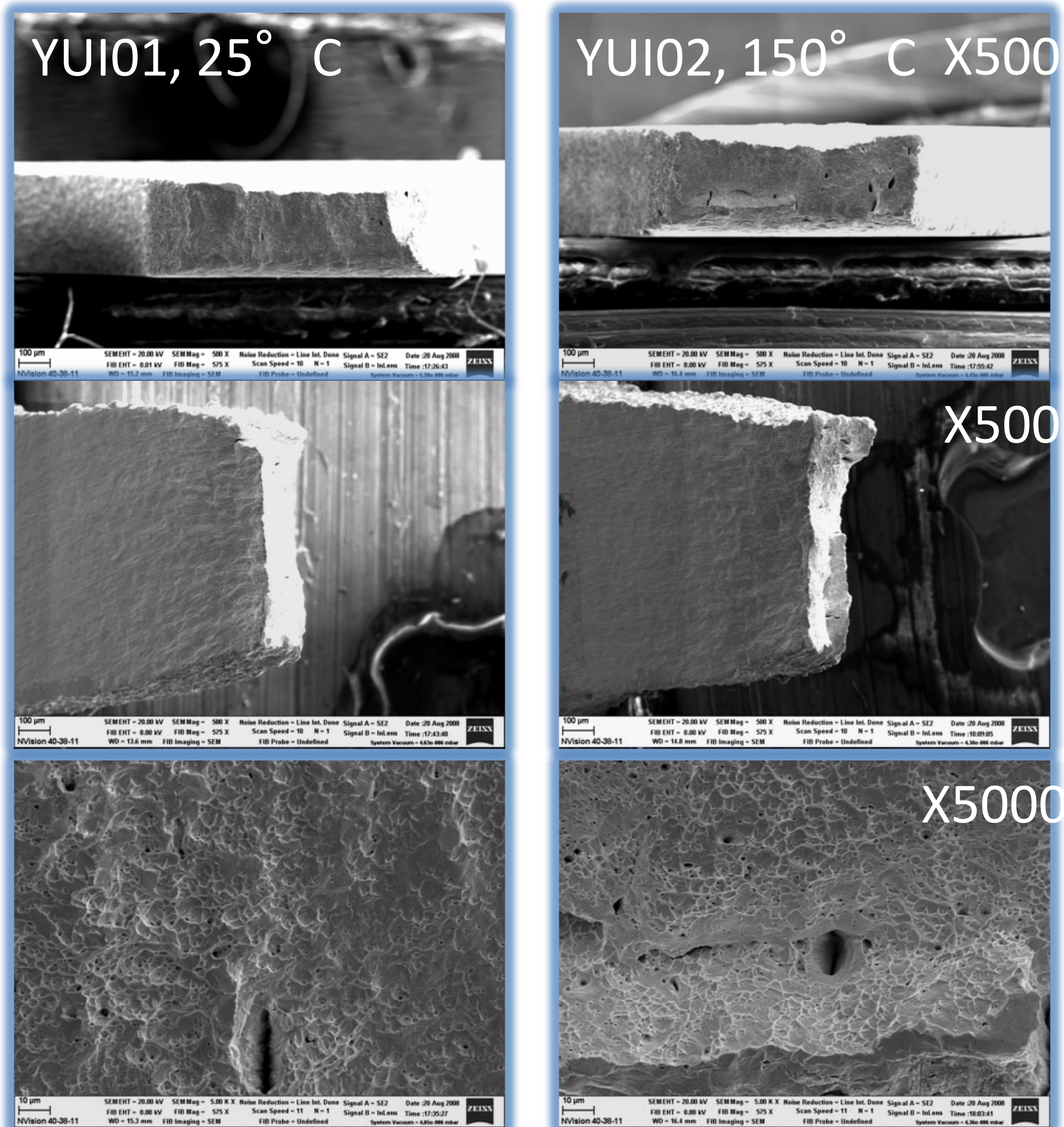
NNSA

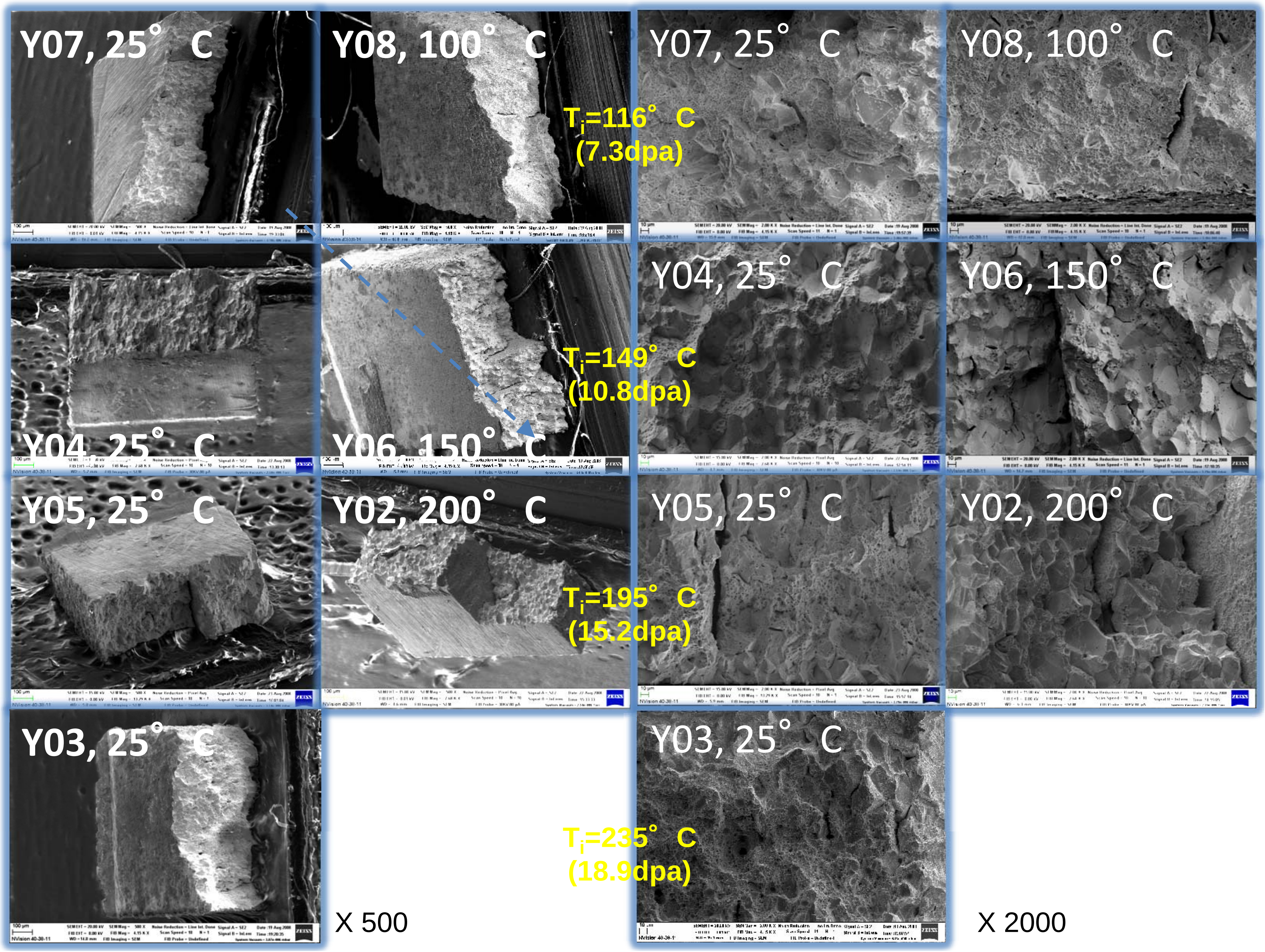
Result – Au alloys

◆ After irradiation



Fracture surface Unirradiated Au alloy (75Au-9Ag-16Cu)

