PASI WP1

PASI meeting 28th February 2013

WP1 progress report

D.M.Jenkins

PASI WP1

- M1.1 Review of existing and proposed targets for high power neutron production
  - M1.1.1 Review of spallation targets – Stephen has discussed this with Fermi Lab and SNS too

Existing Targets

Milestone 1.1 requires a review of existing (or previously constructed or under-construction) high power targets, whether for neutron spallation or otherwise.

NB:

- 0 in columns for pulses indicates CW operation.
- X (@Y) power indicates that X is the design power but has only achieved Y megawatts in operation so far.
- Powers in Watts are time-averaged; energies in Joules are for an individual pulse. The kJ/pulse column shows beam energy, whereas the volumetric (W/cm^3, J/cm^3) shows the heat deposited in the target at the most intense point.
- Temperatures are the max and min attained by the target material during operation. Rise per pulse is the highest ΔT found anywhere in the target.

Facility	Power: MW avg.	kJ/pulse (rep. rate, Hz)	W/cm^3 (J/cm^3)	Material: Target	Coolant	Window	Temperature: Max (Min), °C	Rise in pulse, K	Beam: Species	Energy, GeV	Pulse length, µs	Operation: year(s) beam on target	Target lifetime
J-PARC - Current Hadron Target[5]	0.075	3.5 (0.167)	200 (1240)	Pt(Au)-rod, Cu-base	H_2O	Be	872 (avg. 407)	710	p	30	2000000	2012	
J-PARC - T2K[5]	0.75	2500 (0.3)	83 (300)	C	He	Ti-6Al-4V	800 (30)	196[4]	p	30	5	2009	5 years
MiniBooNE[7]	0.032	6.4 (5)	120 (24)	Be	Air	Be		7[4]	p	8	1.6	2002	5+ years
NuMI[7]	0.4	750 (0.53)	320 (600)	C	H_2O	Be		391[4]	p	120	8.6	2004	1 year
ANU/NOvA[7]	0.7	933 (0.75)	450 (600)	C	H_2O	Be		391[4]	p	120	10	2012	0.5 year
FNAL Pbar[7]	0.052	104 (0.5)	7650 (15300)	Inconel	Air	Be		4287[4]	p	120	1.6	1986	0.5 year
PSI SINQ/Solid Target[6]	0.97	0	800	Pb/Zr	D_2O	$AlMg_3$ (D_2O cooled)	500 (30)	0	p	0.59	0	1997	2 years
PSI SINQ/MEGAPIE[6]	0.97	0	1000	LBE	LBE	SS T91 (D_2O cooled)	340 (230)	0	p	0.59	0	2006 (only)	1 year
PSI UCN[6]	0.014 (1.42 peak)	10400 (0.00125)	500	Pb/Zr	D_2O	$AlMg_3$ (D_2O cooled)	500 (30)	470	p	0.59	2000000–8000000	2011	>20 years
SNS[2]	1.4 (@1.0)	23 (60)	750 (13)	Hg (in stainless steel)	Hg	Inconel-718 (Aluminum-6061 next change-out)	200 (60)	7[4]	p	1	0.7	2006	5000MW.hrs design (10DPA), 3250 so far
ISIS TS1[3]	0.2 (@0.16)	4 (50)	1000 (25)	W (Ta clad)	D_2O	Inconel-718 (water cooled)	250 (30)	10[4]	p	0.8	0.1 (x2, spaced by 0.3)	1985	~5 years
ISIS TS2[3]	0.05 (@0.04)	1 (50)	1000 (100)	W (Ta clad)	H_2O	Al alloy 5083-0 (passive He cooled)	400 (36)	39[4]	p	0.8	0.1 (x2, spaced by 0.3)	2008	~5 years
LANSCE - Lujan	0.1	5 (20)	350 (18)	W				7[4]	p	0.8	0.25		
LANSCE - UCN	?	? (20)	350 (18)	W				7[4]	p	0.8	0.25		
LANSCE - IPF	0.1	5 (20)	350 (18)	Various					p	0.1?	0.25		
CNGS[1]	0.51	1538 (2/6s, 50ms apart)	?	C					p	400	10.5	2007	

Sources

Original whole table: John Haines (SNS), updated by Patrick Hurh (FNAL), arrived at Stephen Brooks (RAL) via ISIS.

