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Title: Irradiated T91 Testing from the MEGAPIE Experiment

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Irradiated T91 Testing from the MEGAPIE Experiment

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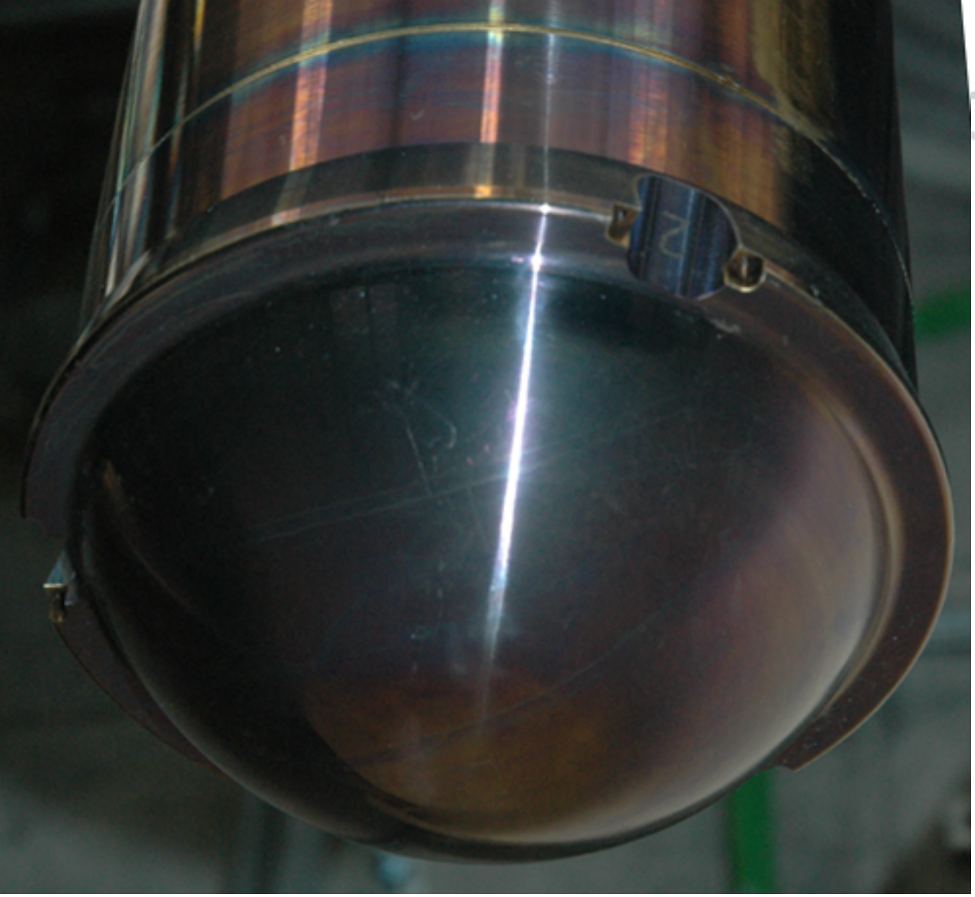
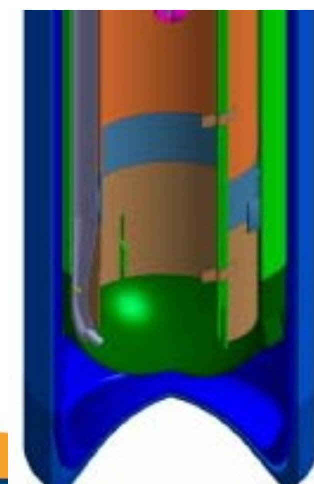
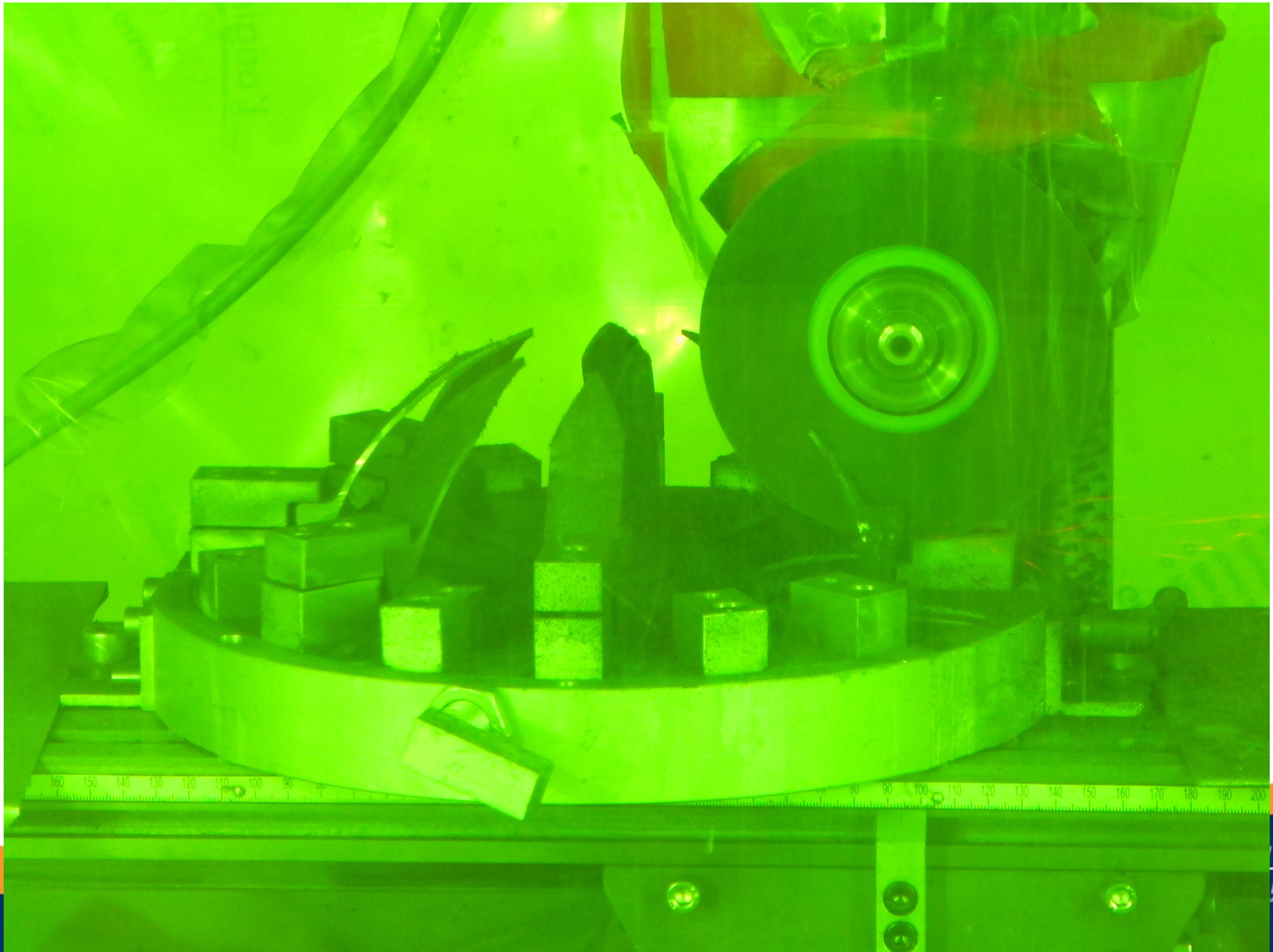
MEGAPIE!