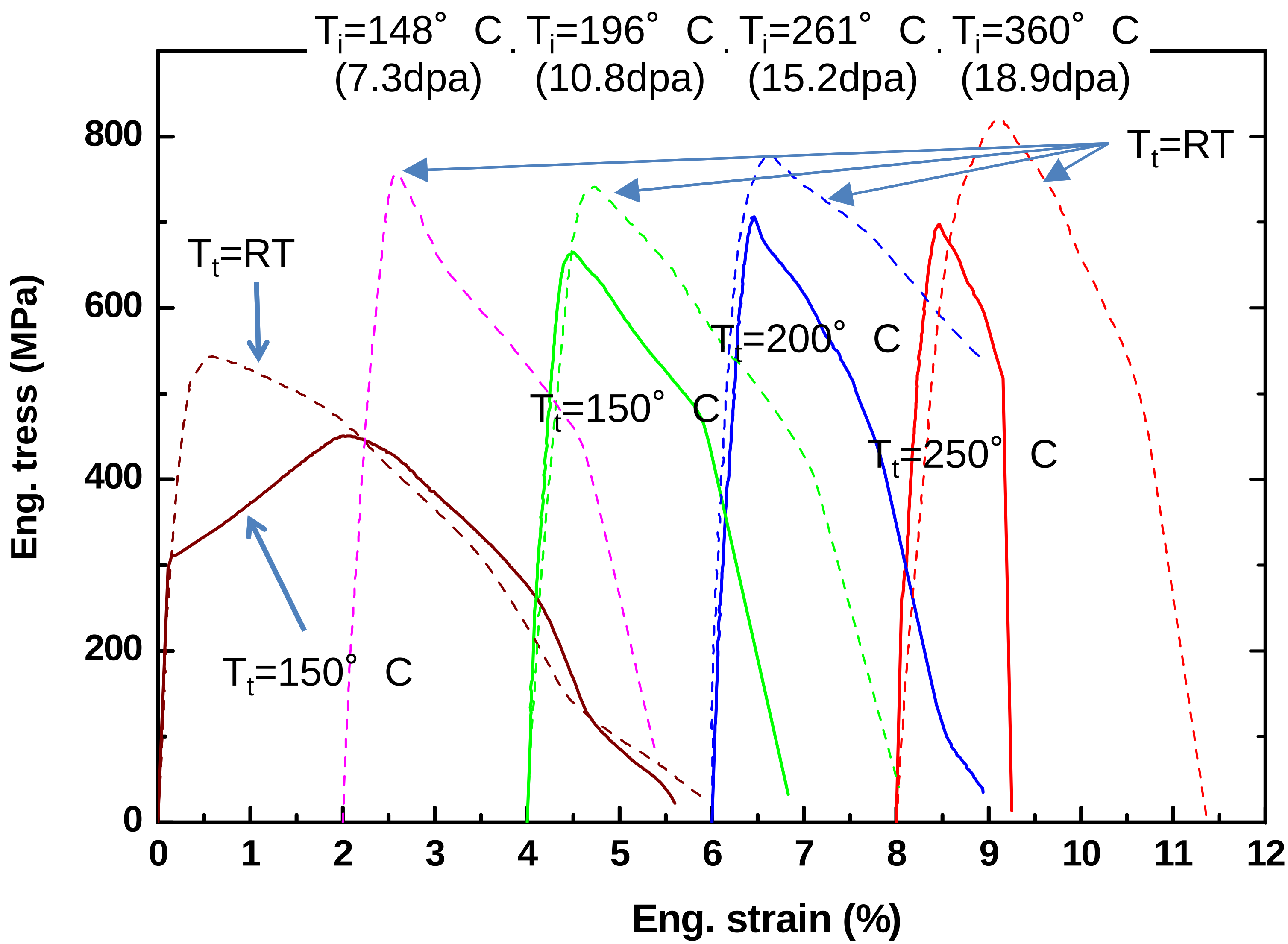




Y07, 25° C
Y08, 100° C
Y07, 25° C
Y08, 100° C
Ti=116° C
(7.3dpa)
Y04, 25° C
Y06, 150° C
Y04, 25° C
Y06, 150° C
Ti=149° C
(10.8dpa)
Y05, 25° C
Y02, 200° C
Y05, 25° C
Y02, 200° C
Ti=195° C
(15.2dpa)
Y03, 25° C
Y03, 25° C
Ti=235° C
(18.9dpa)
X 500
X 2000

Result – Pt alloys (95Pt-5Au)