1. http://www.hep.princeton.edu/mumu/target/ilias/ilias_101909.pdf slide 4
2. E-mail from Bernie Riemer, Van Greaves (ORNL). 200°C is maximum mercury hot-spot temperature, 60°C is worst-case inlet temperature.
3. David Jenkins (ISIS, RAL)
4. Rough calculations by Stephen Brooks using the J/cm^3 column and densities and specific heats of materials from the web *at room temperature*. Should be replaced by more accurate values if possible.
5. E-mail from Hideaki Hotchi (J-PARC).
6. E-mail from Bertrand Blau (PSI).
7. Updated spreadsheet from Patrick Hurh (FNAL).

Future Targets

Milestones 1.2 and 1.3 require knowledge of the requirements for future high power target projects and candidate target materials.

PASI WP1

- M1.1 Review of existing and proposed targets for high power neutron production
  - M1.1.2 Review of other neutron production targets

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ESS Lund[3]	5	357 (14)	5200 (371)	W	He	?	500	137	p	2.5	2860	2019	
EURISOL	4	80 (50)	100000 (2000)	Hg				1059[2]	p	2.2	3		
IFMIF	10	0	100000	Li(l)				0	d	0.04	0		
J-PARC - Future Hadron Target[4]	0.75	32 (0.292)	140 (98)	rotating Ni disk	H_2O	Be	78.6 (47.9)	30.7	p	50	700000		
J-PARC - T2K Upgrade	4	13333 (0.3)	? (?)	C					p	50	5		
Project X - Kaon[5]	1+	0	?	C				0	p	3	0	2024	2 years
Project X - Muon[5]	1+	0	?	C				0	p	3	0	2024	2 years
Project X - Nuclear[5]	1+	0	?	High-Z				0	p	1.5-3	0	2020	2 years
Project X - Energy Station[5]	1+	0	?	LBE?				0	p	1.5-3	0	2020	1 year
LBNE[5]	0.7	1000 (0.7)	178 (254)	C	H_2O	Be		166[2]	p	120	10	2023	0.5 year
LBNE - Upgrade[5]	2.3	3286 (0.7)	592 (846)	C				552[2]	p	120	10	2030	0.25 year
FRIB	0.4	0	60000000	C				0	Ions (p to U)	1-48	0		
SNS STS long pulse	1.5	75 (20)	39 (57)	W/Ta (rotating) or Hg					p	1.3	1000		
Neutrino Factory[1]	4	27 (50x3)	100000 (750)	Hg (jet)	Hg		1221[2] (30)	397[2]	p	5-15	0.007 (x3 in 240)		
Muon Collider[1]	4	270 (15)	100000 (7500)	Hg (jet)	Hg		4002[2] (30)	3972[2]	p	5-15	0.007		
LANSCE - Mat Test	0.8	6.7 (120)	2400 (20)	LBE				12[2]	p	0.8	1000		

Sources

Original table John Haines (SNS), updated by Patrick Hurh (FNAL), arrived at Stephen Brooks (RAL) via ISIS.

1. E-mail from Kirk McDonald (Princeton).
2. Rough calculations by Stephen Brooks using the J/cm^3 column and densities and specific heats of materials from the web *at room temperature*. Should be replaced by more accurate values if possible. Neutrino factory max temperature calculated with the heating from 3 sub-pulses.
3. Information via Tristan Davenne (high-power targets group, technology divison, RAL)
4. E-mail from Hideaki Hotchi (J-PARC).
5. Updated spreadsheet from Patrick Hurh (FNAL).

Overlap with RadiATE

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- M1.2 Requirements for example future high power neutron projects, e.g. neutron spallation, ADS, irradiation, etc (milestone end of March 13)

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- M1.3 Candidate target materials (end March 13)
    - Rob and Stephen developing list
        - New ways of using existing materials set – meta materials?
    - Ali to set out ideas for figure of merit for materials too
  - M1.3.1 Materials already in use or under study (mid Dec 12)
    - See section 1.4
    - Sample of TS1 tungsten clad in tantalum with David Armstrong at Oxford for micrograph initially
    - Eamonn Quinn has samples of hipped tantalum being analysed for oxygen content at Oxford Science Park (Begbroke)
  - M1.3.2 Possible new materials (end Jan 13)
    - ISIS reviewing the use of molybdenum in conjunction with tungsten as a flux trap target
    - Chris Densham's team and Oxford University and the RadiATE collaboration
  - M1.3.3 Selection of materials for further study (end March 13)
    - Chris Densham's team and Oxford University and the RadiATE collaboration