- **Mega**watt **Pi**lot **E**xperiment
- Inserting a lead-bismuth target as the spallation target in the SINQ neutron source (590MeV Protons)
  - ADS R&D
  - Provides irradiated T91 (~9Cr, 1Mo, 0.1C, Si, Ni, V, Mn etc.) and 316SS samples
  - Lead-bismuth corrosion studies
- 15+ year project, ending this year
- 10 Labs, throughout the world
  - CEA, KIT, PSI, SCK-CEN, JAERI, LANL/DOE
  - CNRS, ENEA, KAERI


Sample Cutting



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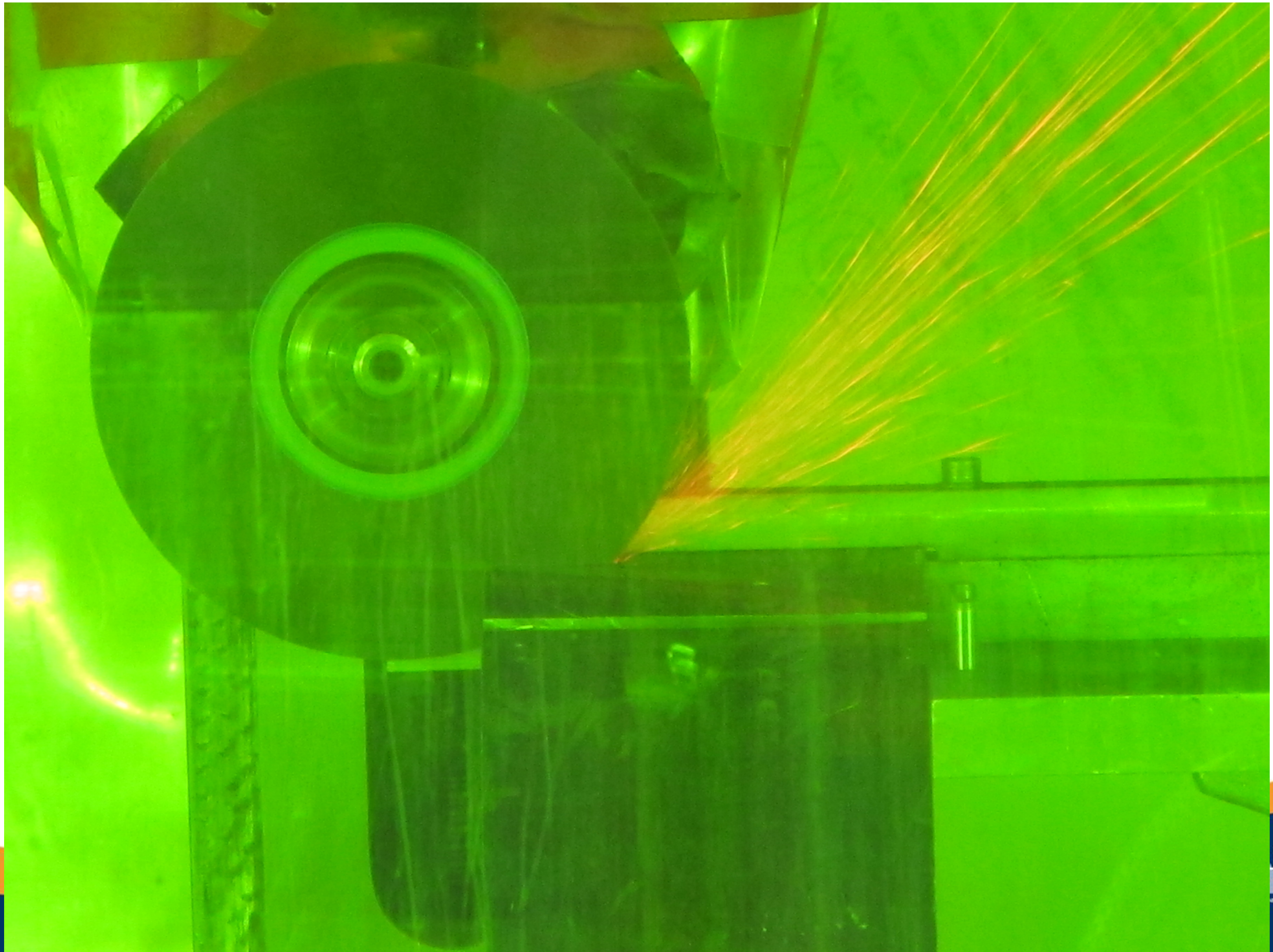