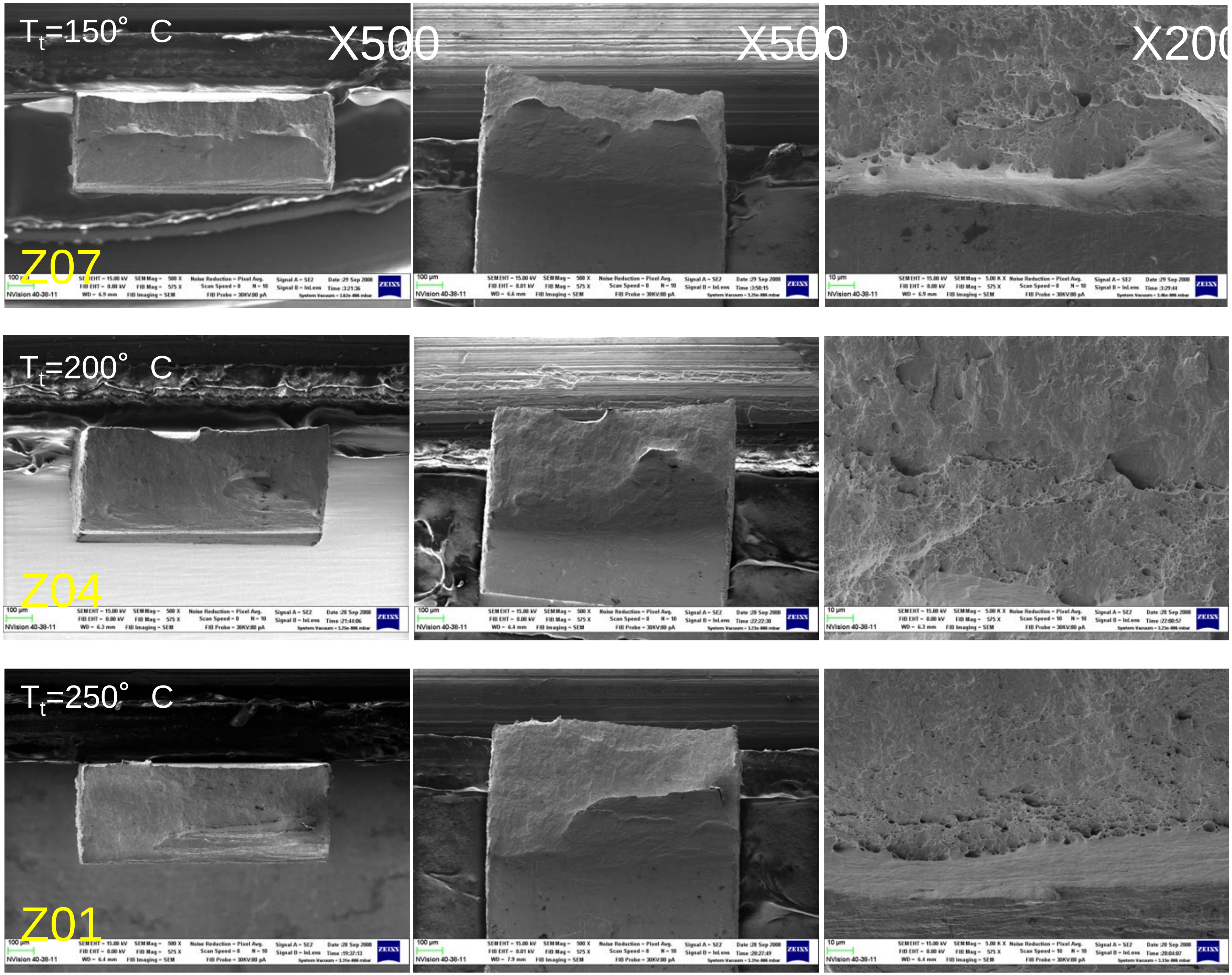
- **After irradiation**



T_i=196° C (10.8dpa)

T_i=261° C (15.2dpa)

T_i=360° C (18.9dpa)



- Tensile tests and fracture surface investigation were performed on Au and Pt alloys irradiated on STIP-II in order to know design data of mechanical properties on these
- Au alloy (75Au-9Ag-16Cu) showed good tensile strength and elongation before proton irradiation
- Significant ductility loss occurred after irradiation
- Only samples tested at 150° C (Y06) and 200° C (Y02) showed significant loose of strength, which is more like embrittlement
- The sample irradiated above 200° C (Y03, T_t=RT) shows rather ductile fracture surface
- May be due to the gases (He, H) introduce by irradiation
- Pt alloy (95Pt-5Au) showed rather unique deformation, which is kind of one side slip deformation
- No significant deformation features were observed after irradiations for Pt alloys except for the UTS increase of about 200MPa

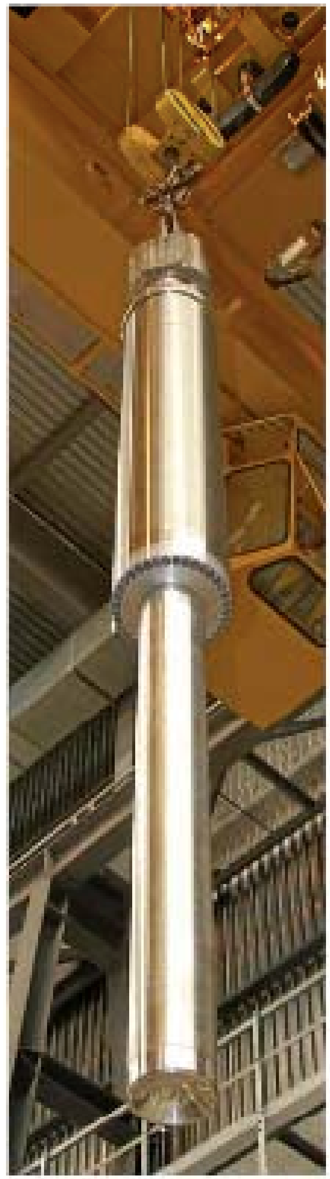
Spallation neutron source for ADS

- MEGAPIE project in cooperation with PSI, ESS(CNRS, CEA、ENEA, FZ, SCK-CEN), JAERI, LANL、KAERI.
- Materials issues for the beam window, protons/LBE.
- In-situ test at LiSoR, 72MeV-P, flowing LBE and stress
- MEGAPIE run in 2006.8-12, at 0.75MW.
- MEGAPIE target samples will ship this year/2009.
- MIRRAH / SCK-CEN plans XADS（EU)
- PSI plans power-up in neutron flux in LIMETS.
- J-PARC Phase-II plans experiment facility for ADS.

