SINQ Target Irradiation Experiments STIP-IV to -VI

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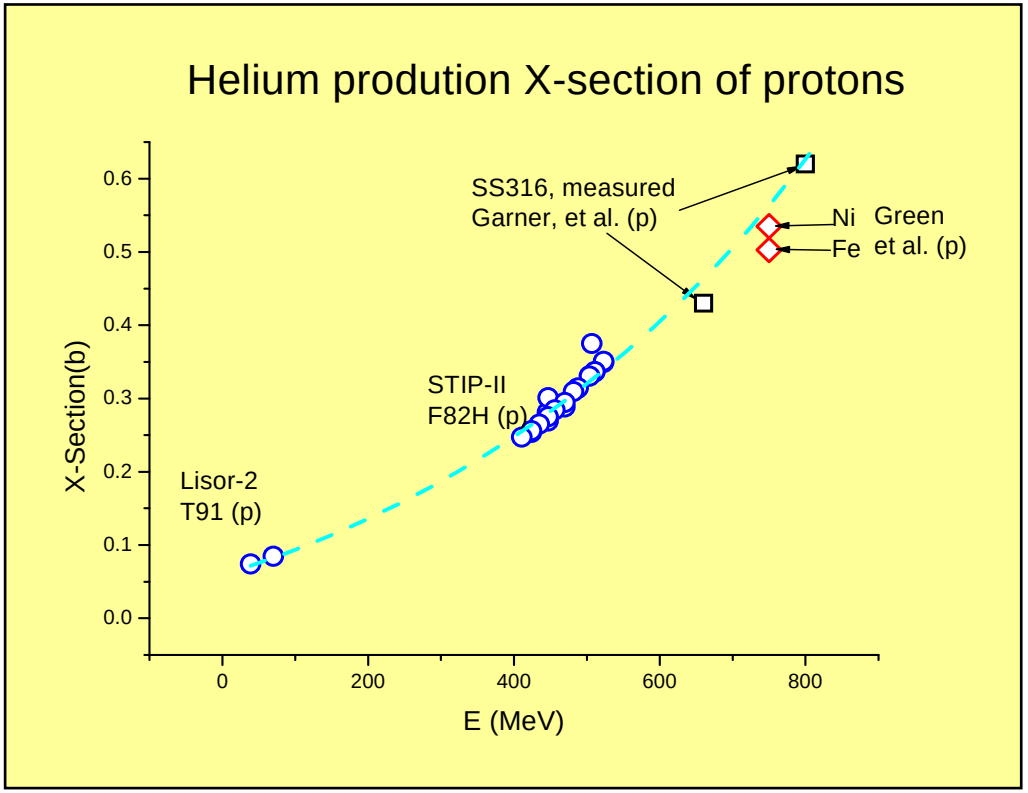
IWSMT-10, Beijing, China, October 18-22, 2010

Introduction

High energy protons induced high He and H production rate in Materials



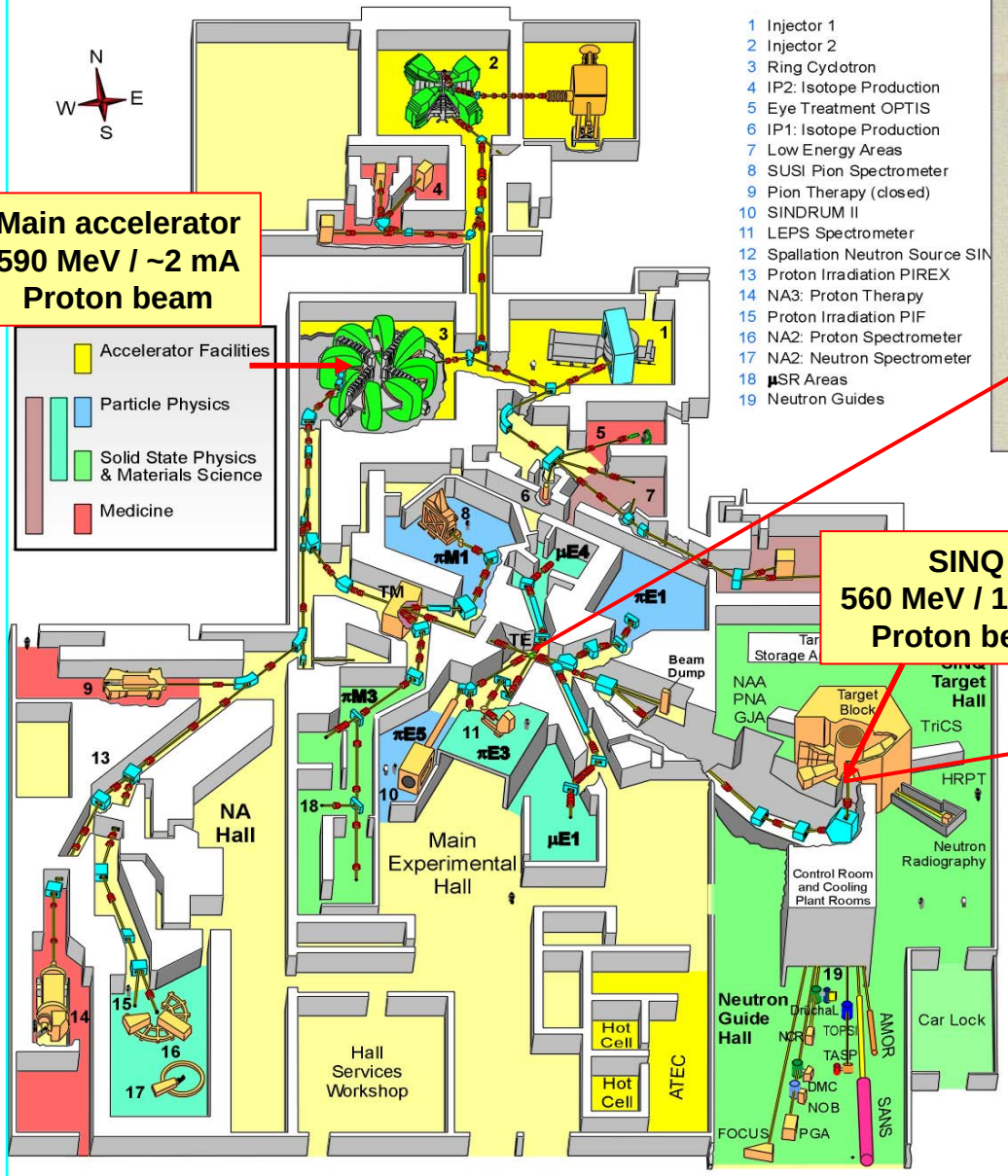
He-to-dpa ratio

<u>In spallation targets</u>: up-to 100 appm He / dpa

<u>In fusion reactors:</u> 10-15 appm He / dpa

<u>In fission reactors:</u> < 1 appm He / dpa (for most of materials)

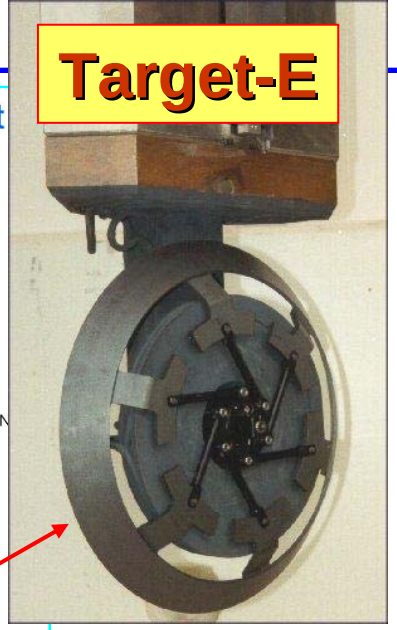
Accelerator Facilities of the Paul Scherrer Institut



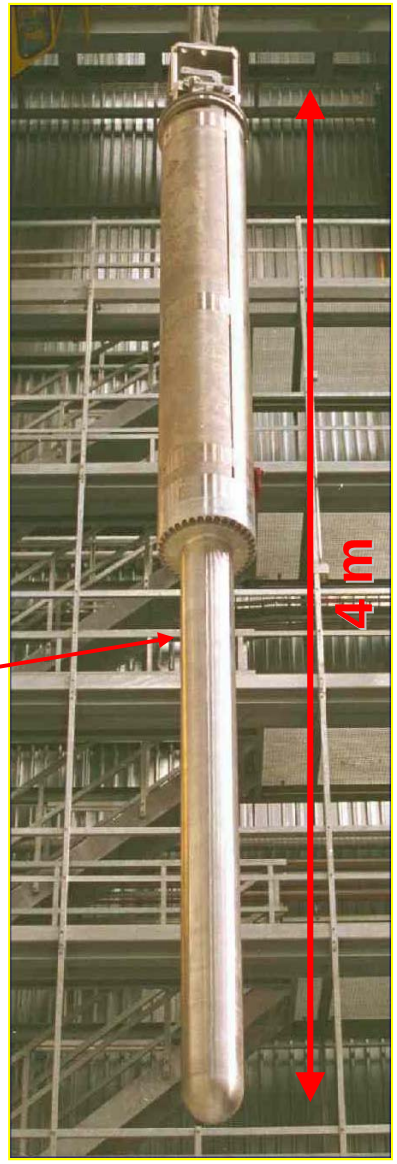
Main accelerator 590 MeV / ~2 mA Proton beam