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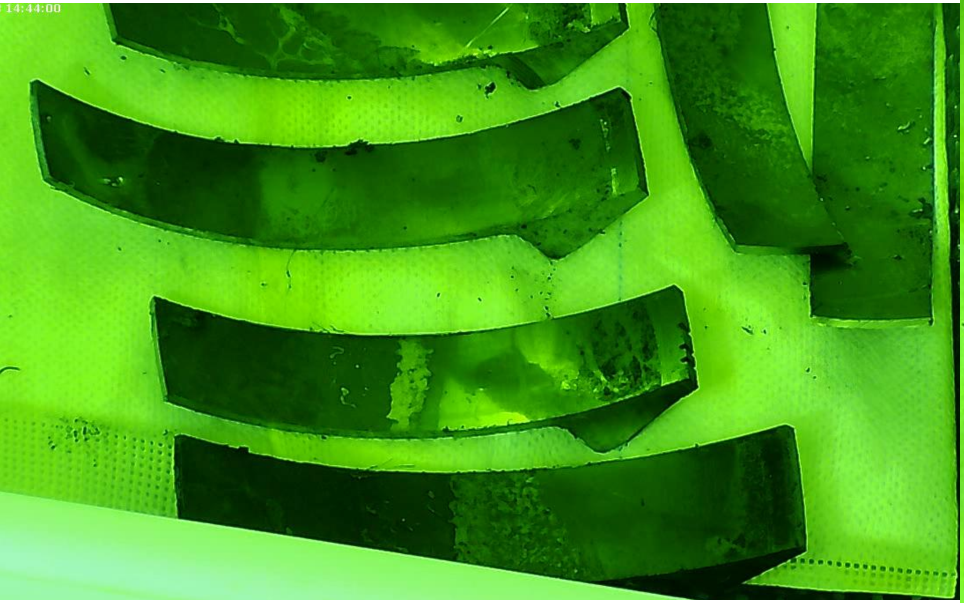