the MEGAPIE target

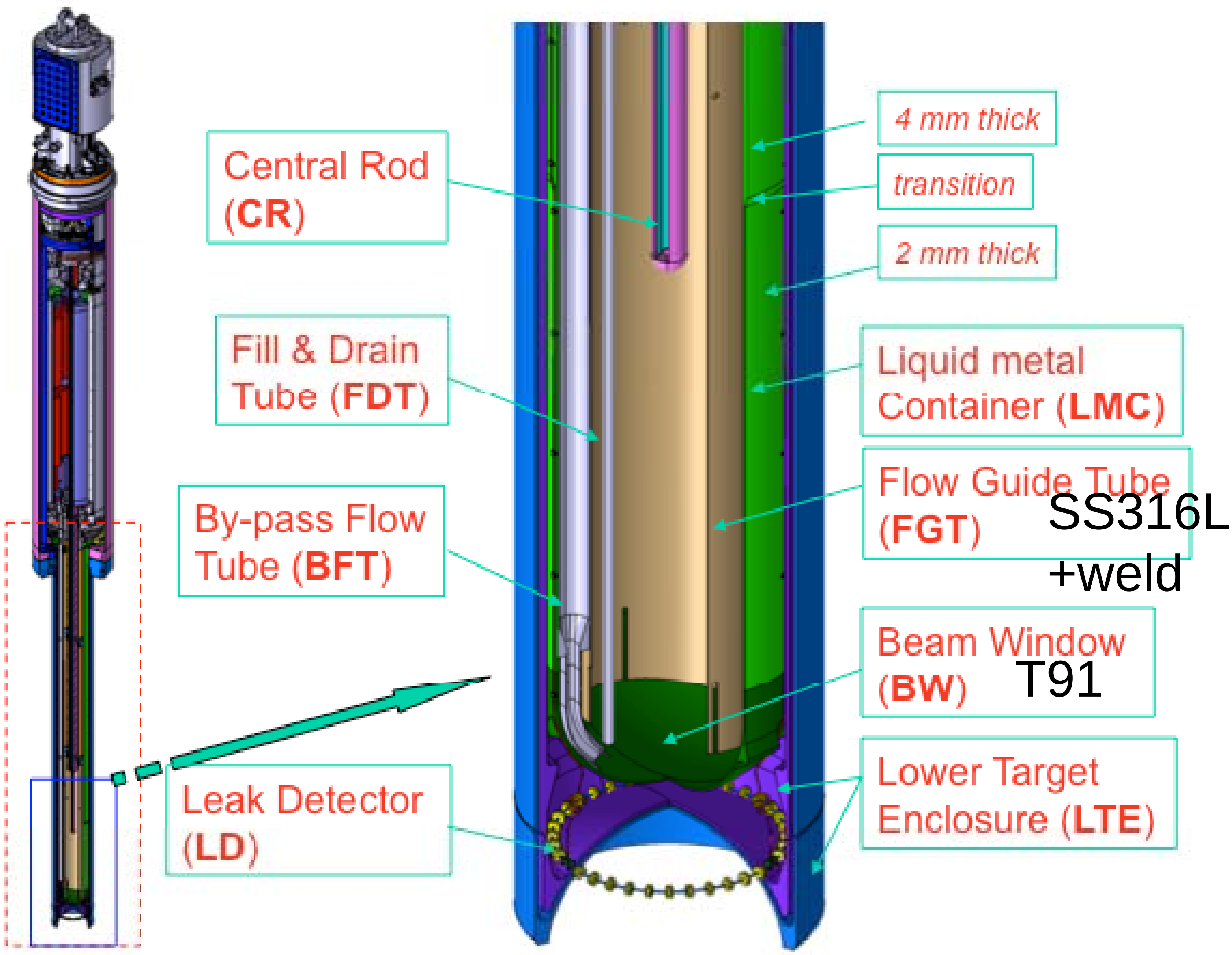
final
assembly

E leak
tector:
st view



inserting the target into SINC
with the exchange flasl

MEGAPIE LBE target, 600MeV, 1.2mA / PSI



Dai, PSI

The GOALS of LIMETS

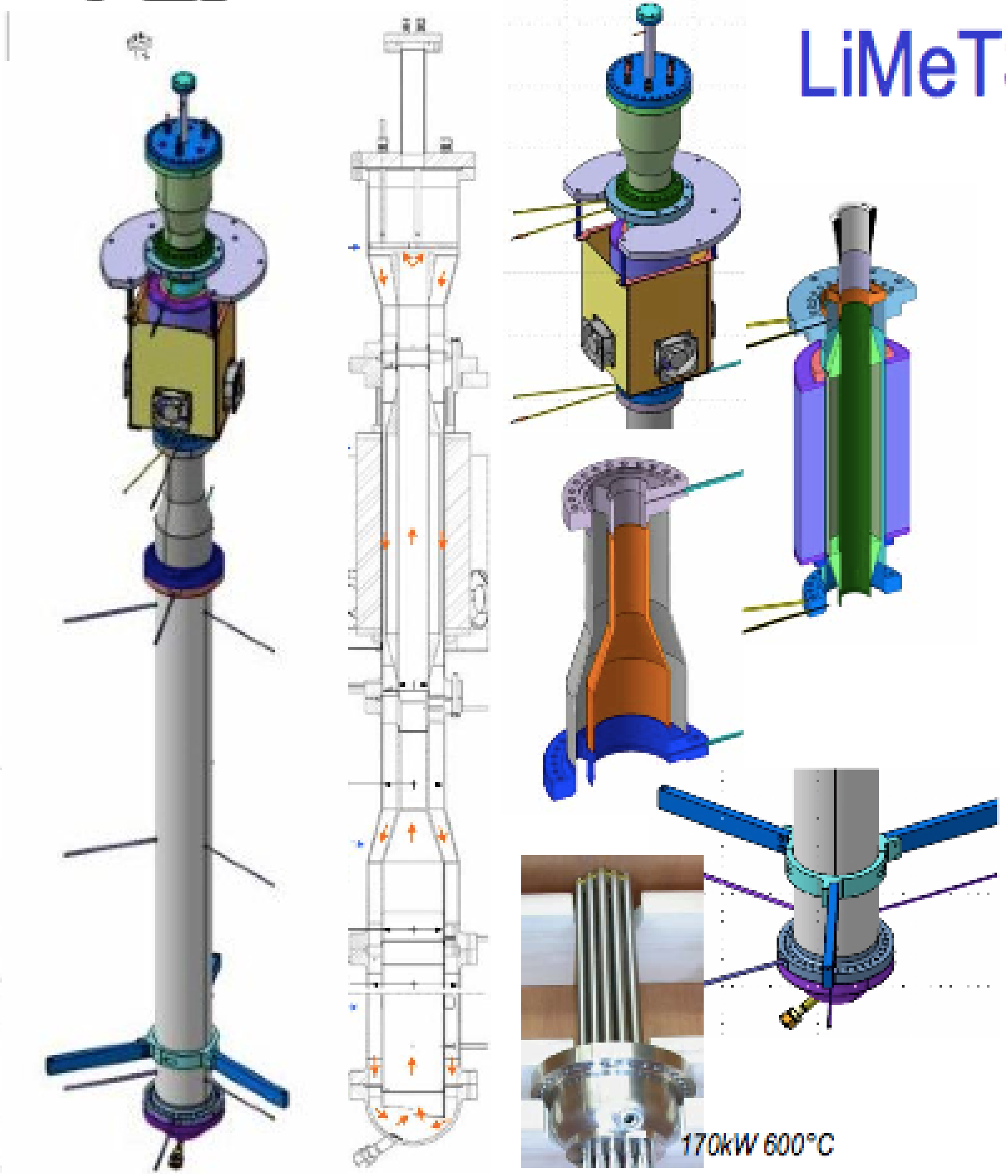
Liquid Metal Target for routine operation at SINQ

which must (should) be

- safe
- robust
- easy to operate
- simple & reliable
- efficient
- interesting to a wider community
- cheaper than MEGAPIE

Wagner, PSI

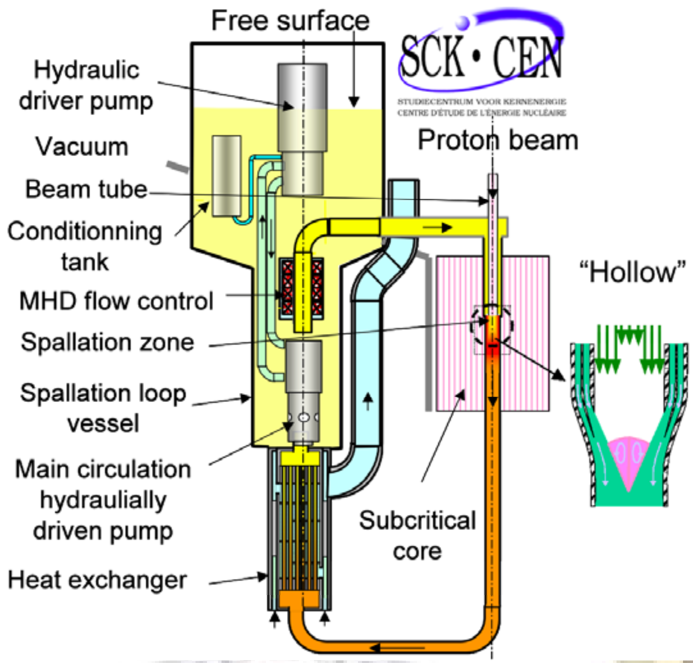
LiMeTS mock-up design (stage 1)



Basic technical parameters:

- **Modular design** allowing testing of different concepts of the THX, EMP, BEW
- Existing EMP (prototype of EMP1 for MEGAPIE) is adopted for the mock-up
- – **Working fluid** **PbBi** eutectic (melting temp. 126°C) **or Pb** (327°C), volume 65 l
- Maximum operating temperature – **500°C**
- **Liquid metal flowrate**, nominal – 4 l/s
- Design pressure – 10 bar
- extensive **instrumentation** (temp., pressure, flow)
- **Electric heater** – 170 kW (former MEGAPIE test heater)