SINQ 560 MeV / 1.3 mA Proton beam

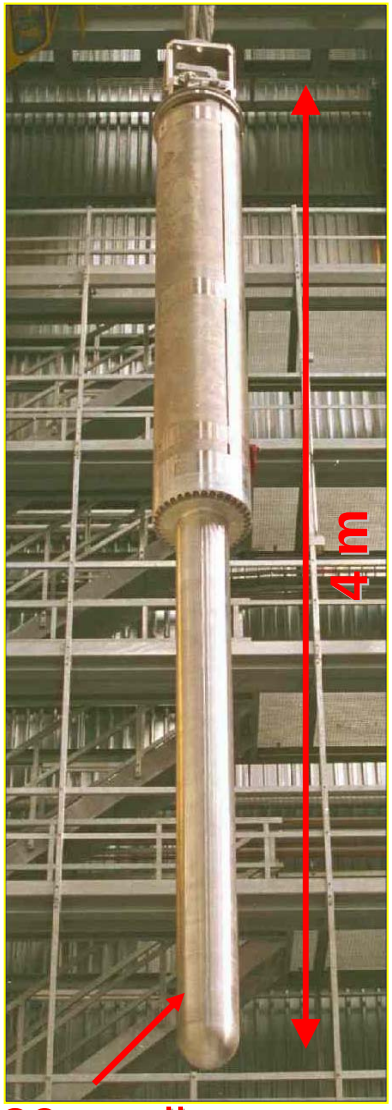
Target-E



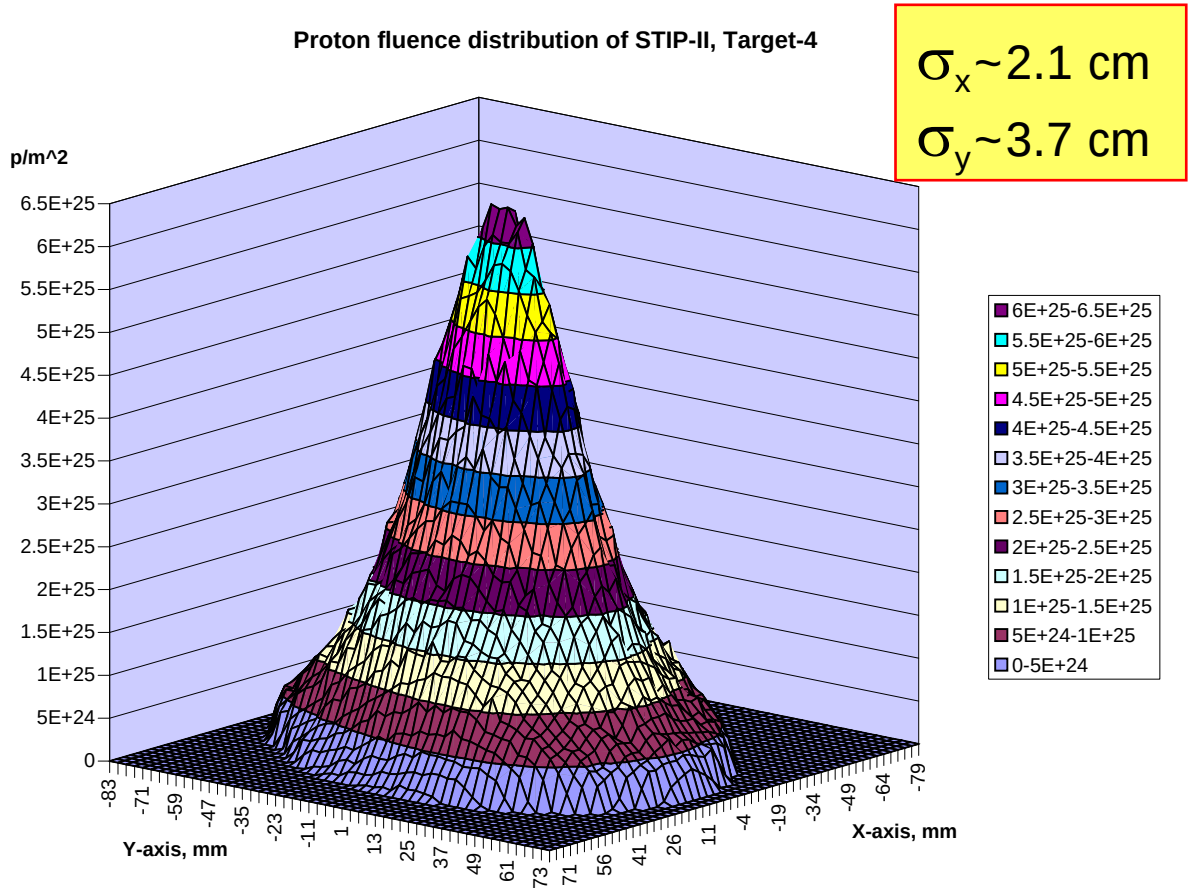
SINQ Target



SINQ Target Irradiation Program - STIP



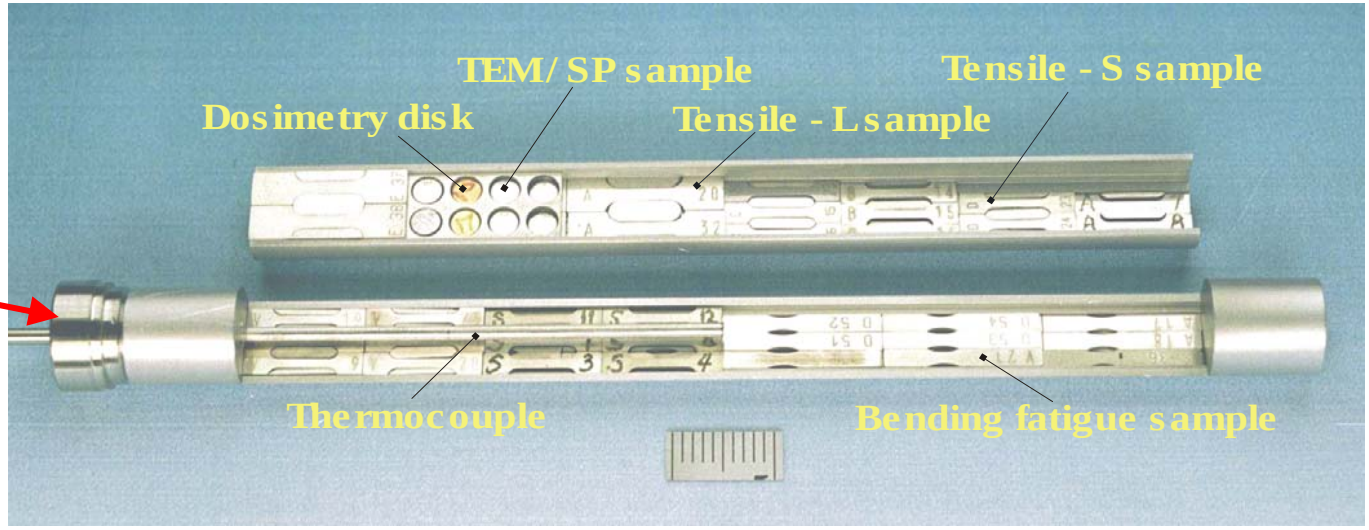
Integrated Proton Distribution Profile



σ_x~2.1 cm

σ_y~3.7 cm

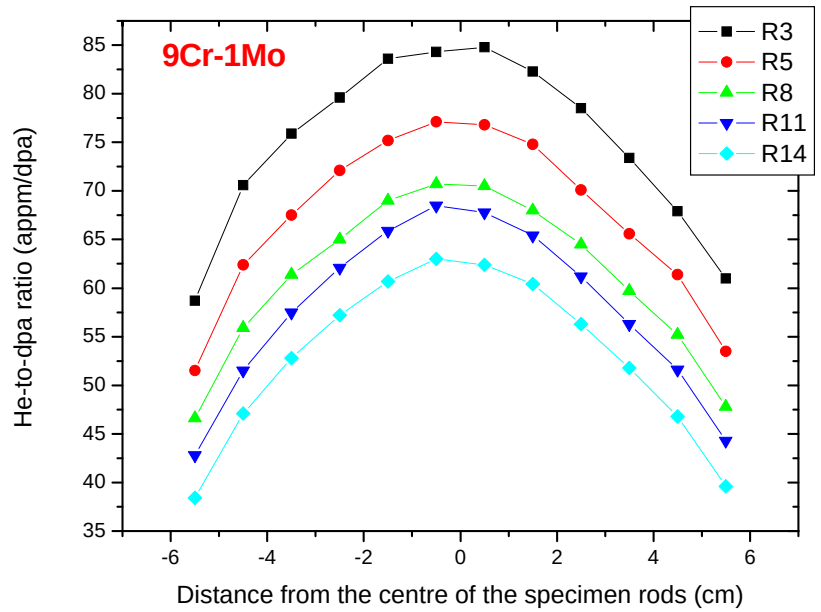
Specimens

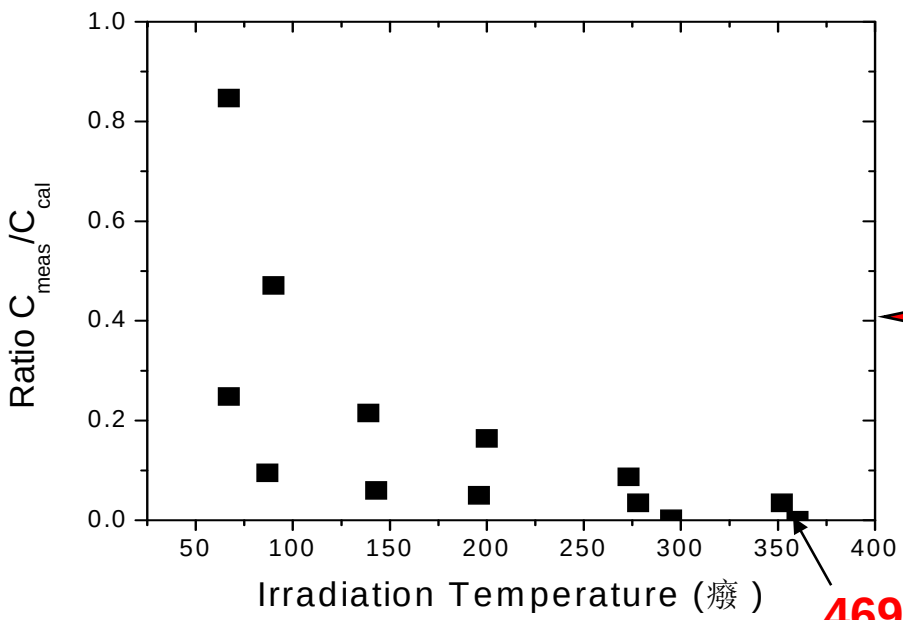


L = 130 mm
D = 10.8 mm

Irradiation parameters

For steels:
~ 12 dpa / year
40 - 90 appm He / dpa
200 – 400 appm H / dpa



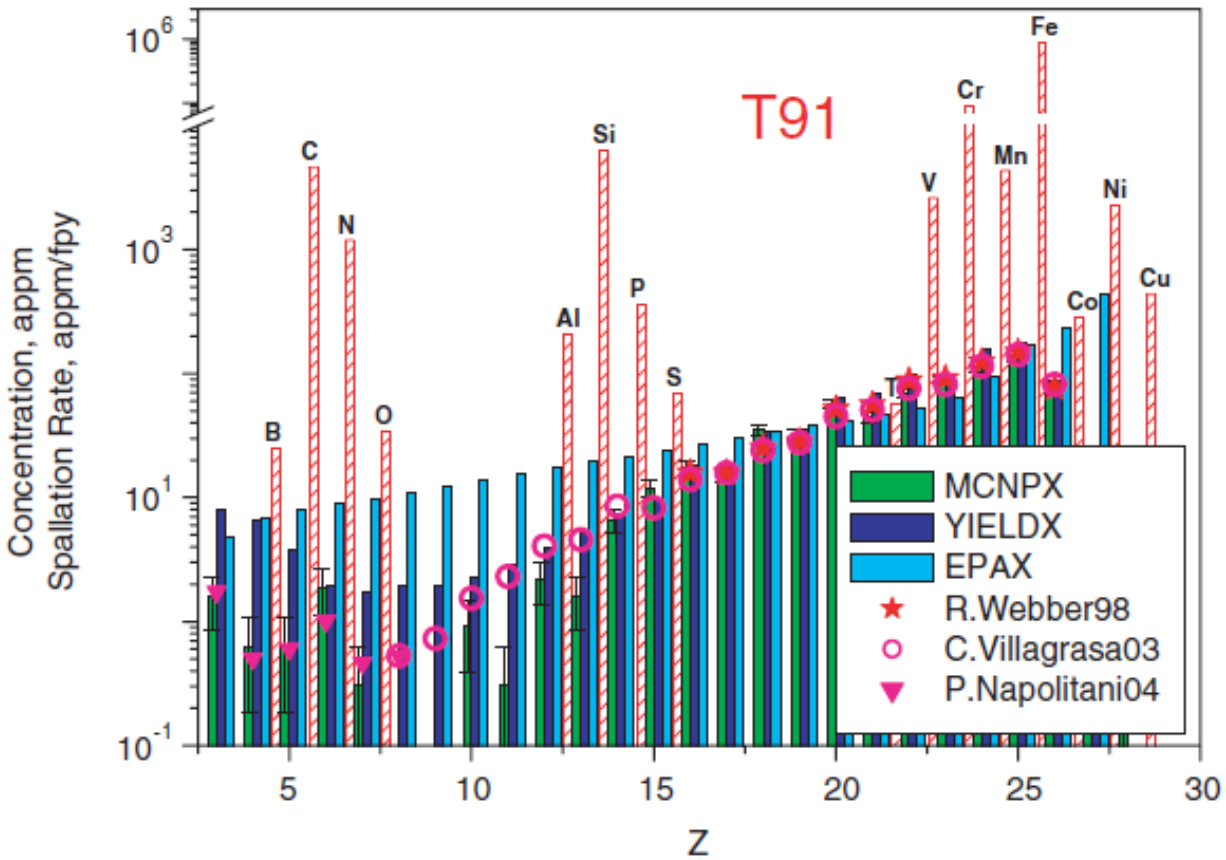


Gas measurements show that most of H diffused out steel (SS and FMS) samples if Tirr >~250°C.

Dai, Oliver et al., JNM 318(2003)167.

4690 appm produced, 360 appm measured

Irradiation parameters



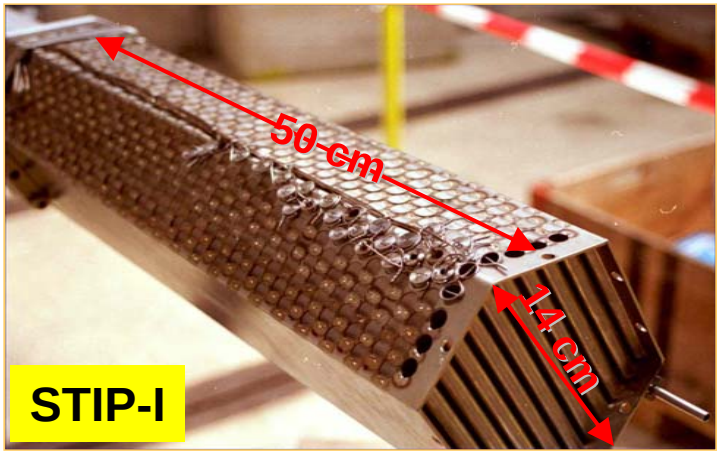
Impurity production
P: < 0.4 appm/dpa
S: < 0.5 appm/dpa

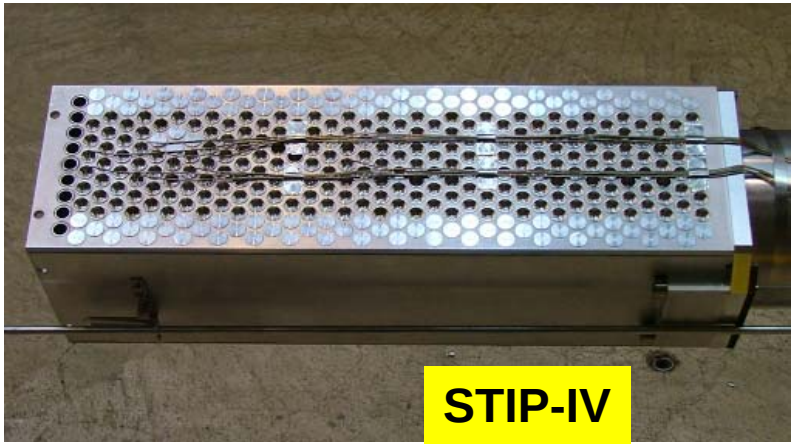
A spallation target of ADS with 600 MeV proton beam, 32 dpa/y

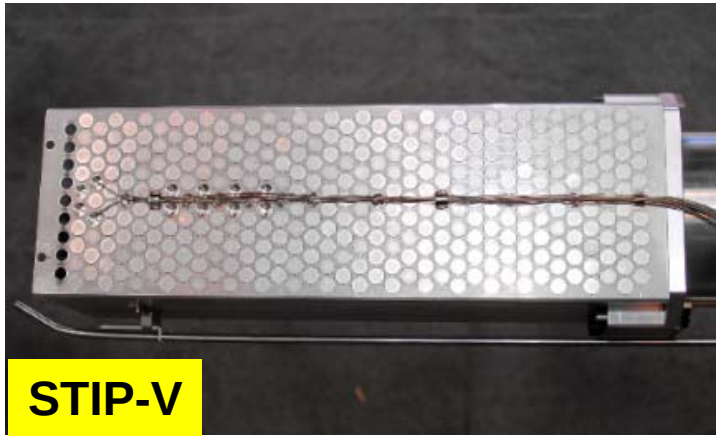
P. Vladimirov, A. Möslang, JNM, 356 (2006) 287.