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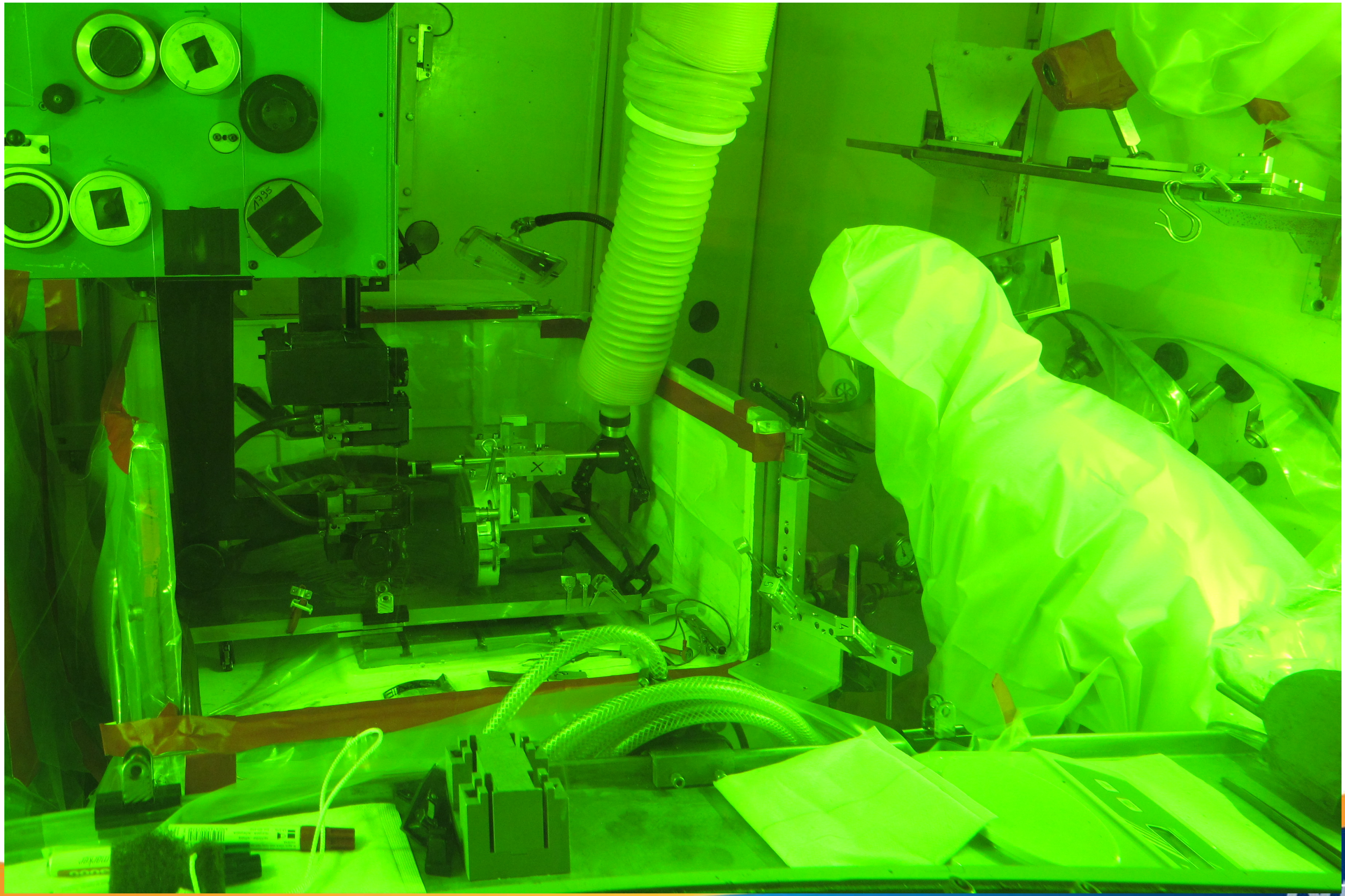

Tensile Samples