MYRRHA spallation target LBE loop
2.2 mA at 600 MeV



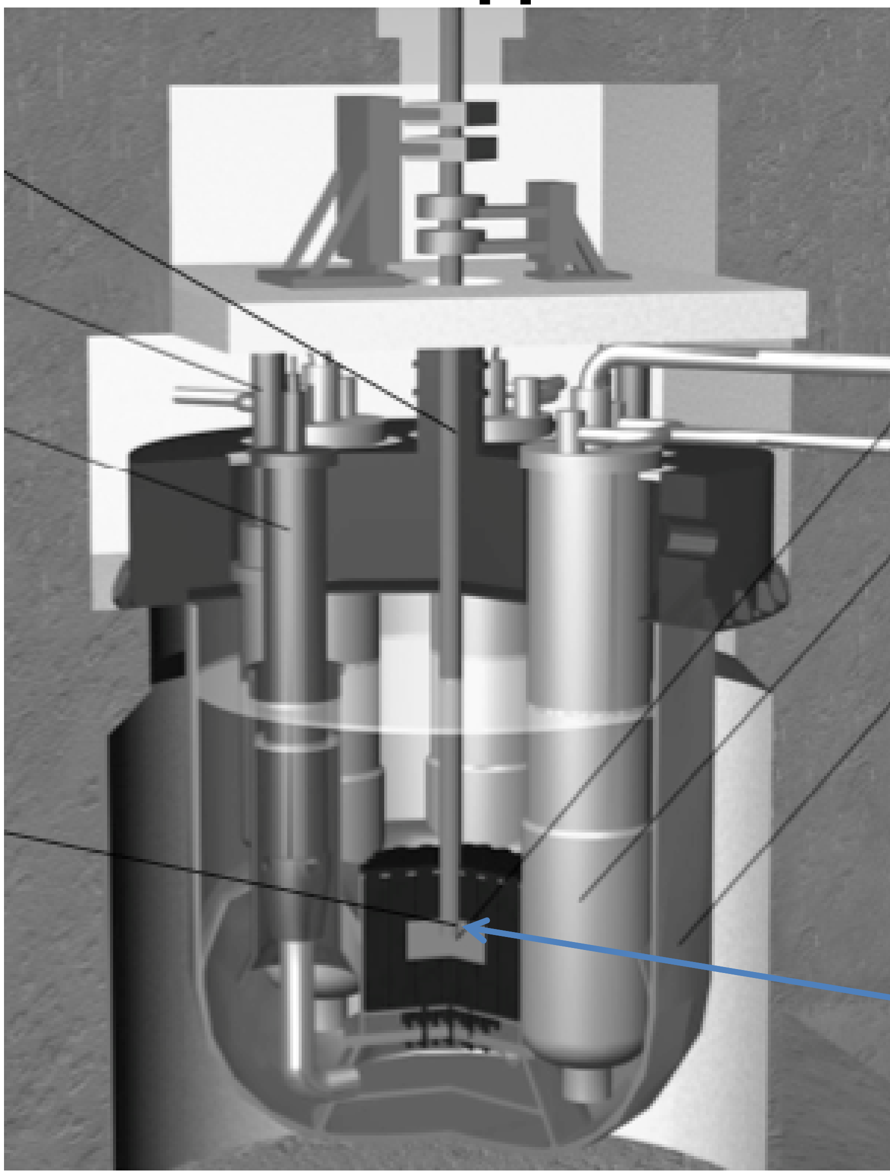
1. inner vessel
2. guard vessel
3. cooling tubes
4. cover
5. diaphragm
6. spallation loop
7. sub-critical core
8. primary pumps
9. primary heat exchangers
10. emergency heat exchangers
11. in-vessel fuel transfer machine
12. in-vessel fuel storage
13. coolant conditioning system

316L (→ 2. guard vessel, 4. cover)

T91 (→ 6. spallation loop, 7. sub-critical core)