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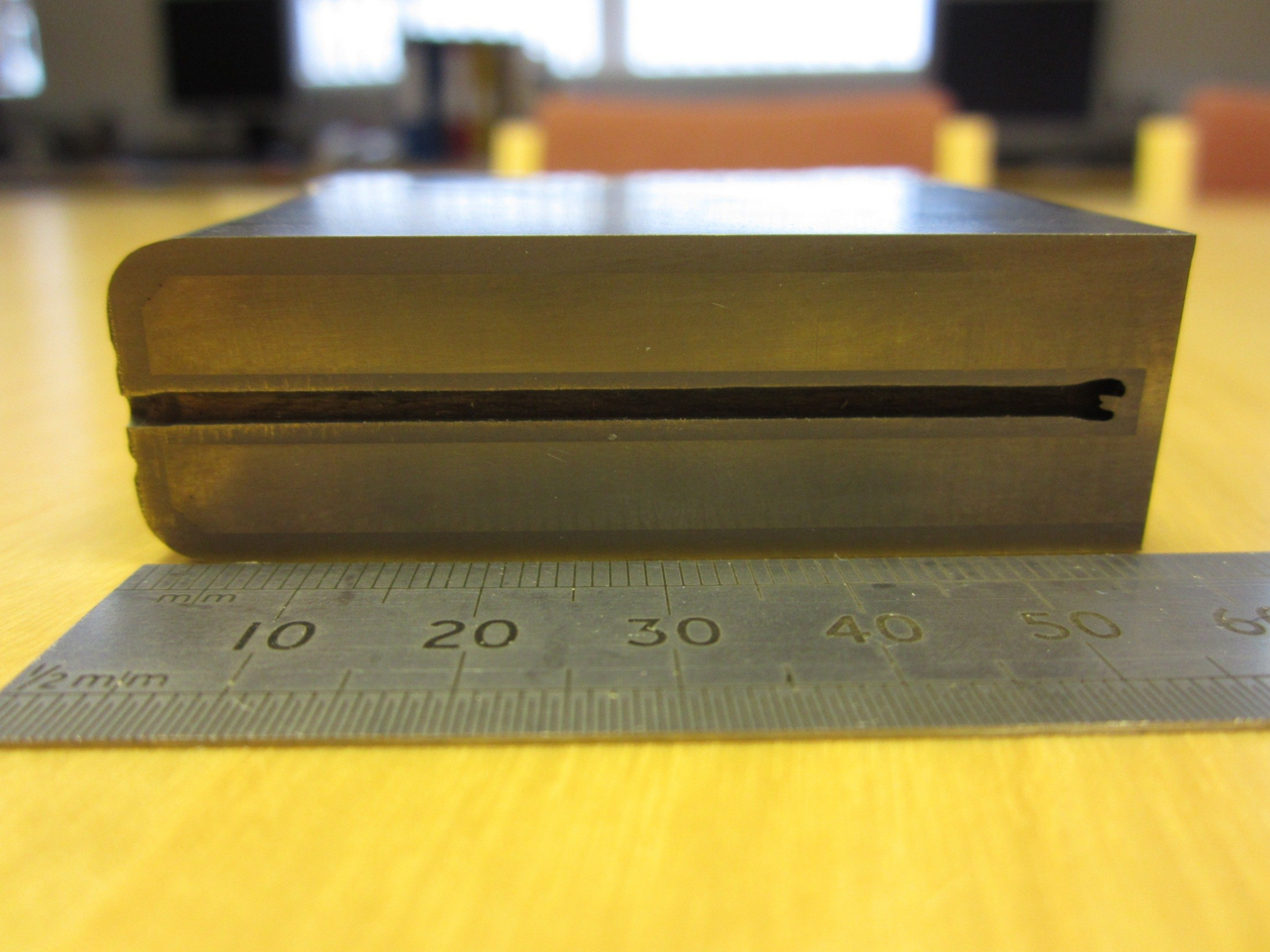
- M1.4 Limits of targets vs requirements (milestone end of March 13)
    - David J to set out ISIS target design philosophy?