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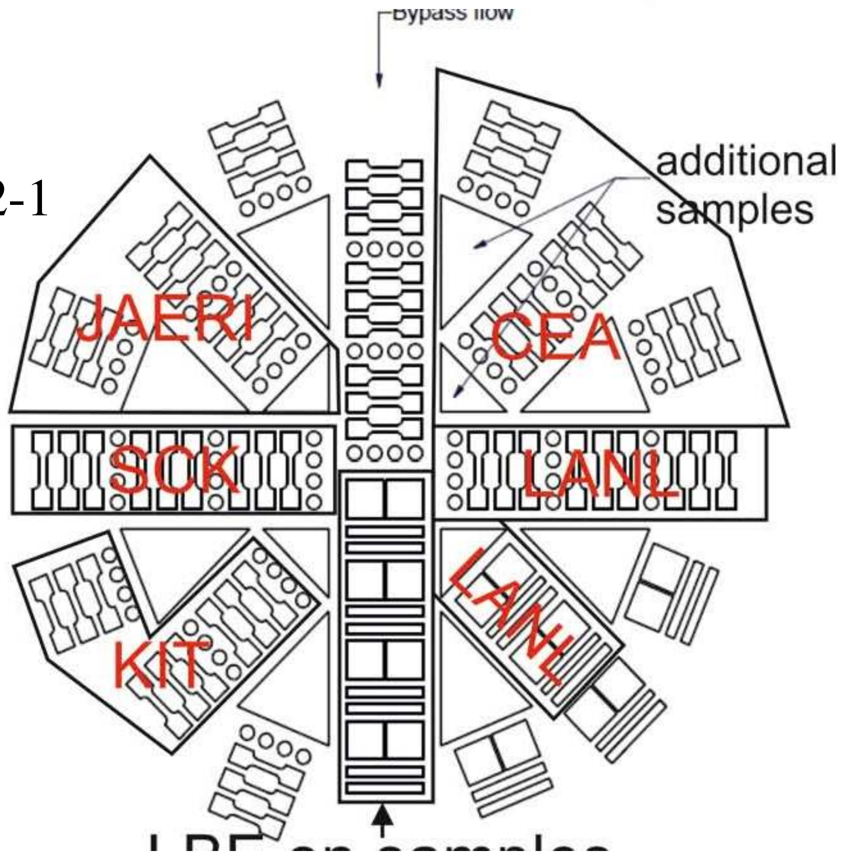
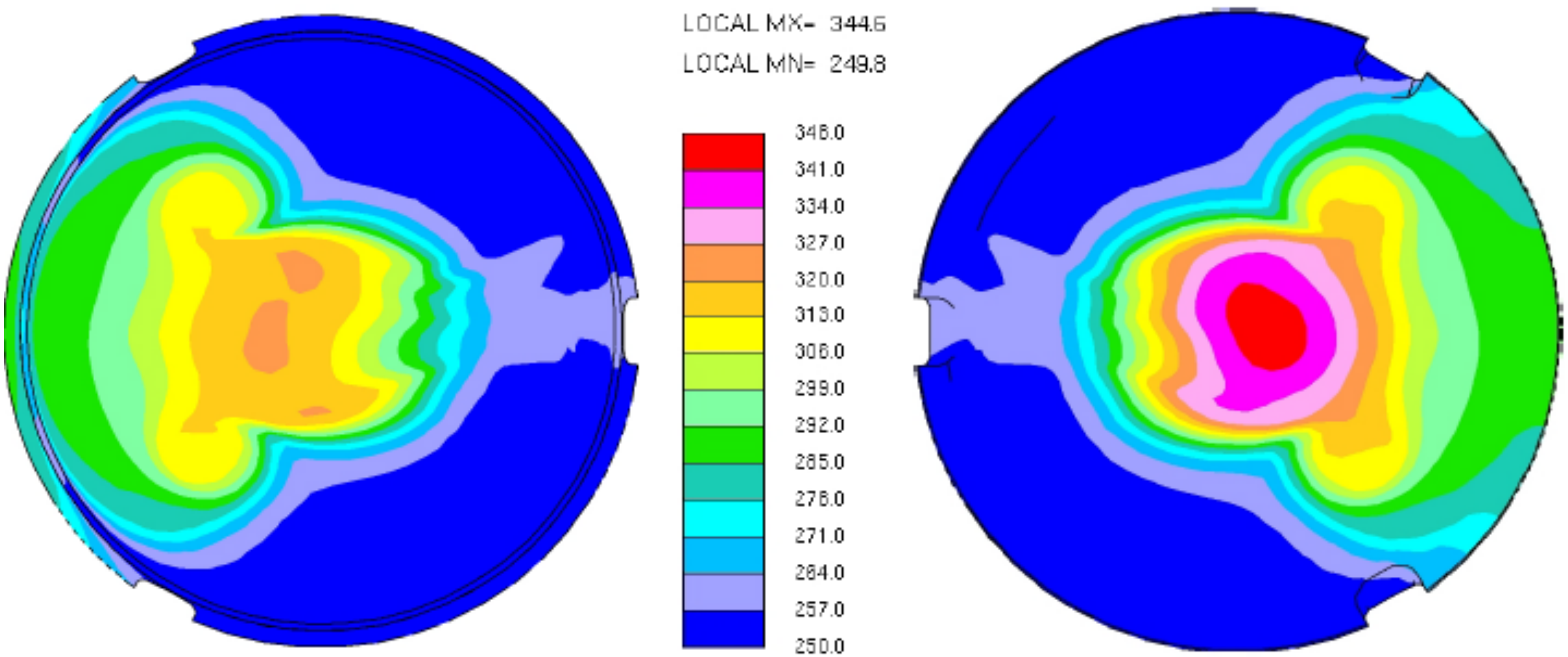
- 9 Samples from HO2-1