SINQ Targets

~360 rods of Pb with SS 316L or Zircaloy-2 cladding, and 15-20 specimen rods

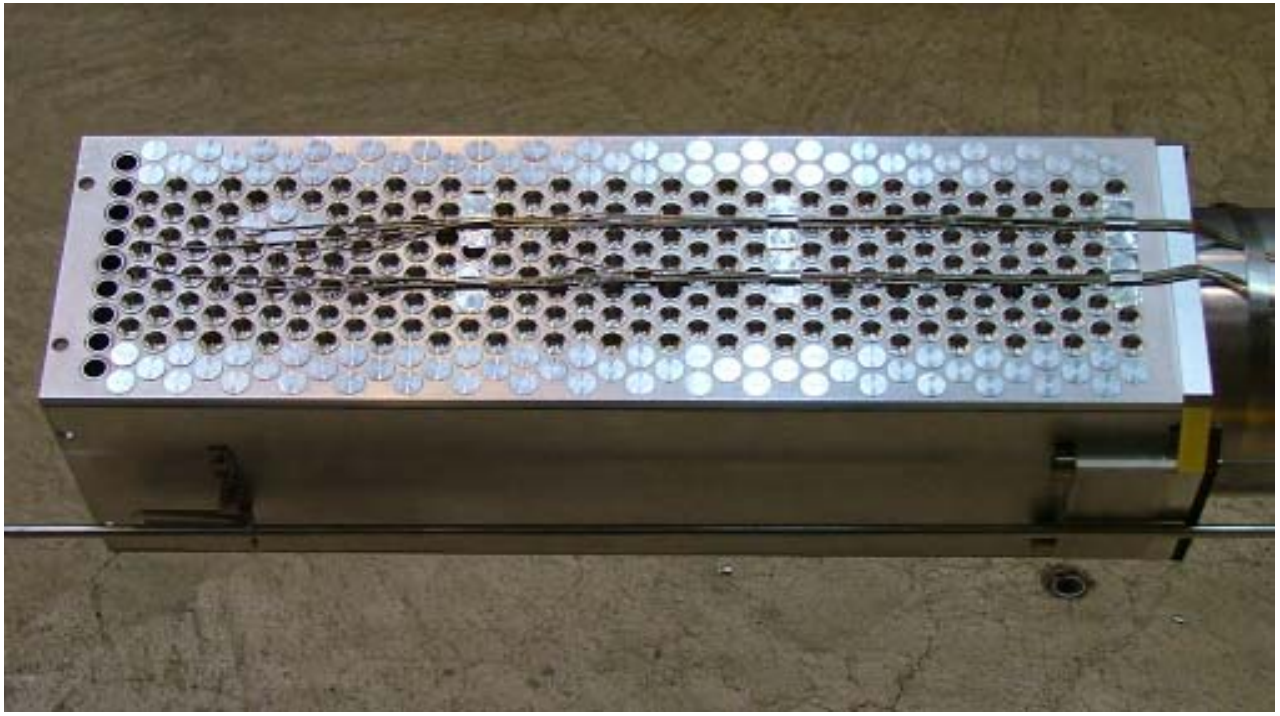






Max. Proton flux: 2.4x10^{14} p/cm^2/s.
Max. Neutron (1-560 MeV) flux: 2.3x10^{14} n/cm^2/s.

STIP - IV



Irr. Matrix

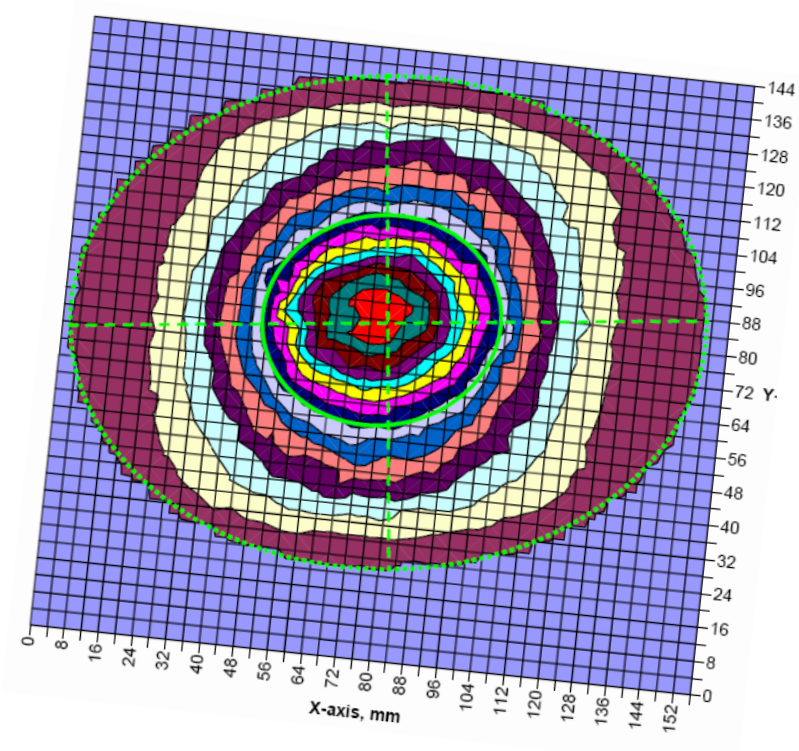
	Irradiation Matrix of STIP-IV (Target-V)									
ID	Materials	Tensile S	Tensile L	B-fatigue	Bend bar	Charpy	SP	TEM	SANS	Supplier
A	JLF1	8					14	1		CEA
B	T91-A	8				8	8	2		CEA
C	T91-B	8					7	2		CEA
D	T92	16				8	15	3		CEA
G	MA957	8				8	8	2		CEA
E	Eurofer 97 (Hip)	11								PIREX
F	Eurofer 97	24				27		6	1	PIREX
O	Eurofer 97 ods	16				5		5	3	PIREX
J	Ti-alloy					4				PIREX
K	FG-316	12						9		JAERI
L	HCM12A	12						9		JAERI
M	T92	8		9	8					PSI
B'	T91				8					
N	12CrWTi ods	15	6	9	10	16		9		PSI / CIAE
P	DIN 1.4922	20			10	16		9		PSI
H	DIN1.4313	20			10	16		9		PSI
Q	PM2000	12	8		8			9		PSI (LWV)
R	Ti-Al	12	9		6			7		PSI (LWV)
S	TZM	9	8		8			6		PSI (LWV)
T	SiC/C (1)				5					PSI (LWV)
U	C/C-SiC (1)				5					PSI (LWV)
V	C/C-SiC (2)				5					PSI (LWV)
W	SiC / SiC (1)				5					PSI (LWV)
X	SiC / SiC (2)					4				PSI (LWV)
Y	SiC / SiC (3)				6					PSI/JAERI

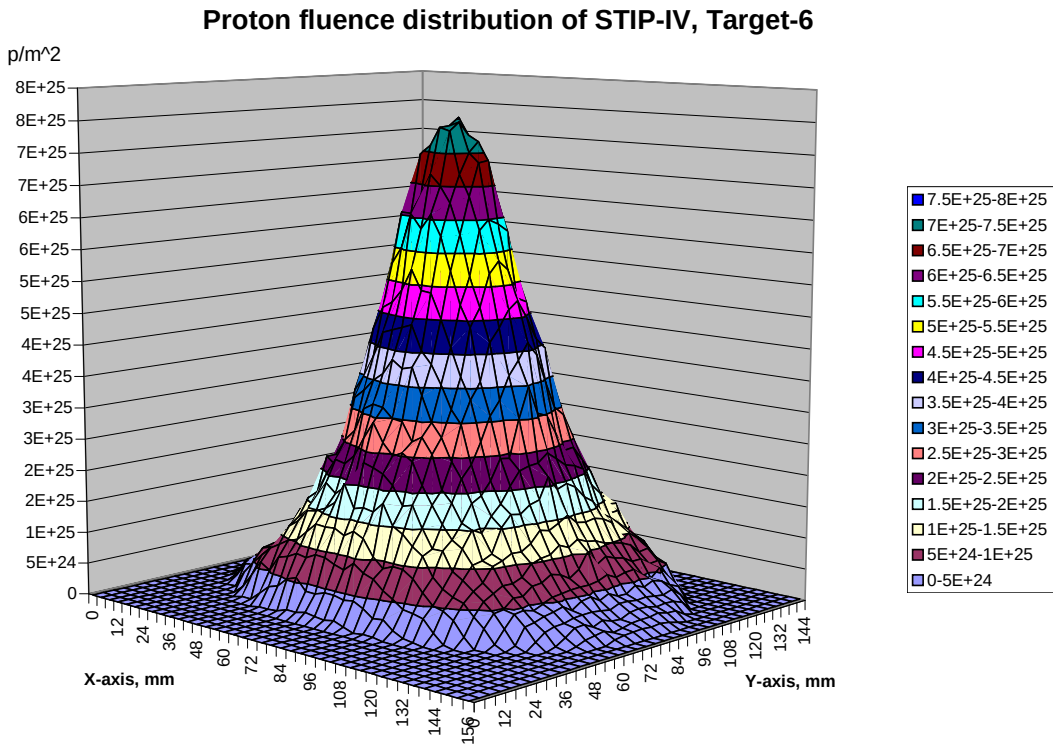
	Irradiation Matrix of STIP-IV (Target-V)									
ID	Materials	Tensile S	Tensile L	B-fatigue	Bend bar	Charpy	SP	TEM	SANS	Supplier
Z	mod. 316								6	CIAE
AA	Ta								2	CIAE
AB	W								2	CIAE
AC	W single cystal	4						4		CIPH
AD	W-3Re	4						4		CIPH
AE	W-9R	4						2		CIPH
AF	W-15Re	9						4		CIPH
UA	9Cr-2WVTa		5							LANL
UB	V-4Cr-4Ti		5					2		LANL
UC	T91		12					6		LANL
UD	EP823-I (STIP2)		12					10		LANL
UE	EP823-II (IPPE)		6					6		LANL
UF	A21N		5							LANL
UG	HT-9		12					12		LANL
UH	5Cr-2WVTa		5							LANL
UK	Ta HP							6		LANL
UL	Ta LP							5		LANL
UM	Ta Single crystal		5					5		LANL
UN	Fe Single crystal							8		LANL
UO	NiAl							5		LANL
UP	ZrN							5		LANL
UR	FeAl							5		LANL
US	RuAl							5		LANL
UT	50Mo-20Ru-15Pd-15Rh							6		LANL
UV	UMT122							3		LANL
UX	UMT91							6		LANL
UZ	UMHT-9							5		LANL
FA	12YWT		5					2		LANL
FD	14YWT		5					2		LANL