  – M1.4.1 Maximum operating temperatures and cooling rates (milestone end Nov 13)
    - Chris/Tristan D/Peter L/Dan W analysis of ISIS TS1 and TS2 target cooling
    - David J review of existing CHF and BO curves used in ISIS design
    - Ali to review CHF and BO source material
    - Roger reviewing Binary Ice cooling and possible test programme

  – M1.4.2 Existing data on tensile strength as a function of temperature (Dec 13)
    - Results from PSI SINQ Target Irradiation Programme (STIP) – need pulling together perhaps?
    - Text book and supplier data
    - David J / Shu Yan Zhang carrying out measurement of residual strain in hipped TS1 target block on Engin X soon
    - Roger B to look at using pulsed hot wire rig to add to existing data set but at lower temperatures


m/m
10
20
30
40
50
½ m/m

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- M1.4 Limits of targets vs requirements continued
  - M1.4.3 Measurement of tensile strength for candidates using RAL test rig(s) (end Oct 14)
    - Eamonn Q- tensile tests carried out by test house on hipped tantalum
      - results presented at IWMST Ghent.
    - Roger as outlined above?
  - M1.4.4 Study of erosion/corrosion rates of target and target cladding materials. (End Jan 14)
    - Leslie J presented case of TS2 mkI target cladding failure and recovery at IWMST Ghent
    - Tristan D/Otto C planning water jet erosion on hipped tantalum samples and svd tantalum (Tantaline)
    - Eamonn Q – starting to review ISIS TS2 target cooling water conductivity changes
  - M1.4.5 Study/development of novel target condition monitoring systems. (Jan 16)
    - Roger B has proposed using thermal imaging via a fibre optic to monitor target temperatures

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ISIS

Eamonn Quinn[1]

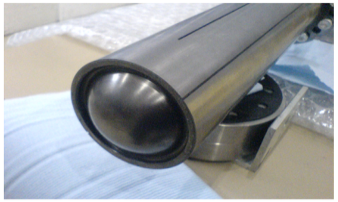
Material Properties Evaluation of a Hot Isostatically Pressed Tantalum Pressure Vessel for the ISIS TS-2 Target

[1] Science and Technology Facilities Council, Rutherford Appleton Laboratory, Didcot, OX11 0QX, United Kingdom.

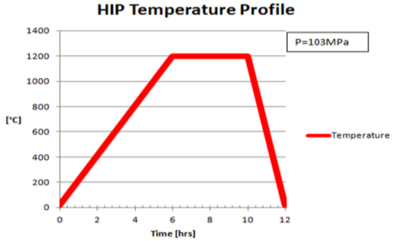
Computer aided engineering analysis requires sound mechanical properties data to be effective. High quality data for Hot Isostatically Pressed (HIP) Tantalum was not available so a series of tests were conducted to establish the in service properties of a pressure vessel assembly manufactured from materials made by this route.

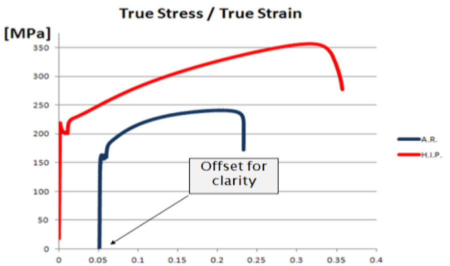
Tube Tensile Test Results.

CONDITION	ID	0.2%PS[MPa]	.UTS [MPa]	E [GPa]
A.R.	71485	194	238	
	71486	194	239	208.6
	71487	161	212	208.8
	Mean	**183.0**	**229.7**	**208.7**
	SD	19.05	15.31	0.17
H.I.P.				
	70779	207	268	173.1
	70780	187	270	171.5
	70781	186	264	171.4
	Mean	**193.3**	**267.3**	**172.0**
	SD	11.85	3.06	0.94

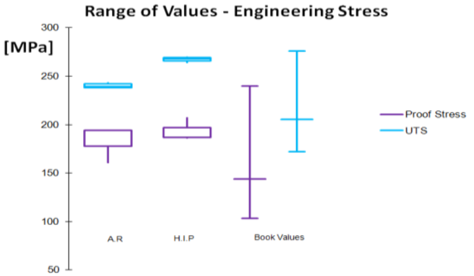


A Completed ISIS TS2 Target Awaiting Final Inspection.





Tensile Test Based on ASTM E8M



Conclusions

On the Tantalum sample tested the HIP process effected both UTS and Elastic Modulus. Increasing the measured UTS by approximately 16% and reducing the Elastic Modulus by a similar amount at room temperature.