Computed temperatures in lower structures (1)

Beam Window

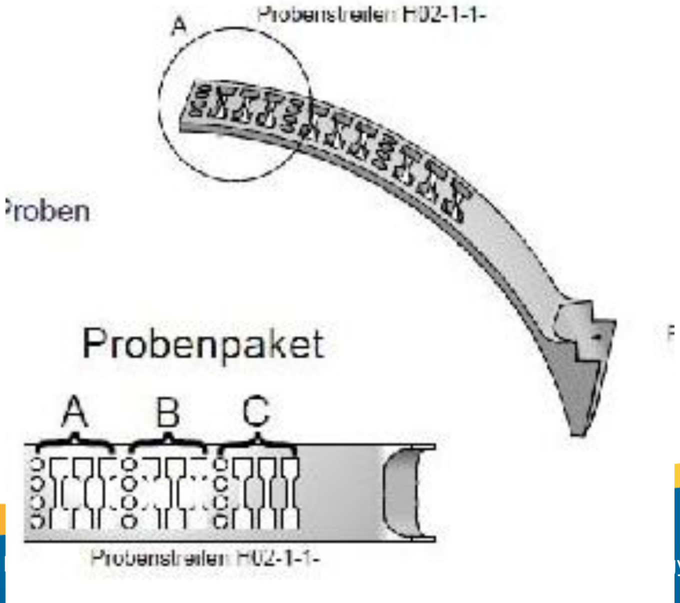


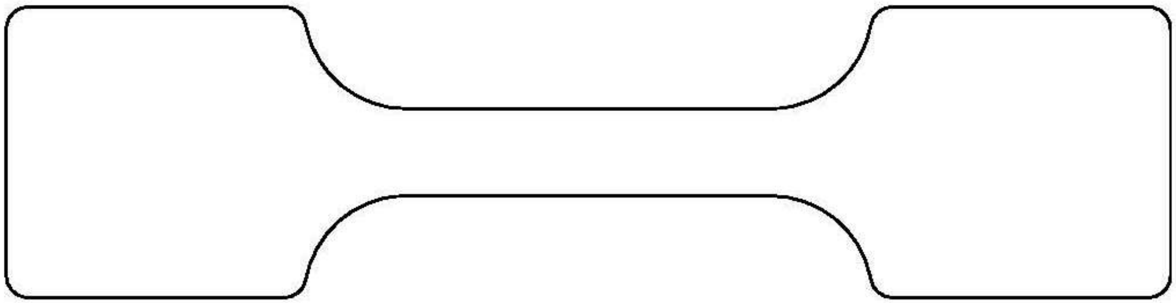
Section H02 inner side

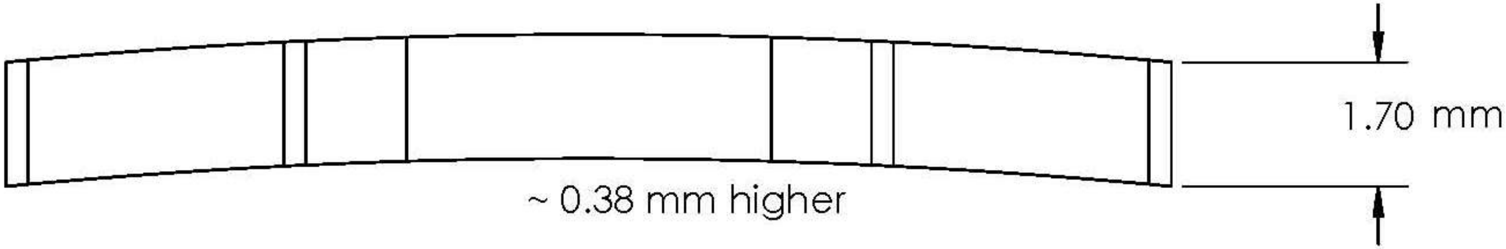
Section H02 outer side

Heat Treated Control Specimens

- Heat Treated at 750C for 2 hr
- Hardness dropped 301 (+/-13) to 233 (+/-6)
- Machined a few flat specimens out of curved control sample to test later…







No alignment hole, slight curvature (0.25mm under grip section) necessitates adjustments to tensile jig.
Slight differences in thickness along height of calotte.

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Shoulder Loading Fixture

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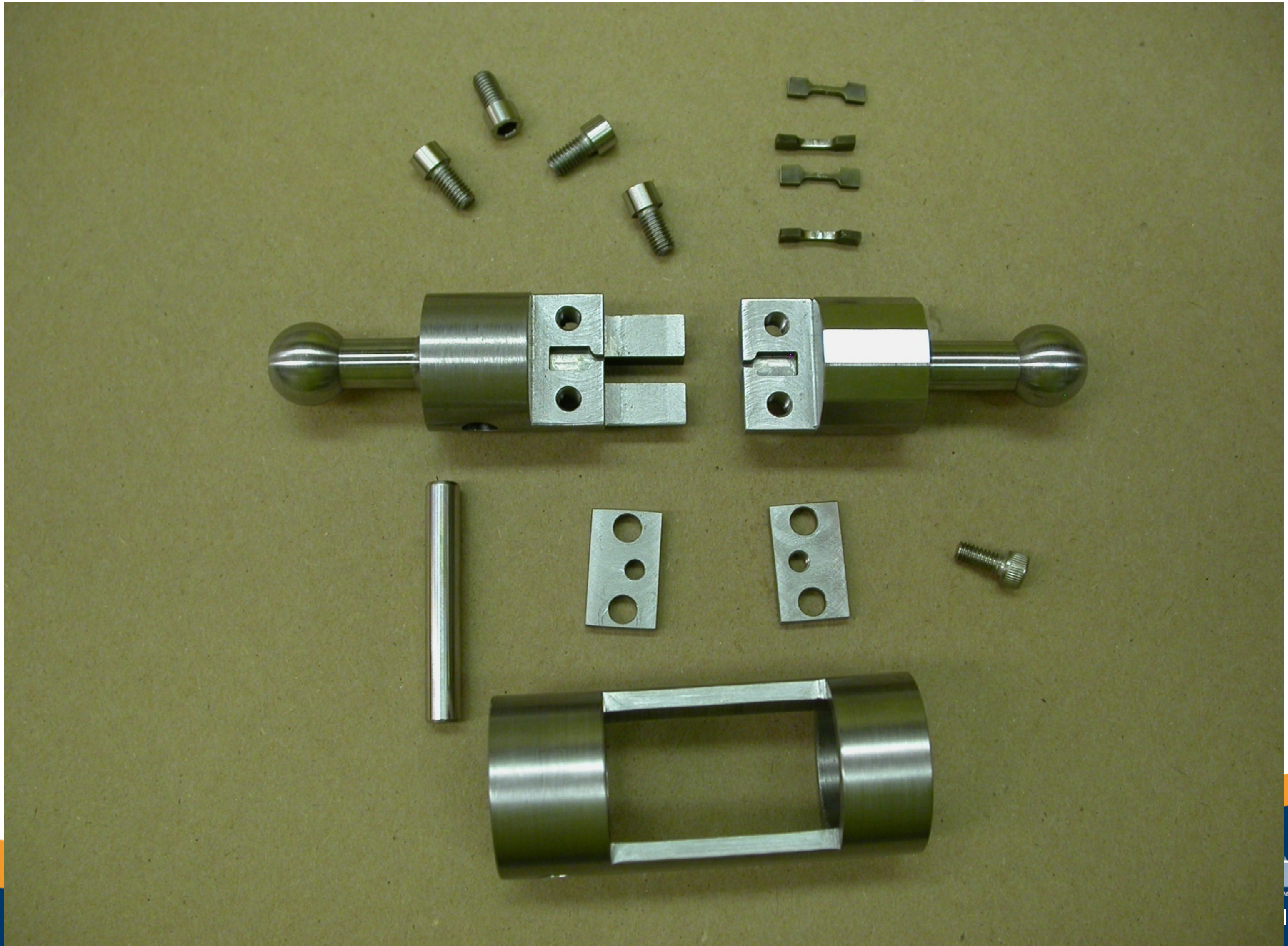