Profile of accumulated proton fluence of STIP-IV

Max fluence: 7.5x10^{25} p/m^2, ~25% higher than that of STIP-II or -III

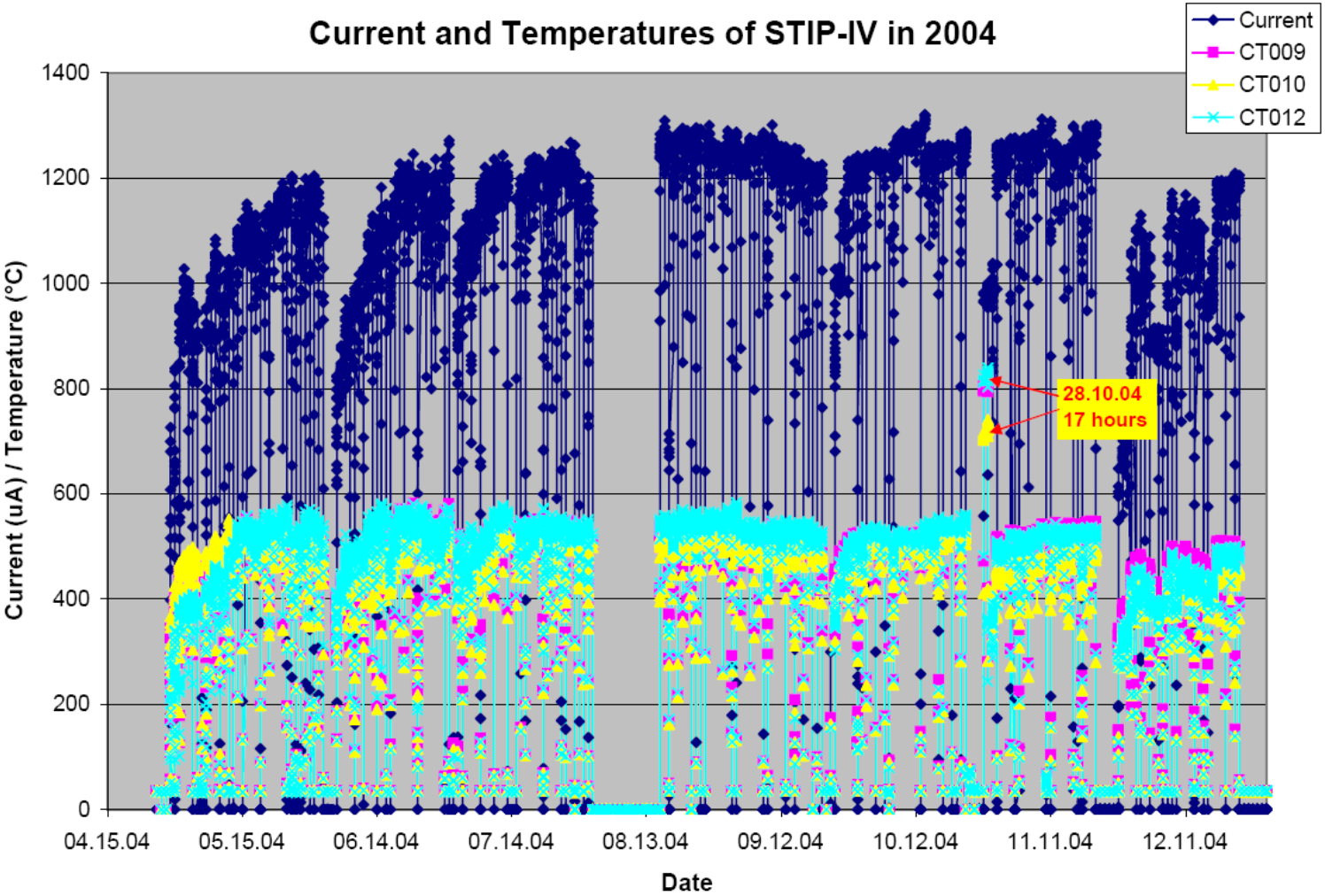
Gamma-mapping (Na-22) distribution



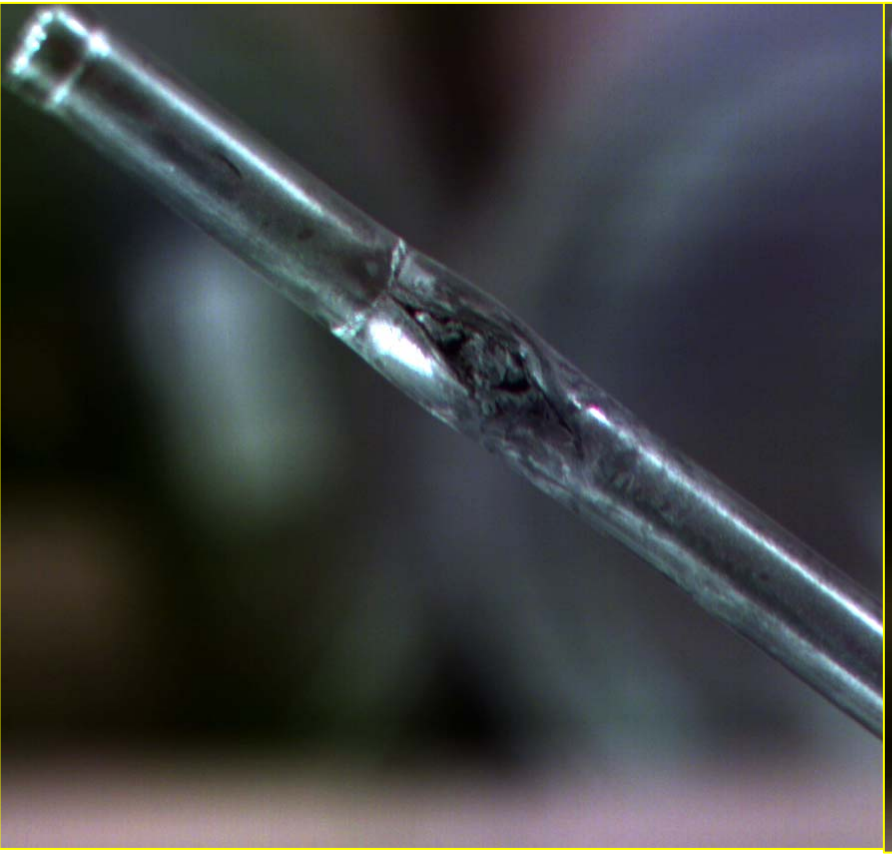


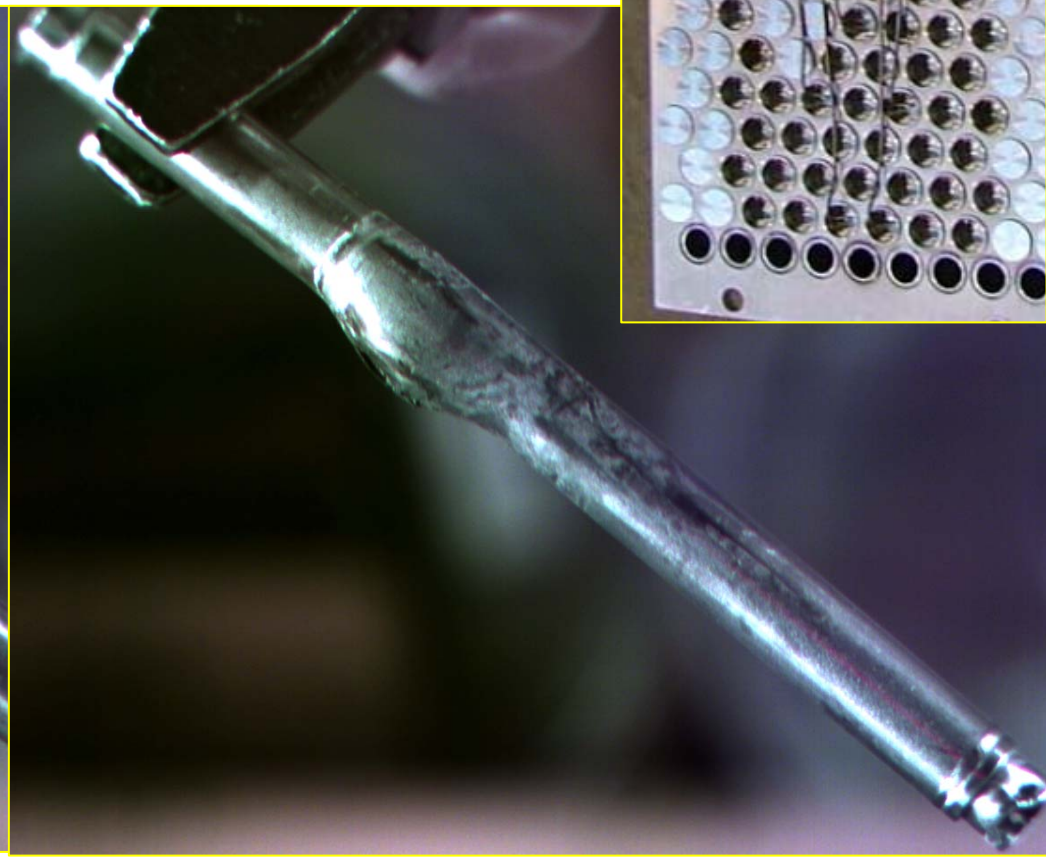
Irradiation history of STIP-IV

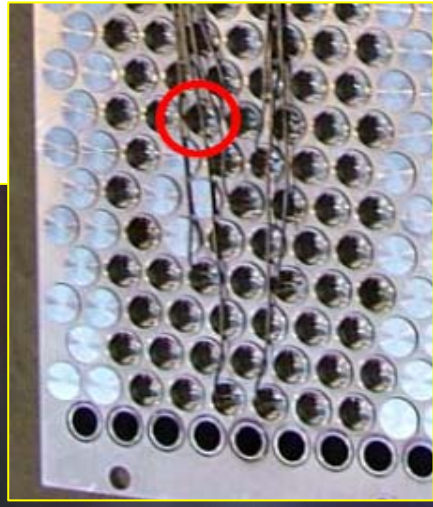
STIP-IV was irradiated during 2004 and 2005

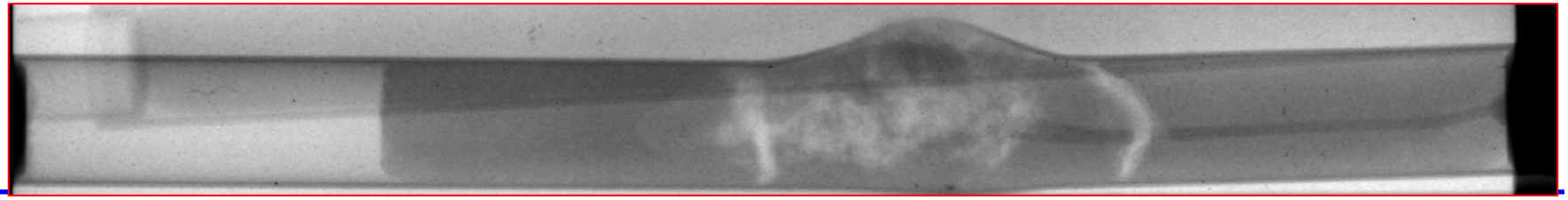


Some unexpected outcomes









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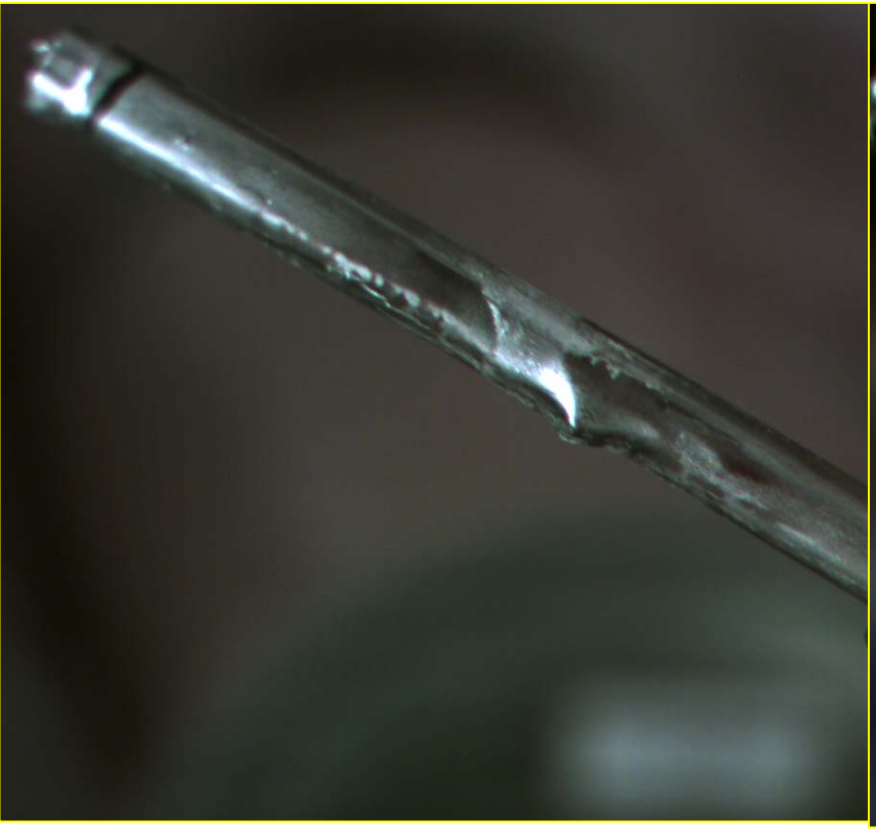
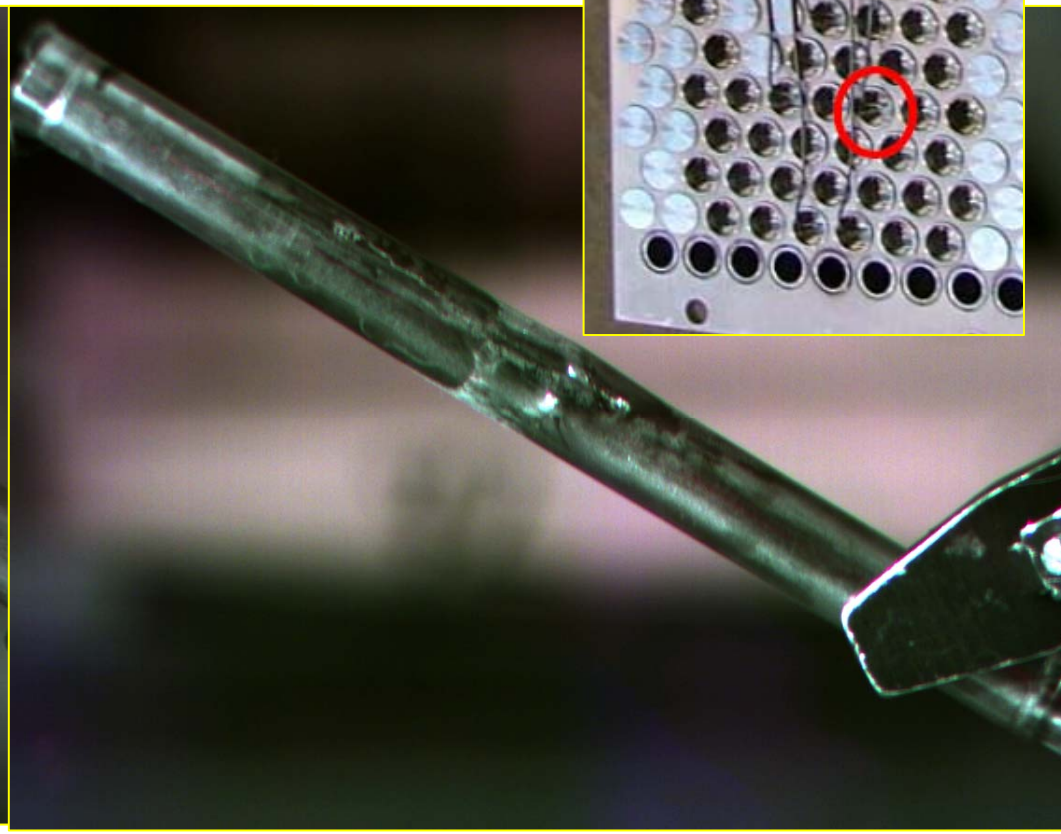
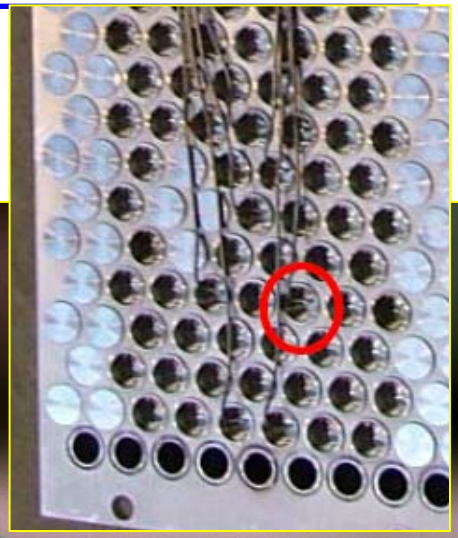
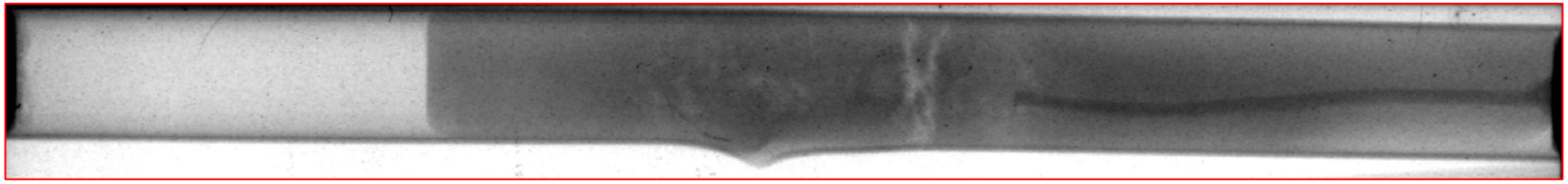
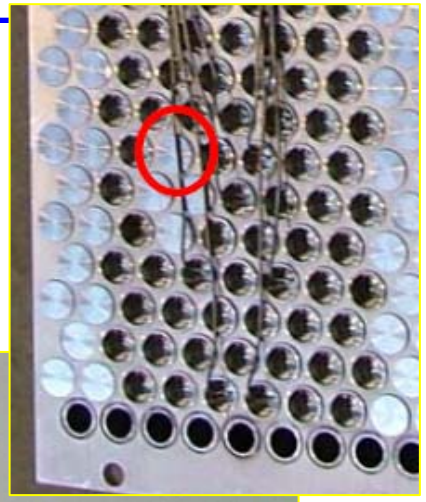