Bosch SCK•CEN

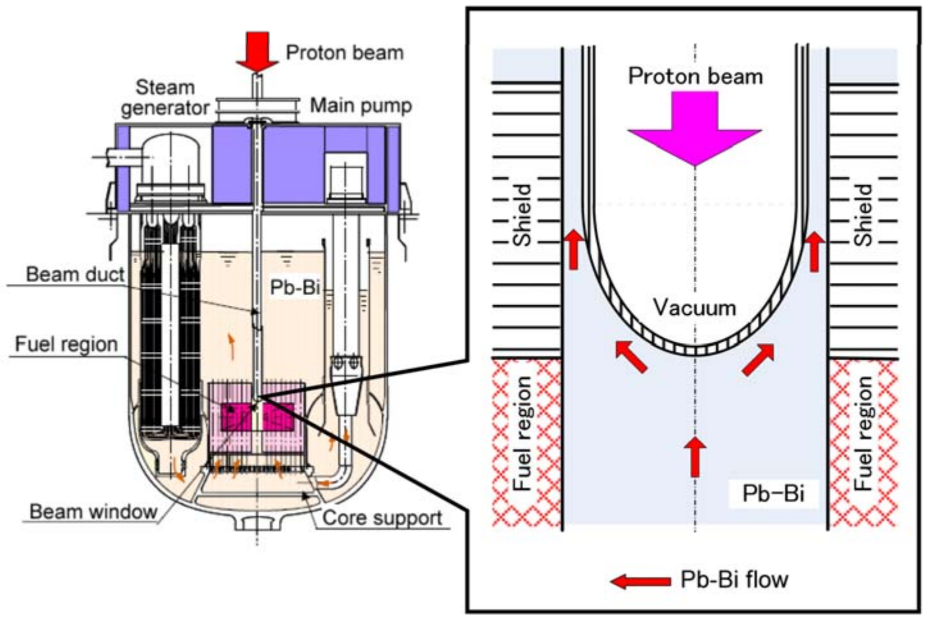
Image of ADS with window

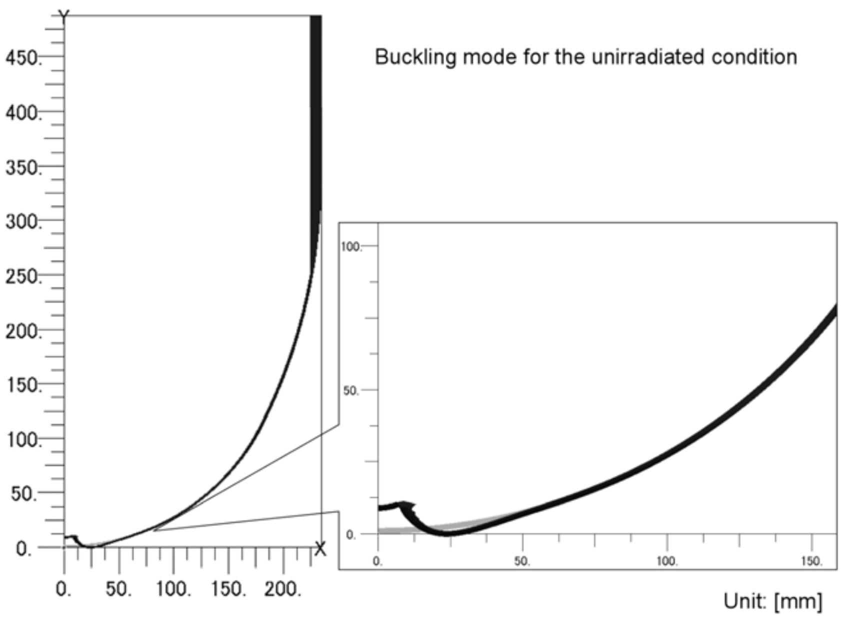


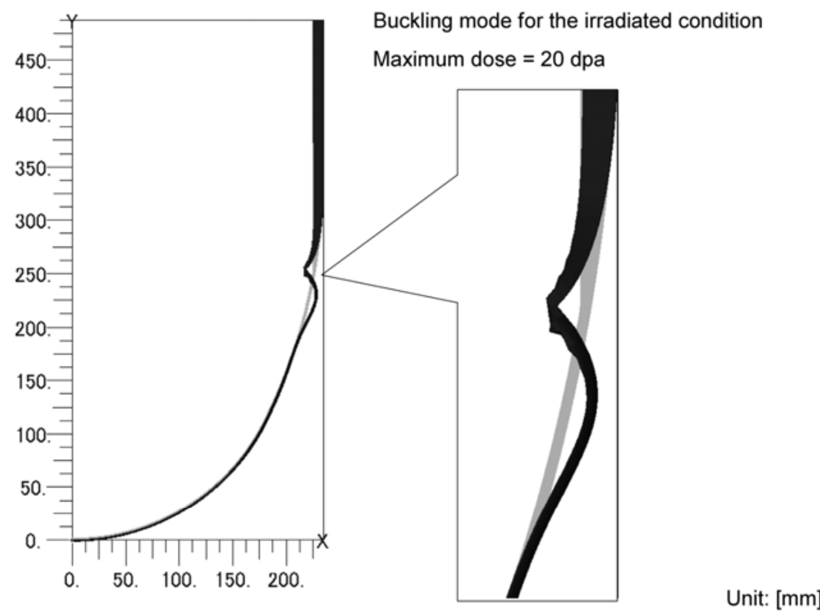
LBE Handbook,AESJ

Buckling mode of the beam window

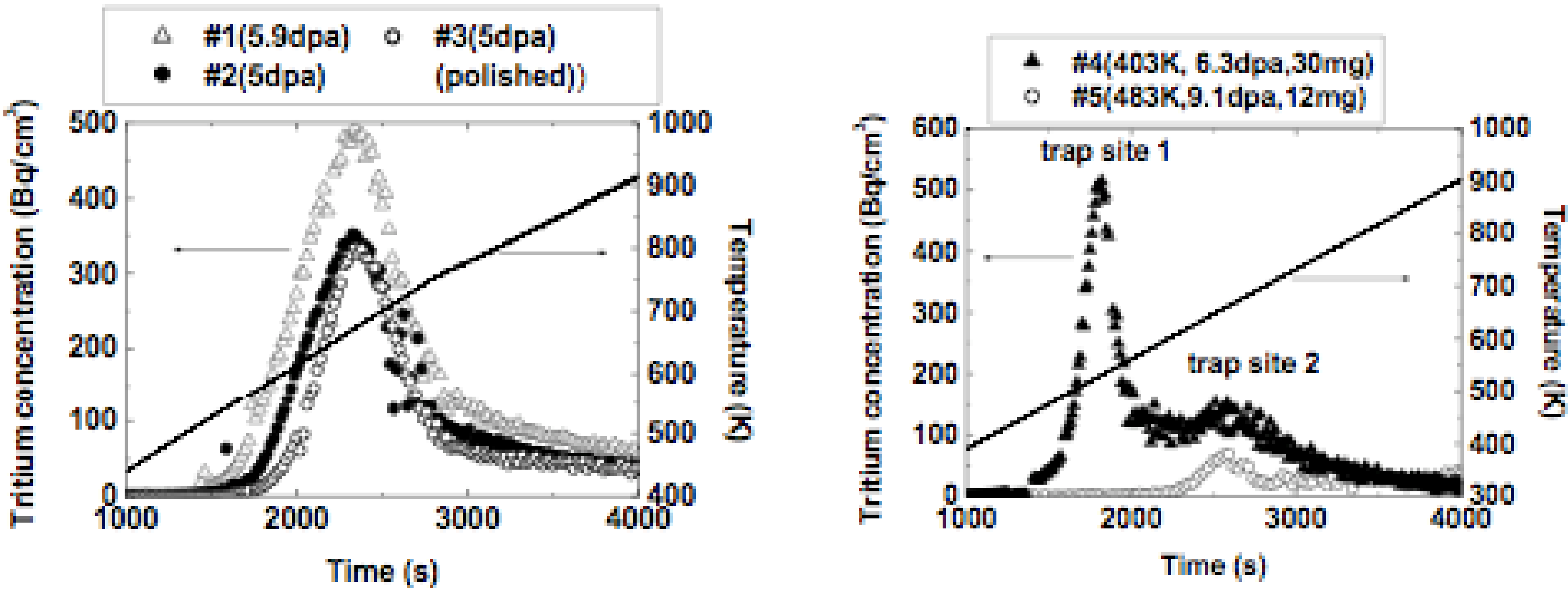
Sugawara et al. NUMA







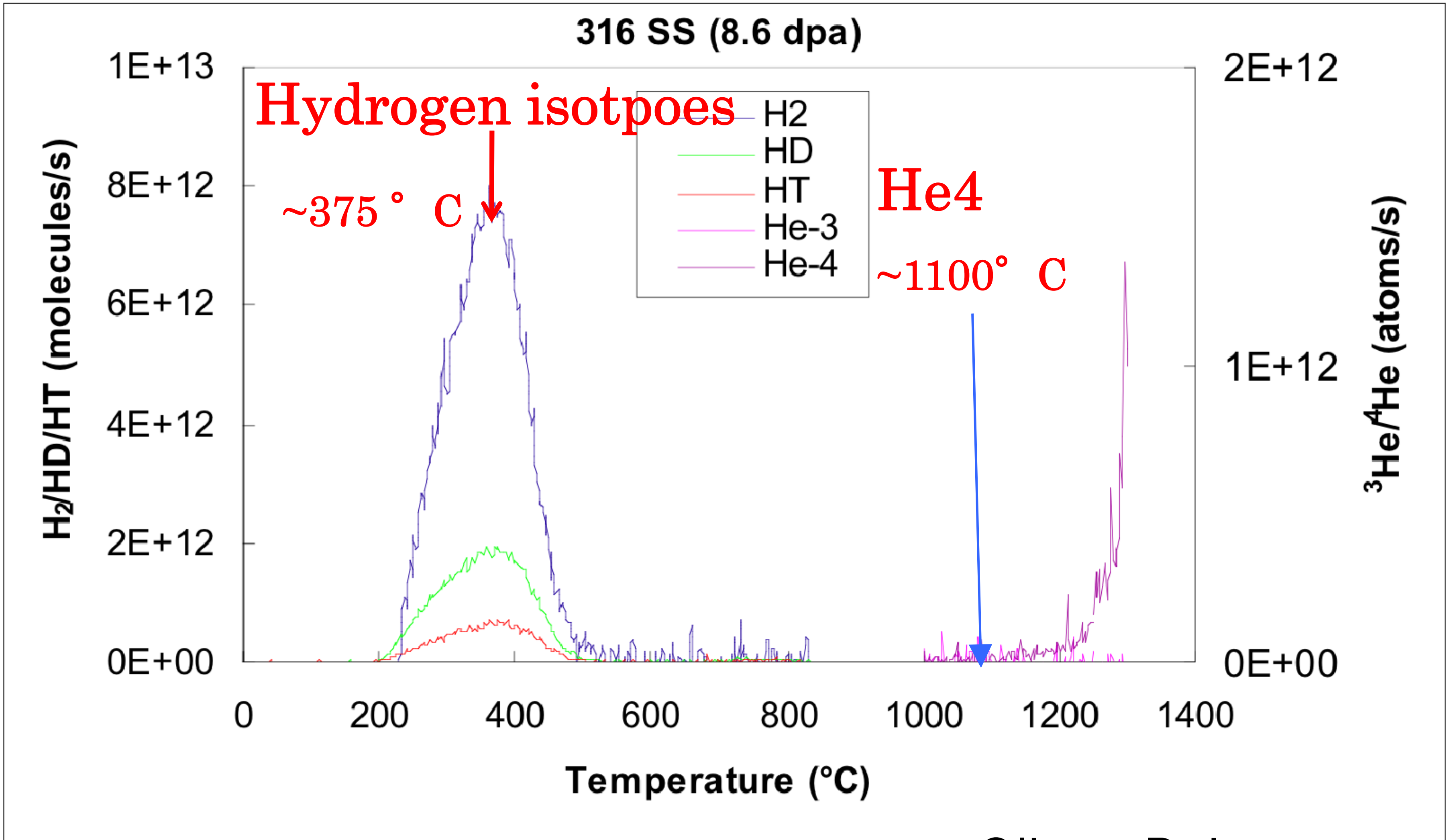
T releases from SS316(L) and F82H(R) by TDS method



SS316 showed peak and F82 showed two peaks in release curves.