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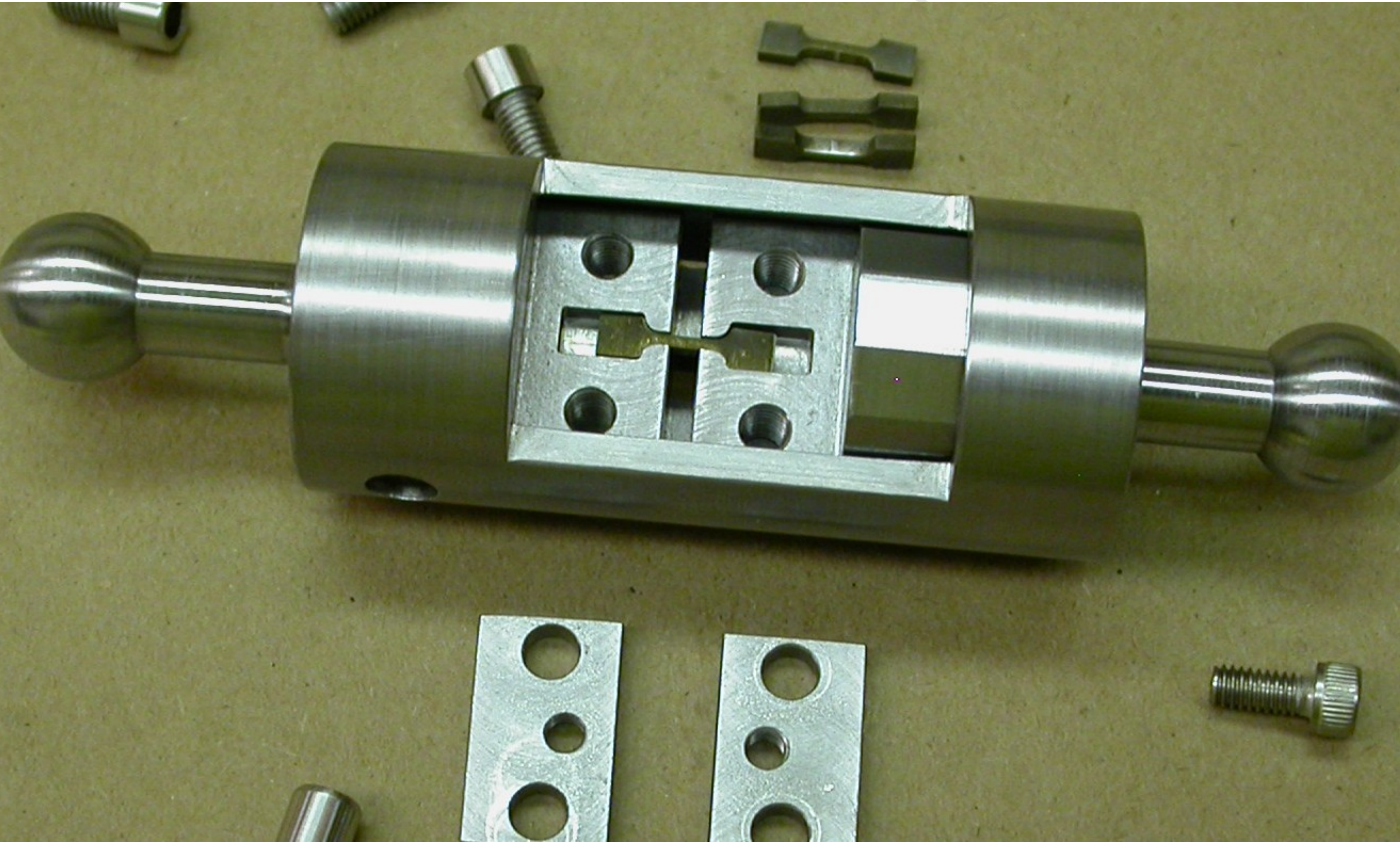
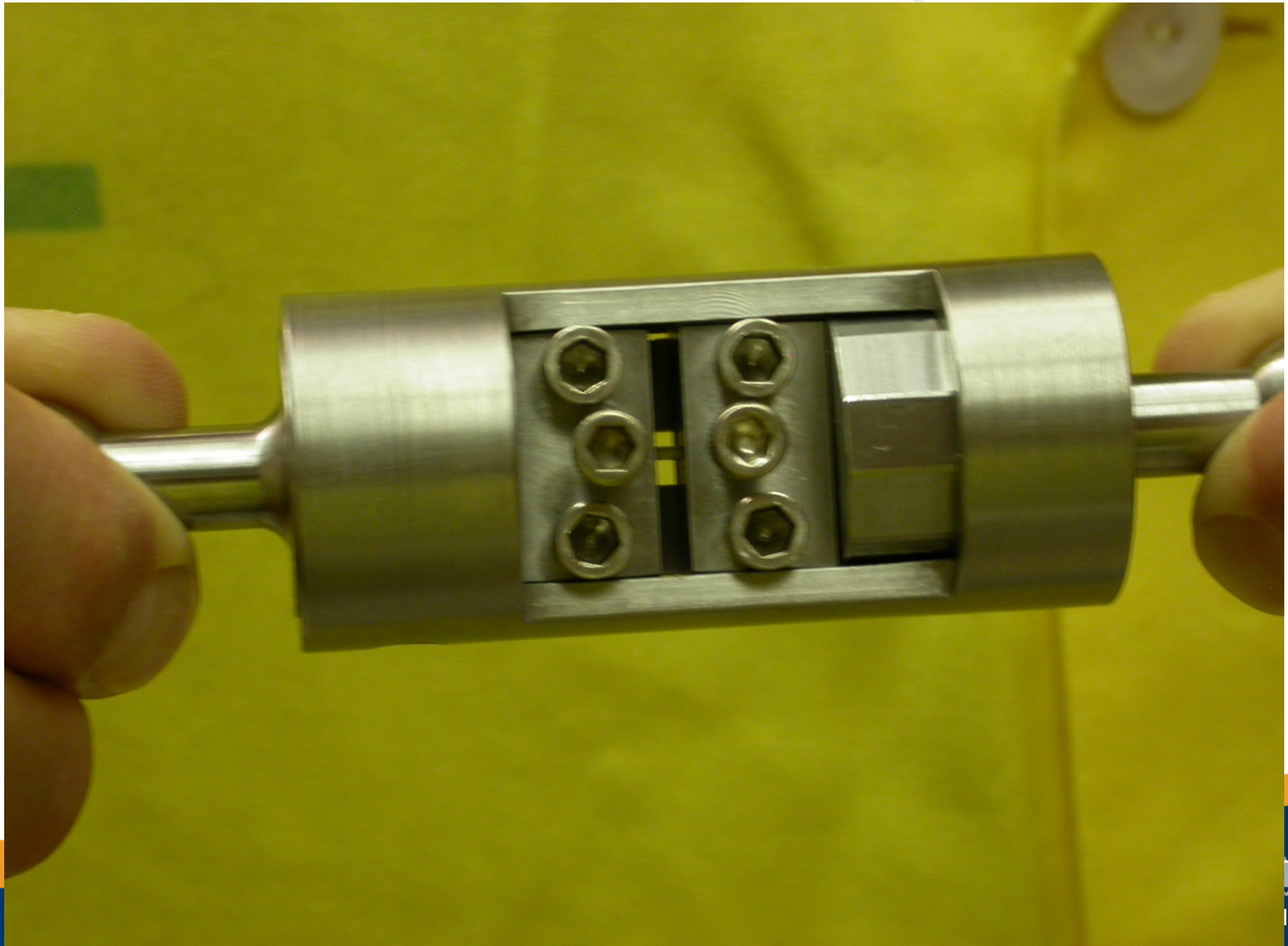
Nuclear Energy