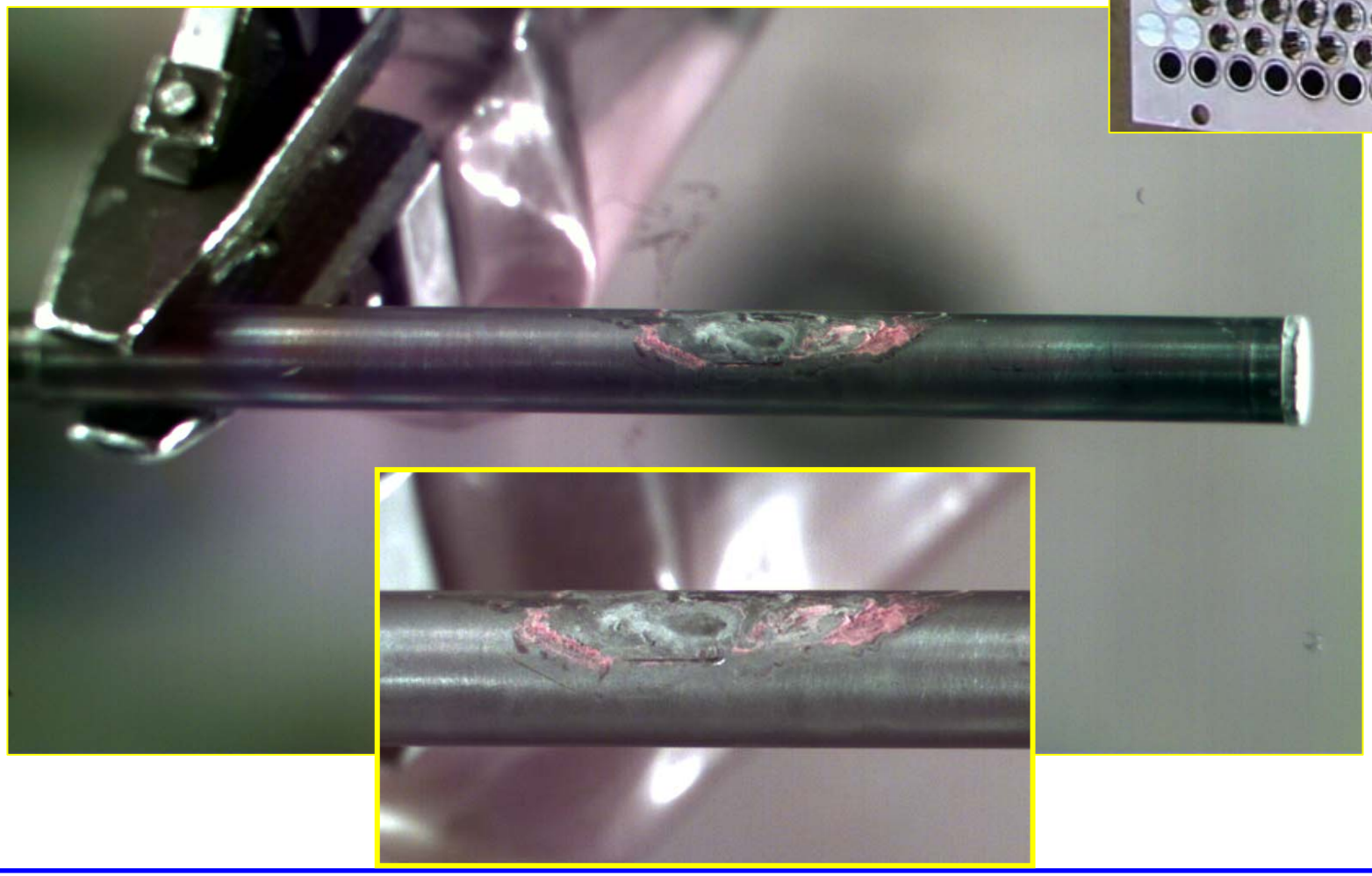




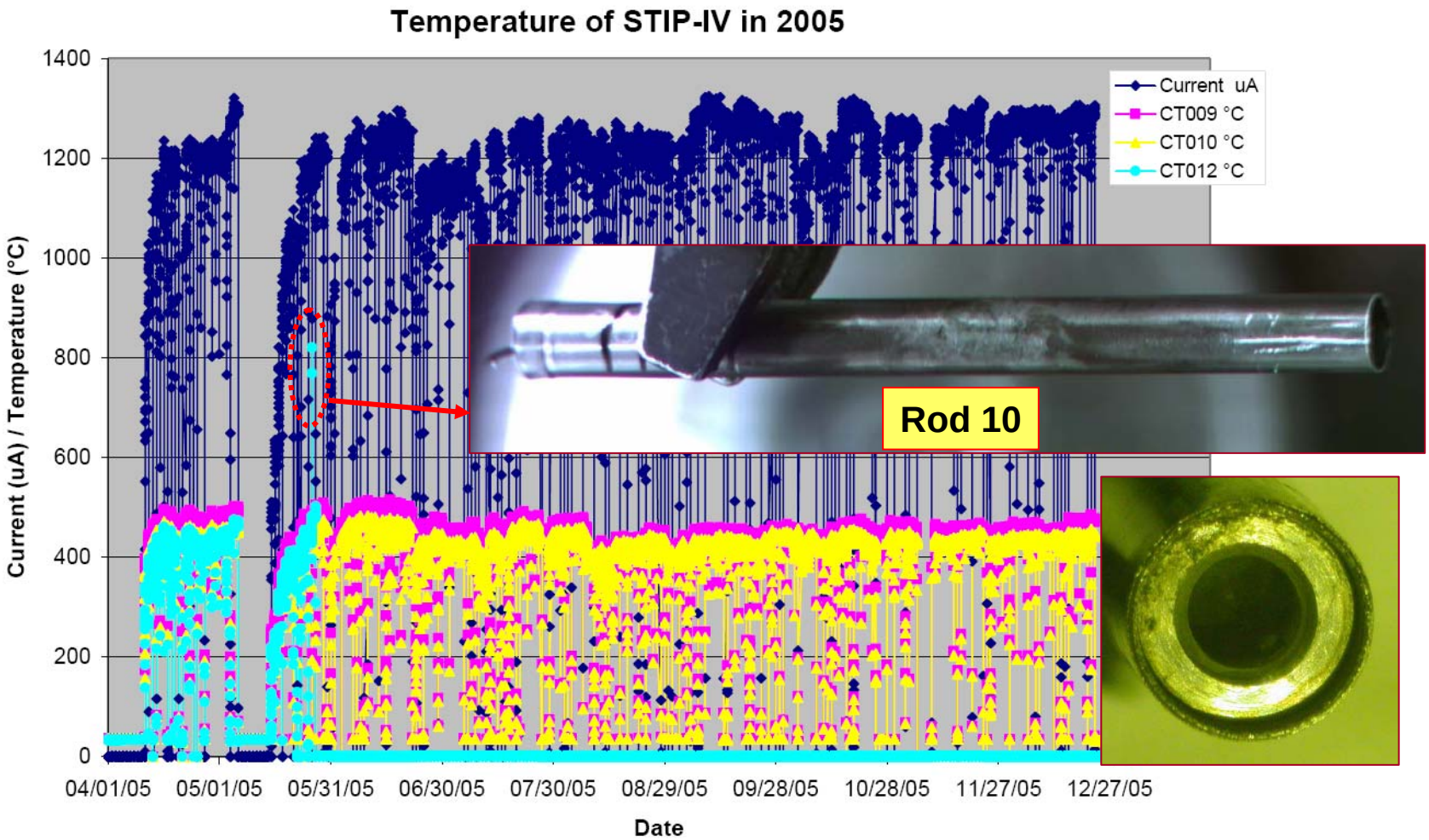


Some unexpected outcomes





Some unexpected outcomes



➢ **All specimens in Rod 10, 350+ tensile and TEM specimens, were lost!!**

Irr. Matrix

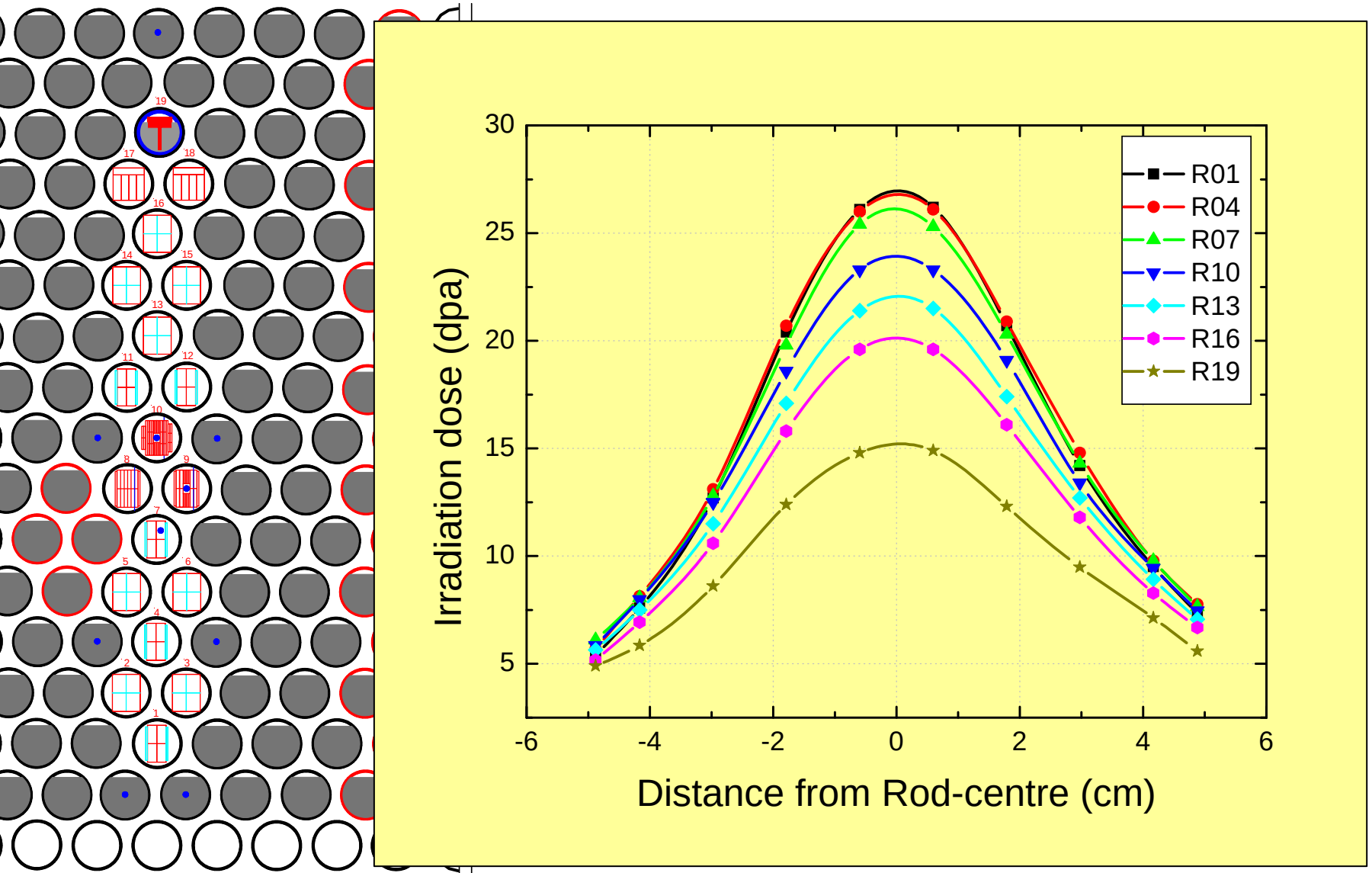
Irradiation Matrix of STIP-IV (Target-V)