Journal Nuclear Materials, 2006. FUSION SCIENCE AND TECHNOLOGY, 2007

Thermal desorption behavior of light gases from STIP samples



Oliver, Dai, IWSMT7

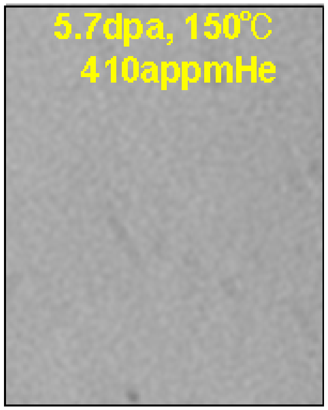
Irradiation Damage on the window in the 800MWth ADS after 300 FPDs

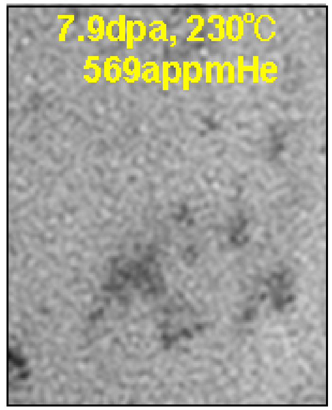
Nishihara, Kikuchi, NUMA 2008

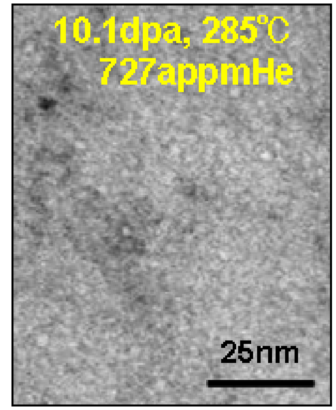
Particle		*I*	*P*	*N*	*C*	Total
Flux (/cm^2/s)		7.57*E* + 13	5.53*E* + 12	8.28*E* + 13	4.32*E* + 15	4.49*E* + 15
Averaged energy (MeV)		1500	107	42	0.75	
Cross section (b)	Heat (MeV b)	224	1010	6.4	1.1	
	DPA	2155	2148	1697	419	
	^{1}H	1.59	12.78	0.338	4.5E-3	
	^{2}H	0.37	0.013	3.3E-3	7.3E-7	
	^{3}H	0.083	1.9E-3	3.4E-4	4.9E-7	
	^{3}He	0.066	1.4E-3	1.3E-4	3.5E-11	
	^{4}He	0.36	0.039	0.021	5.8E-4	
Reaction	Heat (W/cm^3)	229	75	7.2	63	375
	DPA (300 FPDs)	4.2	0.31	3.6	47	55
	^{1}H (appm,300 FPDs)	3119	1831	725	503	6179
	^{2}H (appm,300 FPDs)	727	1.8	7.2	0.082	736
	^{3}H (appm,300 FPDs)	163	0.27	0.72	0.054	164
	^{3}He (appm,300 FPDs)	130	0.20	0.28	3.9E-6	130
	^{4}He (appm,300 FPDs)	709	5.5	45	65	825

- He bubble formation on JPCA was observed at lower temperature compared to EC316LN on STIP-I irradiated samples
- Effect of Ti modification?
- **Ti as an over sized atom lowers the mobility of vacancies**

JPCA

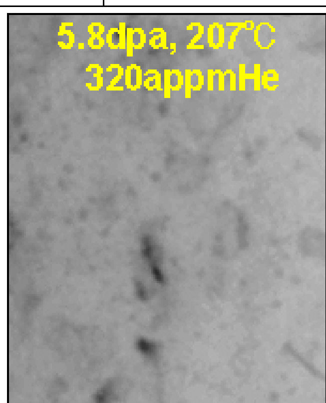


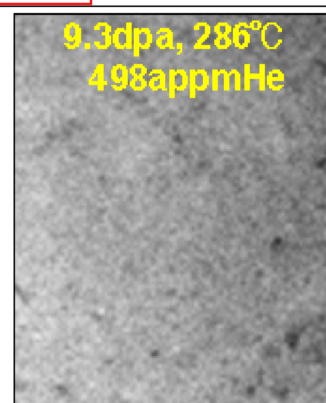




wt%	Fe	Cr	Ni	Mo	Mn	Ti	C	Si	P	S	N
JPCA	Bal.	14.14	15.87	2.29	1.54	0.22	0.058	0.5	0.026	0.004	0.003
316LN	Bal.	17.45	12.2	2.5	1.81	-	0.024	0.39	-	-	0.067