The values found fell within the range of published data, all being toward the higher end.

Further Work

Material properties at elevated temperatures would be useful for future Target designs and so should be measured.

In this testing only a tube off cut was available for testing. Due to the sample size it was not possible to measure Poisson's ratio. It would be useful to measure this in any further work.

ISIS Second Target Station Tantalum Cladding Corrosion Problem and Resolution

Leslie Jones
November 2012

PASI WP1

- M1.5 Assessment of lifetime due to radiation (end Aug 14)
  - M1.5.1 Study of existing radiation damage measurements and limits (end Mar 14)
    - Stephen B investigating simulation of dpa and gas production from MARS code
  - M1.5.2 Identification of materials for which further radiation damage studies are necessary (end Aug 14)

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- M1.6 Radiation damage studies at an existing facility (end Mar 16)
  - Investigation of ISIS tantalum clad tungsten target with ~11 dpa
    - Roger has presented poster at IWMST in Ghent
    - Roger has opened communications with SCK CEN at Mol Belgium re cutting up target and testing too
  - Existing data from ISIS tantalum target with ~11 dpa which was cut up and investigated in the late 1990s

Science & Technology Facilities Council ISIS

J. R. J. Bennett[1], T. R. Edgecock[1], M. D. Fletcher[1], D. M. Jenkins[1], I. Uytdenhouwen[2] and Members of ISIS Department[1], SCK•CEN[2] & the PASI Collaboration[3].

A Proposal to Measure the Properties of Tungsten from an ISIS Target following 800 MeV Proton Irradiation

[1] Science and Technology Facilities Council, Rutherford Appleton Laboratory, Didcot, OX11 0QX, UK
[2] Institute for Nuclear Material Science, SCK•CEN, Boeretang 200, N-2400 Mol, Belgium
3 http://pasi.org.uk/Main_Page

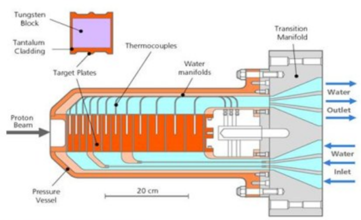
Some of the tungsten targets from the pulsed spallation neutron source, ISIS, at RAL, have received over 12 dpa; this is probably the highest dose received by any sample of tungsten. It is proposed to cut up one of these targets and measure the important mechanical and physical properties of the tungsten. This knowledge will be invaluable in the design of future tungsten targets receiving very high proton irradiations.

The ISIS Department has no suitable remote handling facilities to undertake these measurements. An ISIS tantalum target, with a dose of 12 dpa, was measured[1-3] in a collaboration at the Forschungszentrum Jülich. An agreement is expected to be reached with **the Belgian Nuclear Research Centre, SCK•CEN** to take the target, cut it open and make tests on the tungsten.

ISIS and the PASI Collaboration are looking for partners who can contribute or have an interest in the measurement of highly radioactive tungsten.

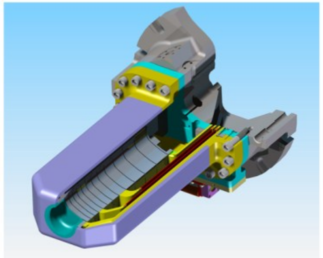
[1] J. Chen, H. Ullmaier, T. Floßdorf, W. Kühnlein, R. Duwe, F. Carsughi, T. Broome, J. Nucl. Mater. 298 (2001) 248-254.
[2] J. Chen, G. S. Bauer, T. Broome, F. Carsughi, Y. Dai, S. A. Maloy, M. Roedig, W. F. Summer, H. Ullmaier, J. Nucl. Mater. 318 (2003) 56-69.
[3] H. Ullmaier, ESS 03-131-T, January 2003, Design Properties of Tantalum or Everything you always wanted to know about tantalum but were afraid to ask.

Section through the ISIS Target



Welded Assembly of Tantalum-Clad-Tungsten Plates. Ready for the last weld.

3D Cut-away Diagram of the ISIS Target



Come and join us and bring your expertise!

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- M1.7 Neutron capture and delivery (end March 16)
  - M1.7.1 Review of existing and planned systems (end Aug 16)
  - M1.7.2 Identify possible improvements for new systems (end Jan 16)

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- M1.8 Shielding, remote handling, disposal, etc, aspects of targets, to be reviewed throughout studies (end Mar 16)