ID	Materials	Tensile S	Tensile L	B-fatigue	Bend bar	Charpy	SP	TEM	SANS	Supplier
A	JLF1						1			CEA
B	T91-A					8	8	2		CEA
C	T91-B						1	2		CEA
D	T92	1				8	1	3		CEA
G	MA957					8	8	2		CEA
E	Eurofer 97 (Hip)	1								PIREX
F	Eurofer 97	2				27		6	1	PIREX
O	Eurofer 97 ods	1				5		5	3	PIREX
J	Ti-alloy					4				PIREX
K	FG-316	1						0		JAERI
L	HCM12A	1						0		JAERI
M	T92			9	8					PSI
B'	T91				8					
N	12CrWTi ods	1	6	9	10	16		0		PSI / CIAE
P	DIN 1.4922	2			10	16		0		PSI
H	DIN1.4313	2			10	16		0		PSI
Q	PM2000	1	8		8			0		PSI (LWV)
R	Ti-Al	1	9		6			7		PSI (LWV)
S	TZM		8		8			6		PSI (LWV)
T	SiC/C (1)				5					PSI (LWV)
U	C/C-SiC (1)				5					PSI (LWV)
V	C/C-SiC (2)				5					PSI (LWV)
W	SiC / SiC (1)				5					PSI (LWV)
X	SiC / SiC (2)					4				PSI (LWV)
Y	SiC / SiC (3)				6					PSI/JAERI

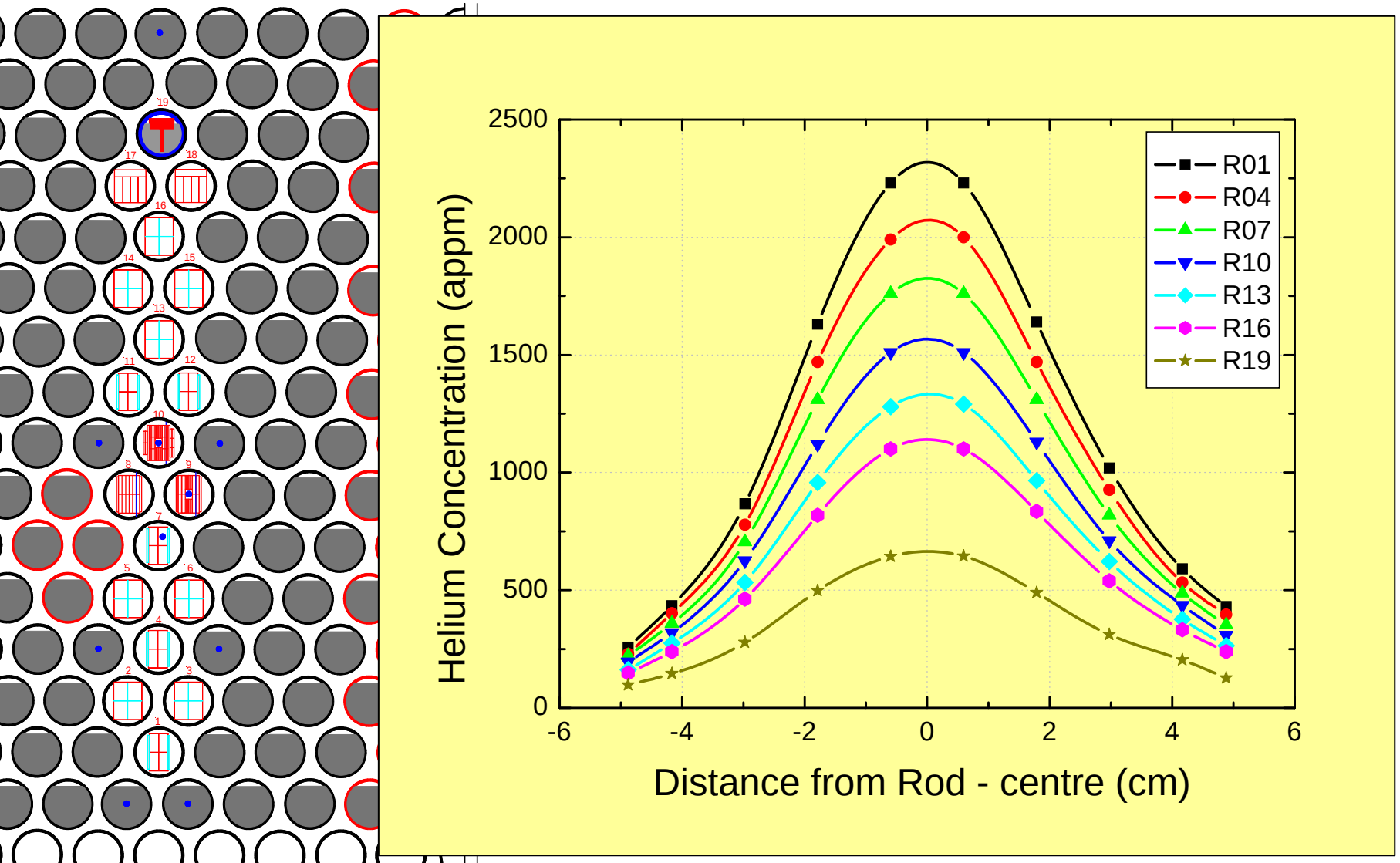
Irradiation Matrix of STIP-IV (Target-V)

ID	Materials	Tensile S	Tensile L	B-fatigue	Bend bar	Charpy	SP	TEM	SANS	Supplier
Z	mod. 316								6	CIAE
AA	Ta								2	CIAE
AB	W								2	CIAE
AC	W single cystal	4								CIPH
AD	W-3Re	4								CIPH
AE	W-9R	4								CIPH
AF	W-15Re	0								CIPH
UA	9Cr-2WVTa		5							LANL
UB	V-4Cr-4Ti		5					2		LANL
UC	T91		12					6		LANL
UD	EP823-I (STIP2)		12					10		LANL
UE	EP823-II (IPPE)		6					6		LANL
UF	A21N		5							LANL
UG	HT-9		12					12		LANL
UH	5Cr-2WVTa		5							LANL
UK	Ta HP							6		LANL
UL	Ta LP							5		LANL
UM	Ta Single crystal		5					5		LANL
UN	Fe Single crystal							8		LANL
UO	NiAl							5		LANL
UP	ZrN							5		LANL
UR	FeAl							5		LANL
US	RuAl							5		LANL
UT	50Mo-20Ru-15Pd-15Rh							6		LANL
UV	UMT122							3		LANL
UX	UMT91							6		LANL
UZ	UMHT-9							5		LANL
FA	12YWT		5					2		LANL
FD	14YWT		5					2		LANL