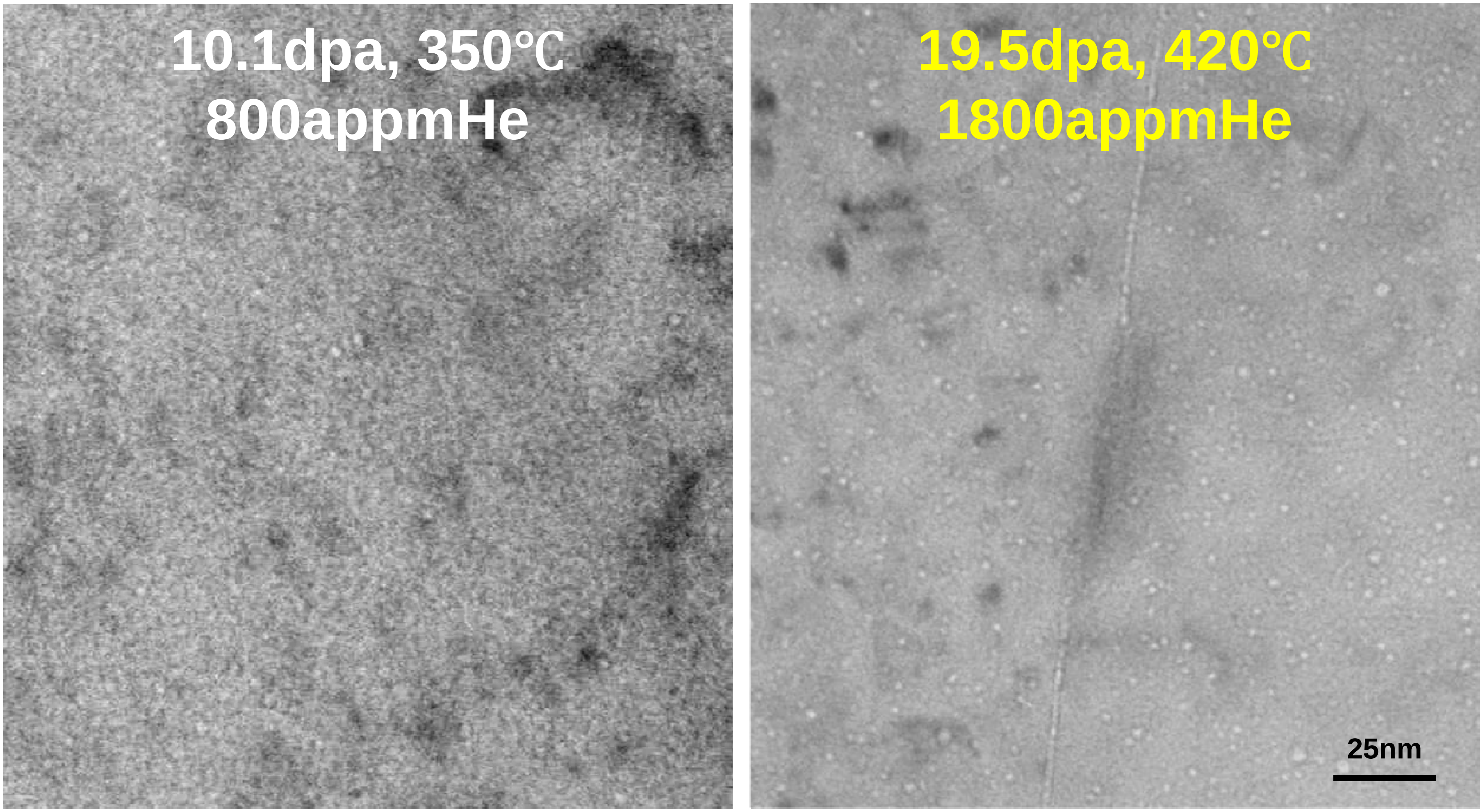
316LN





5 6 7 8 9 10 11 **dose (dpa)**

D. Hamaguchi, JNM 343 (2005) 262



- **In the sample irradiated to 19.5dpa to 450℃, some bubble agglomeration to boundaries is observed**
- **Agglomeration was not observed on the sample irradiated to 10.1dpa, 350℃**
- **Any influence on mechanical properties ?**

DBTT shift of F/M steels

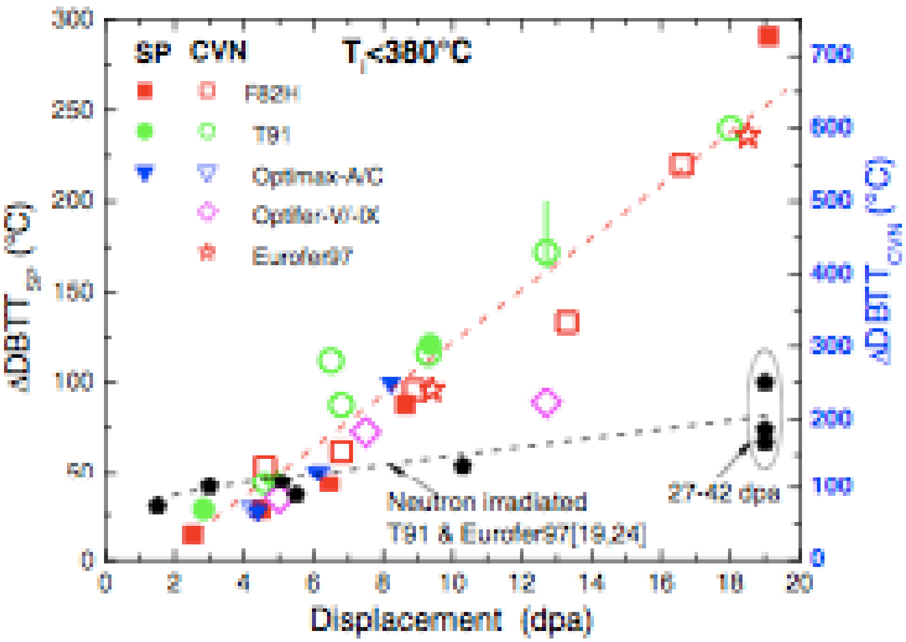


Fig. 5. DBTT shift as a function of irradiation dose for different FM steels irradiated in STIP.

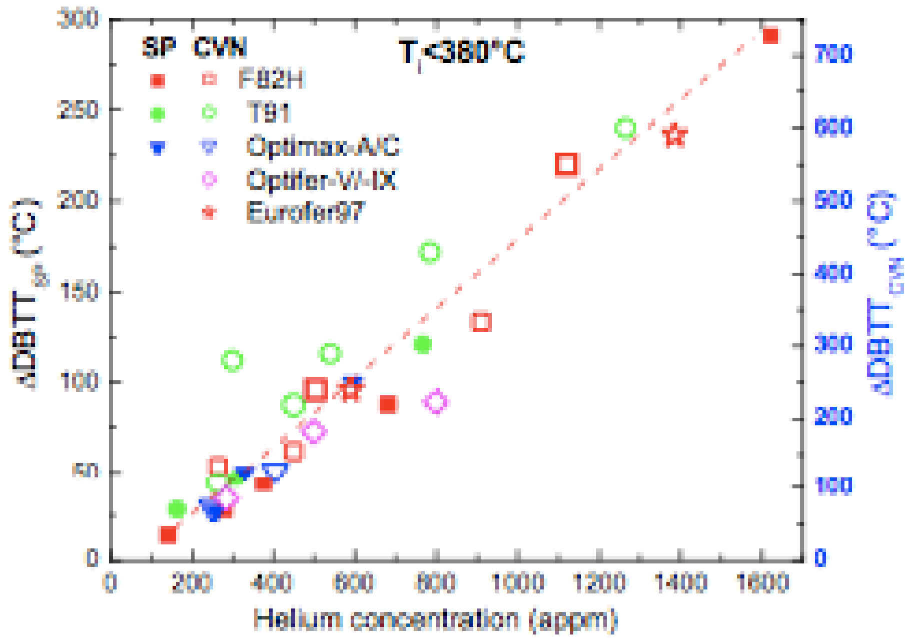


Fig. 6. DBTT shift as a function of helium concentration for both the previous small punch tests [17] and the present Charpy tests.

Dai and Wagner, NUMA

Topics of material issues

- Spallation neutron source design needed proton irradiation data
- IWSMT1、1996、ORNL
- STIP started in PSI、1997
- Pressure wave and neutronic test were done at AGS/BNL, ２4GeV, 1997
- Ductility remains in Ta spent target at ISIS, 8dpa
- Ductility loss in SS316L irradiated by proton at LANL, 4-5dpa
- Pitting found in Hg container for short pulse source
- Life time of Hg container is decided by pitting damage＞irradiation damage
- Guideline for exchange is 5dpa in Hg target vessel

continued

- Modified SS316, JPCA, kept ductility up to 12dpa, AccApp03
- Compressive test of W LANSCE spent target shows no collapse
- STIP-III data for 19dpa stainless steels remains ductility and no intergranular fracture
- ORNL-SNS decided extension of life to 10 dpa at IWSMT9
- Consideration of weight balance in pitting and irradiation under full power
- A short pulsed target issue needs to deal with high intensity and neutron flux
- Solid target approach for high intensity power at CSNS、SNS-T2, ESS-BIBAO?
- LANL evaluation on W erosion