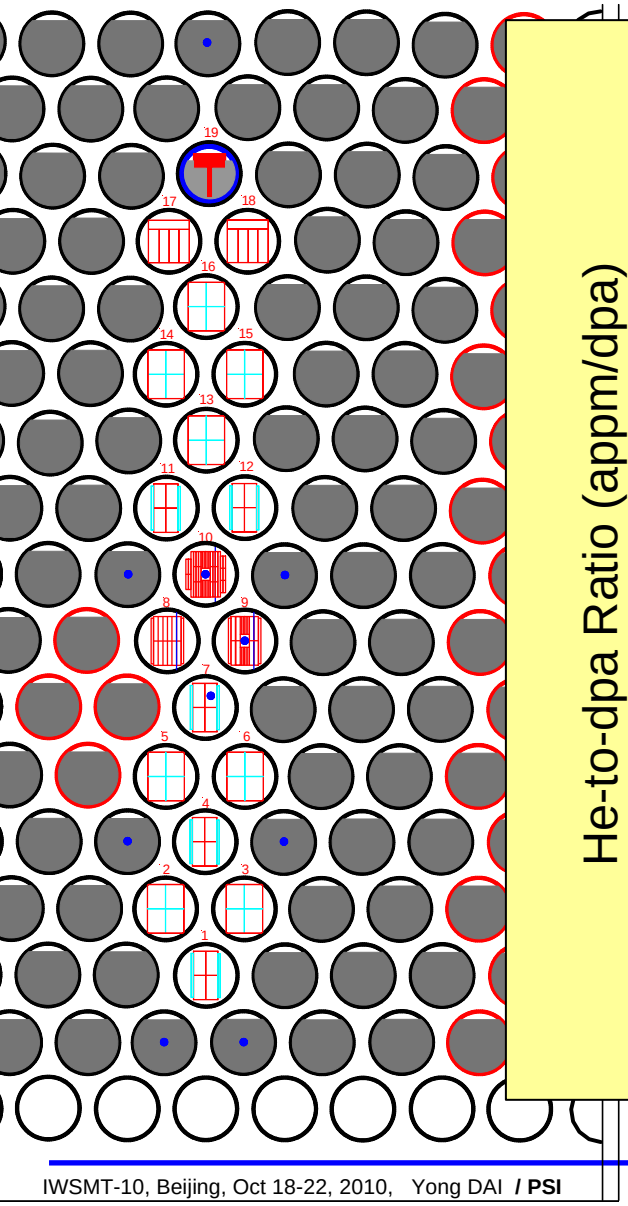
Irradiation dose calculation of STIP-IV

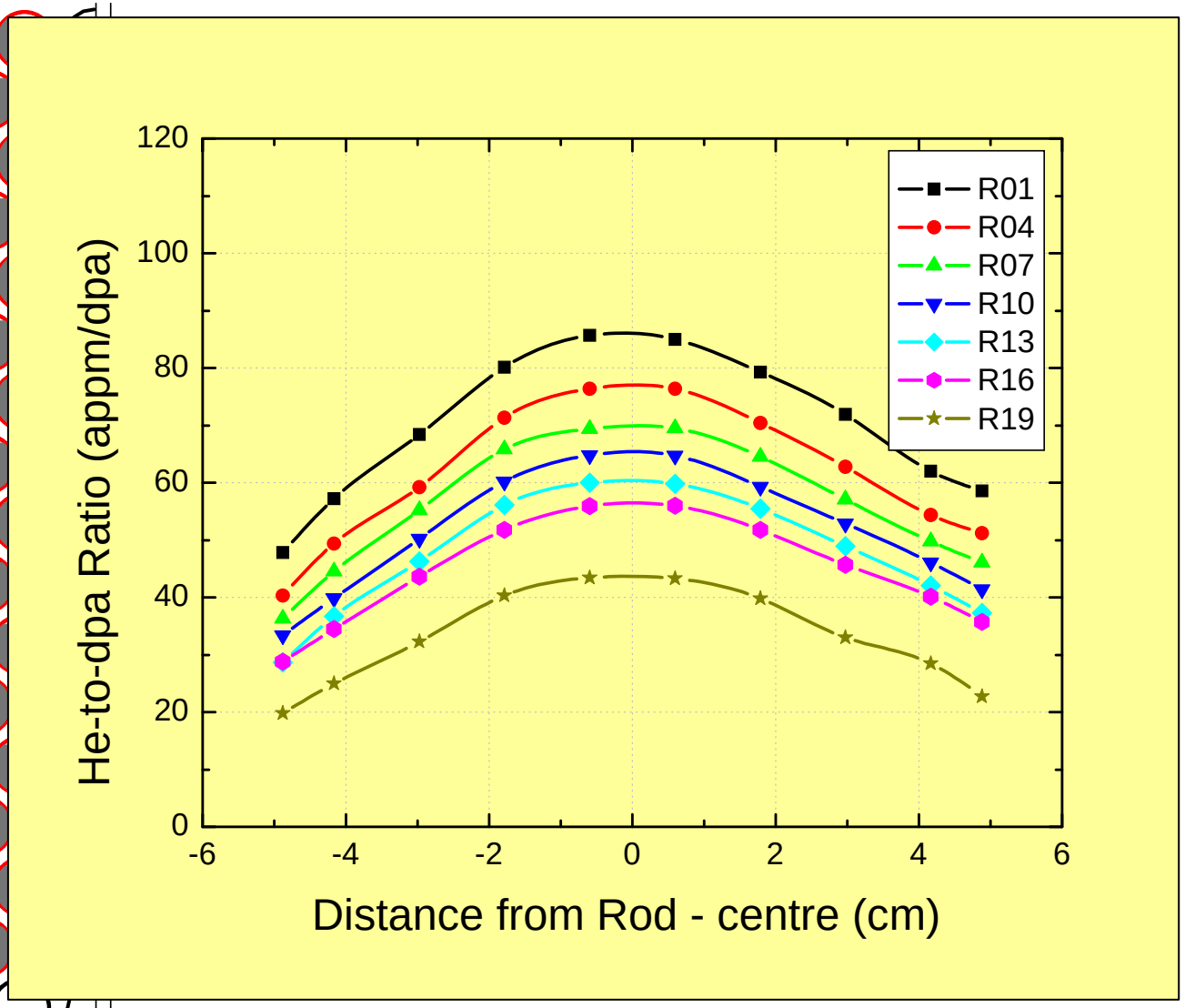


Irradiation dose calculation of STIP-IV

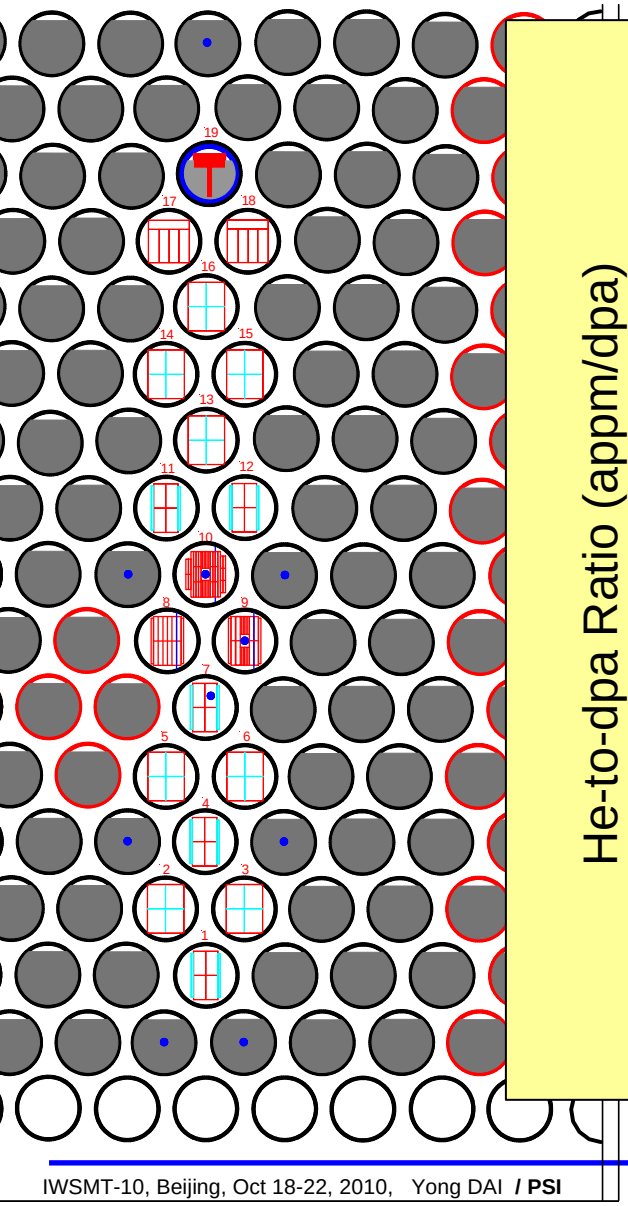


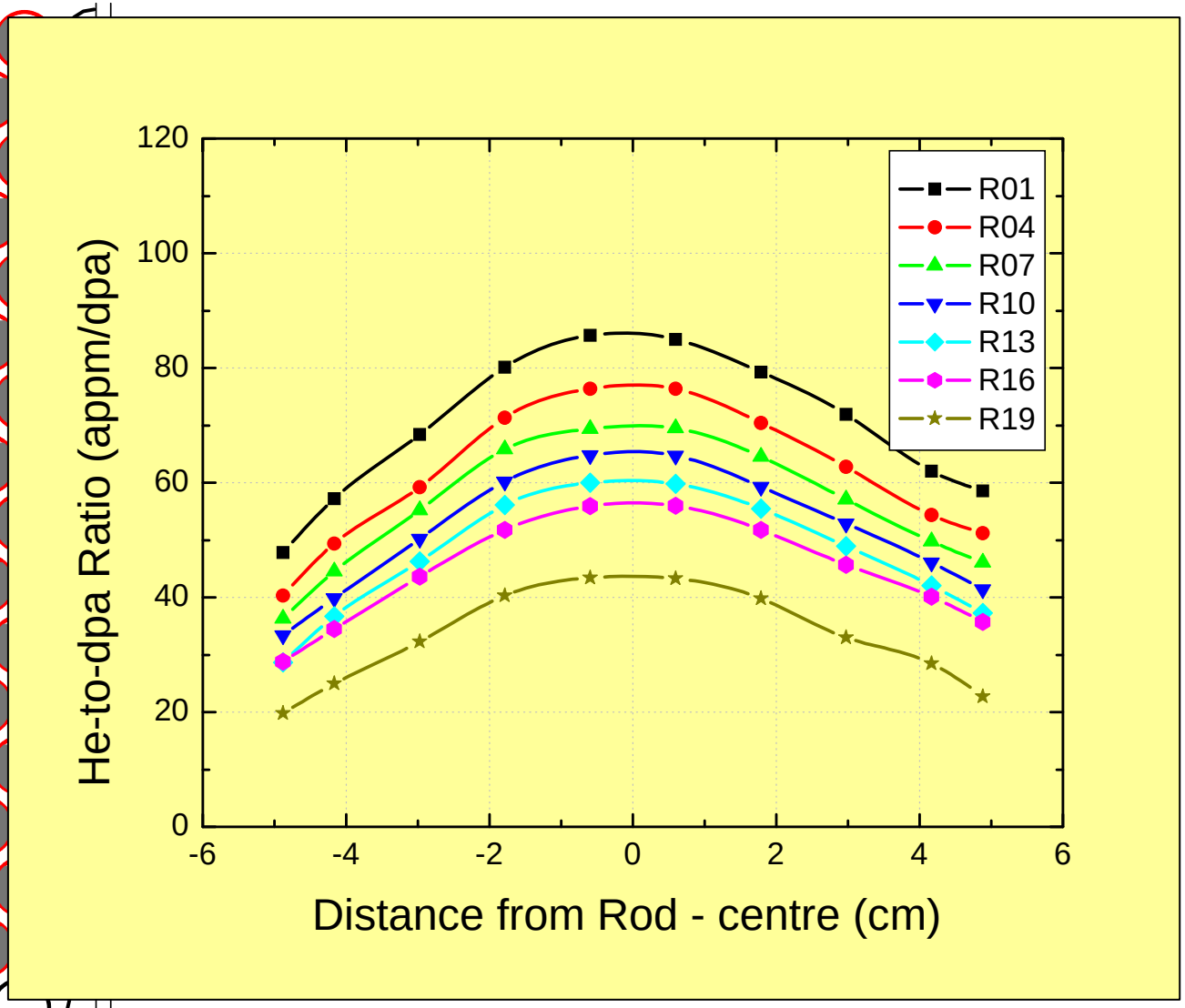
Irradiation dose calculation of STIP-IV





Irradiation dose calculation of STIP-IV

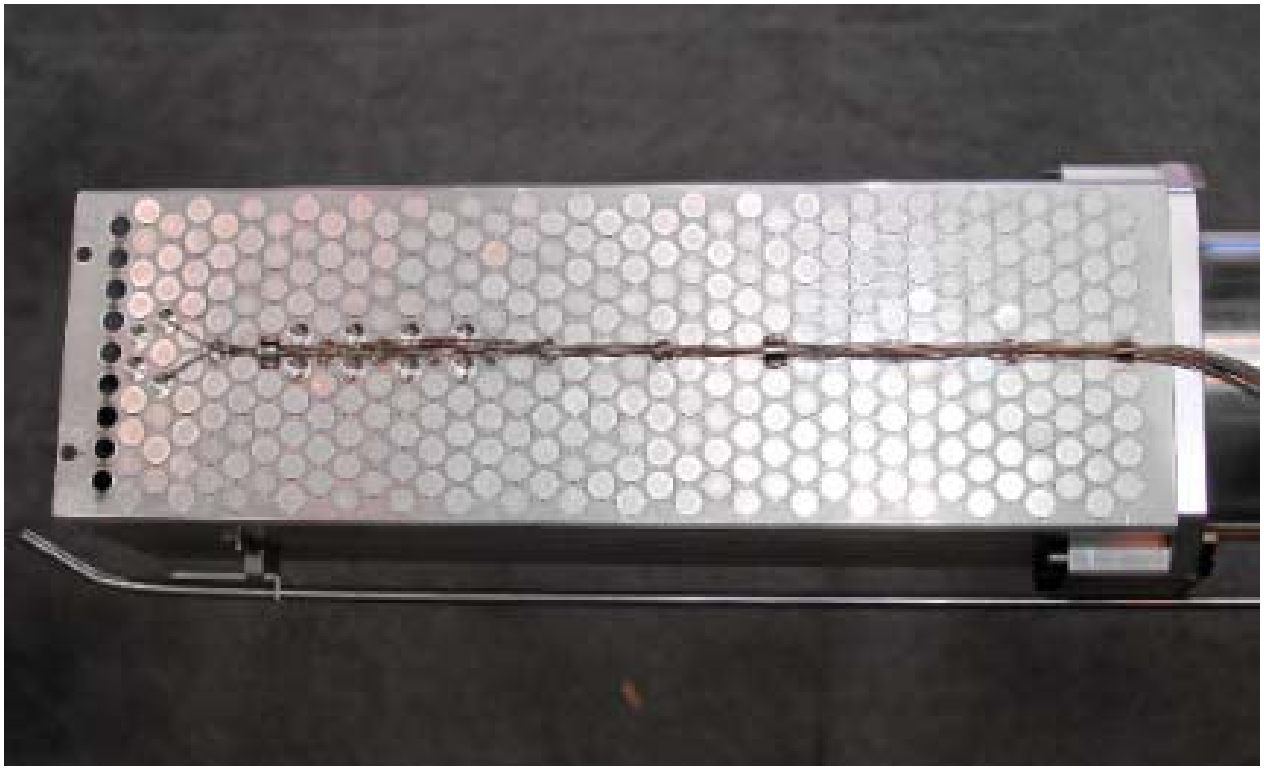




Status of STIP-IV

- Unpacking: Specimens were partly retrieved. Some samples have to be sorted and cleaned.
- Transport: Specimens of CEA were shipped. Specimens of LANL are to be shipped soon.
- PIE: Some impact Charpy tests have been performed.
  (e.g. Session -2: Henry's presentation)

STIP - V



Irradiation Matrix

Irradiation Matrix of STIP-V (Target-VI)

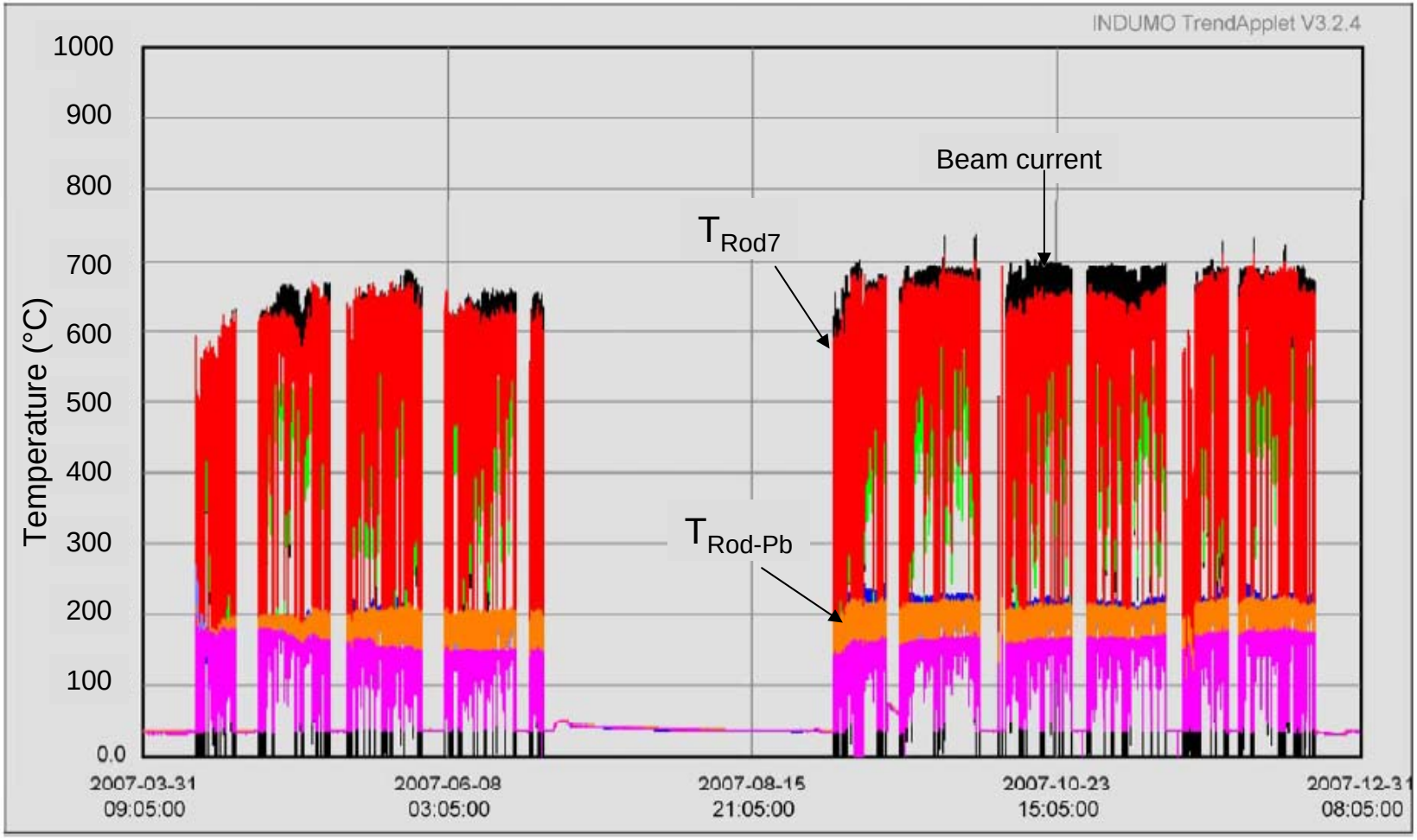
Materials	Tensile S	Tensile L	Bend bar-A	HT-1/3 CVN	KLST Charpy	SP	TEM	SANS	Compression	Supplier
T91	8				8	8	8			CEA
Eurofer ODS	8				8	8	8			CEA
Eurofer	12				8	12	8			CEA
Eurofer "F"	4						8			CEA
Iron							7			CEA
Eurofer 97									15	CRPP
Fe-9Cr MA	16						6	3	15	CRPP
Fe-9Cr-0.1C MA	16						16	3	15	CRPP
CLAM	16				16		18	2		CRPP
Eurofer 97 ODS	12				16		21	2		CRPP
ODS Eurofer-FZK	30	12		12		16				PSI (ASQ)
ODS Eurofer-PL	18	12		12		16				PSI (ASQ)
12CrWTi ODS	12	12		12		12				PSI (ASQ)
PM2000	12	12		12		7				PSI (ASQ)
Inconel 718	8						8			PSI (ASQ)
Inconel 718 EBW	4						4			PSI (ASQ)
TZM		12								PSI (ASQ)
C/C-SiC			6							PSI (ASQ)
SiC/SiC TySA-CVI-Ref			6							PSI/ORNL
SiC/SiC TySA-CVI-Ref				12						ORNL/PSI
SiC/SiC TySA-NITE				8						ORNL/PSI
SiC/SiC CVD SiC				32						ORNL/PSI
SiC30										PSI (LWV)
DIN1.4313		18	4							PSI (LWV)

Irradiation Matrix of STIP-V (Target-VI)

Materials	Tensile S	Tensile L	Bend bar-A	HT-1/3 CVN	KLST Charpy	SP	TEM	SANS	Compression	Supplier
Crofer APU22		12					12			LANL
MA957		12					12			LANL
MA956		12					12			LANL
316L-GS							20			LANL
HT9-GS							23			LANL
Ceramic							6			
HT9-WO		6								LANL
HT9-Shot		6								LANL
T91-Shot		6								LANL
T91-LP							12			LANL
HT9-LP							12			LANL
MA956 Weld		6								LANL
MA956-316L W		6								LANL
9Cr2WVTa		9					14	8		CIAE
HCLAM								8		CIAE
SS316LN		9					16			CIAE
W-26%Re		6								CSNS
SS316L base metal							8			JAERI
SS316 base metal							8			JAERI
SS316L GBE metal							8			JAERI
SS316 GBE metal							8			JAERI
2 complete rods of FM and FM-ODS samples.										UCSB

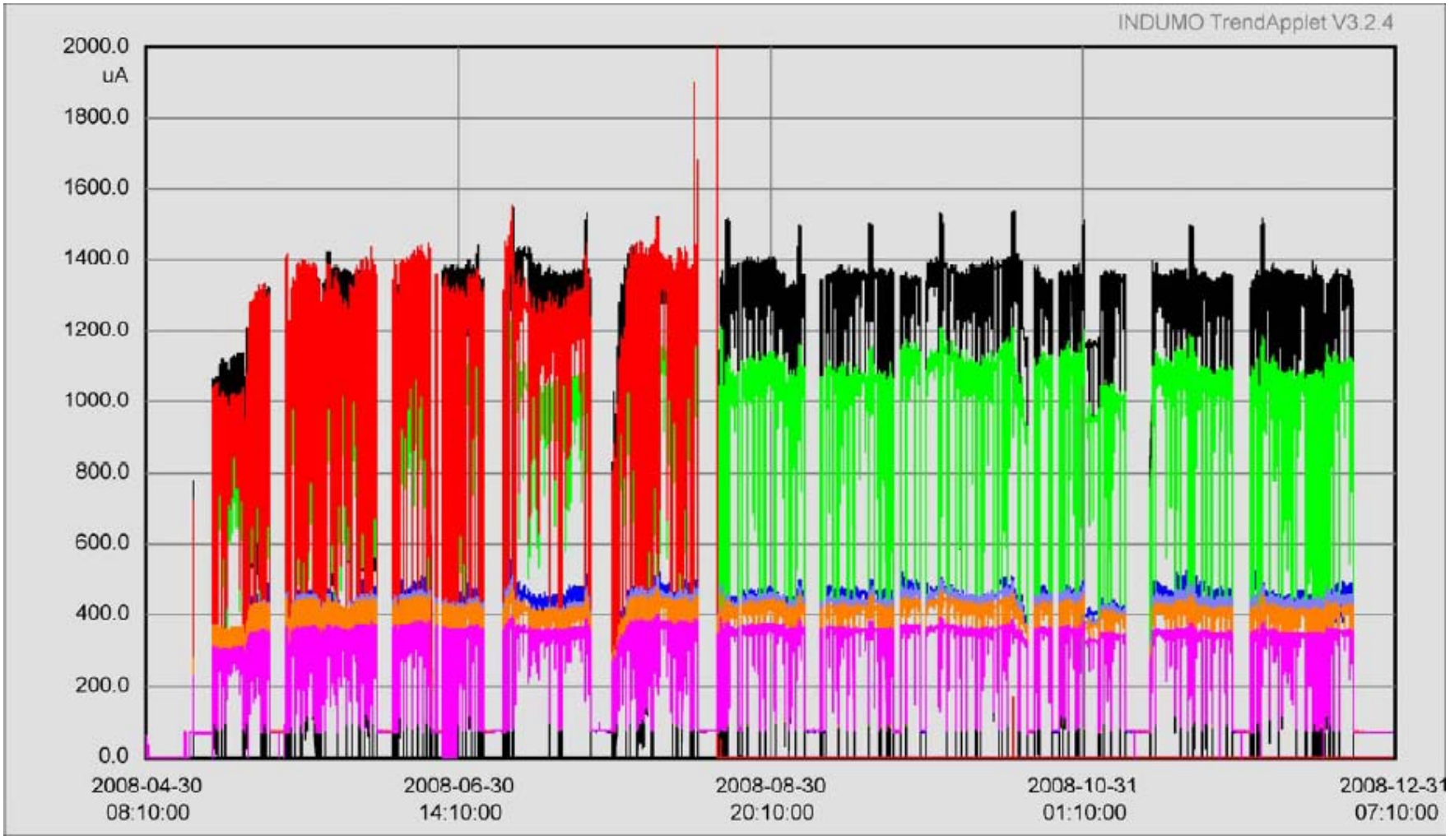
Irradiation history of STIP-V

Temperature and proton beam current in 2007



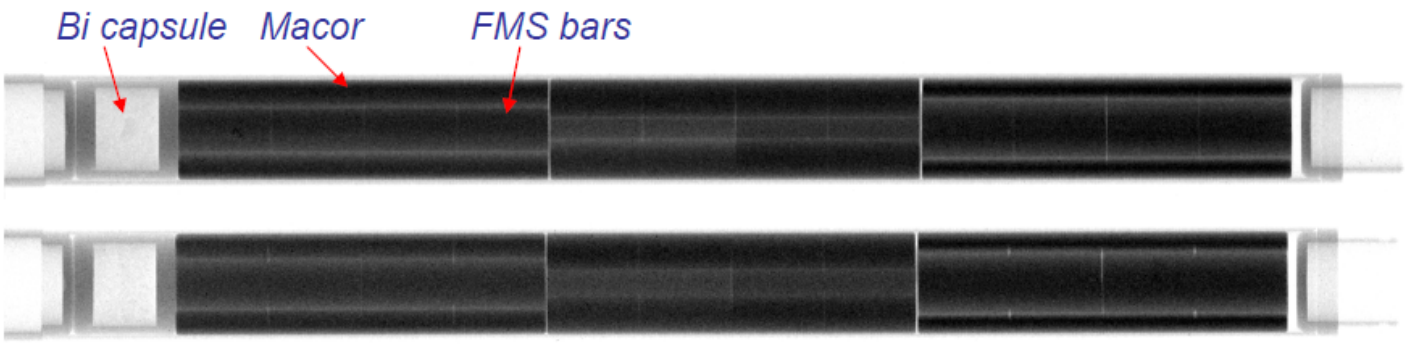
Irradiation history of STIP-V

Temperature and proton beam current in 2008

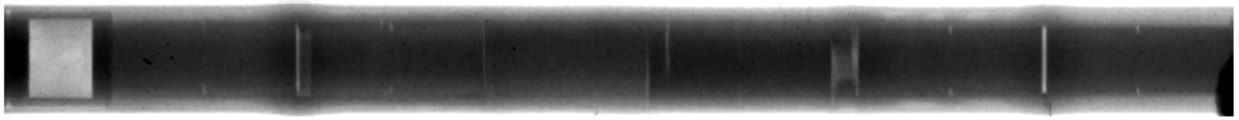


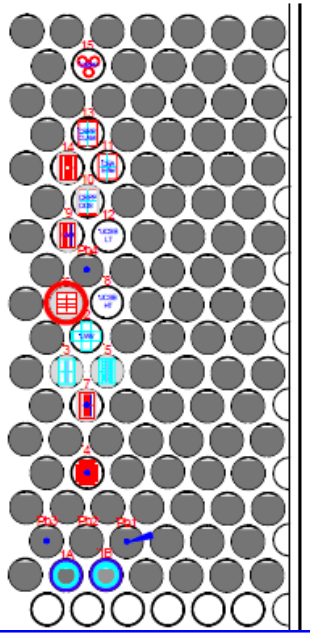
Neutron radiography inspections

Before irradiation



After irradiation

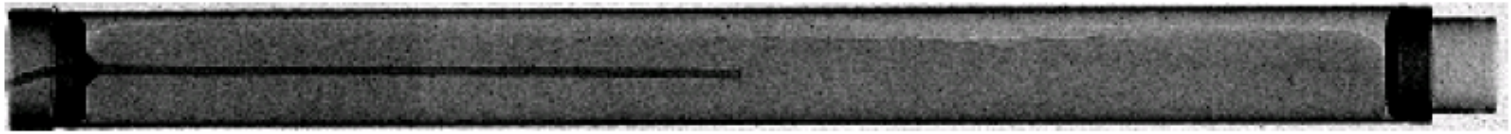




STIP-V (Target-7), Rod 6

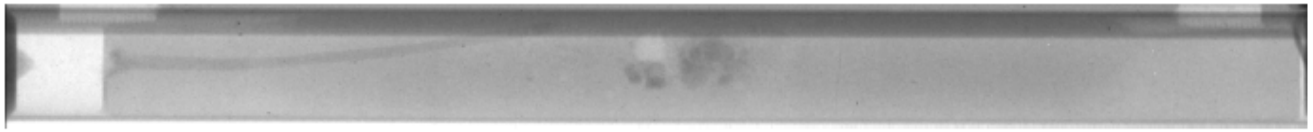
Neutron radiography inspections

Before irradiation (example)



After irradiation

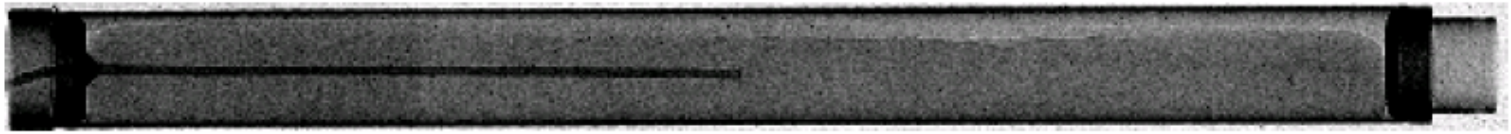
R-Pb1



R-Pb4

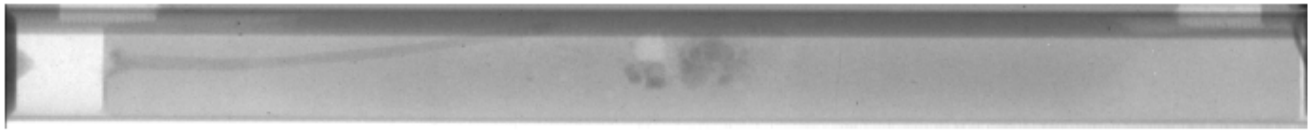
Neutron radiography inspections

Before irradiation (example)



After irradiation

R-Pb1



R-Pb4

Status of STIP-V

- Irradiation was successfully done.
- Specimen rods were extracted from the target and stored in the underground storage of PSI's hot-lab.
- Unpacking of specimens will be done after the extraction of MEGAPIE samples, expected in 2013-2014.

STIP-VI

- Irradiation is being prepared.
- Majority of the specimens are provided by the fusion materials community.
- Specimens are mainly from FM and FM-ODS steels to be irradiated at 300-400°C and 500-650°C.
- Some specimens will be irradiated in environment of PbLi, PbBi and PbAu.
- Irradiation will be conducted in 2012-2013 or 2012-2014.
- The maximum dose will be above 25 dpa (for 2-year irradiation) or close to 40 dpa (for 3-year irradiation).

Thank you!!
谢谢!!