Shoulder Loading Fixture

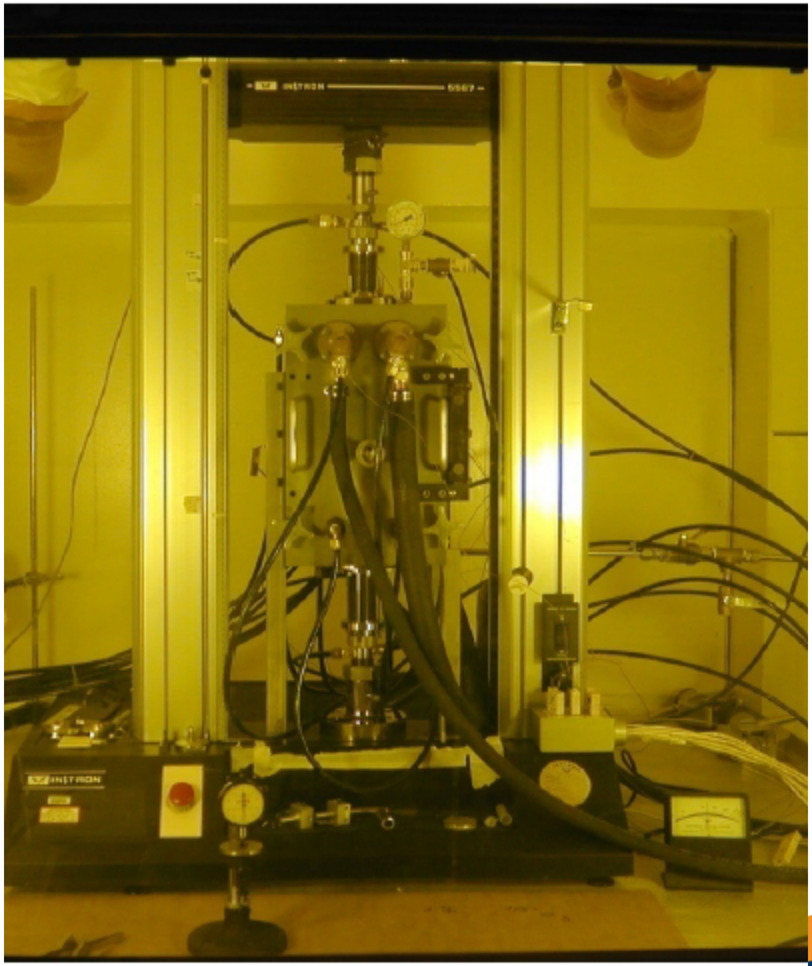
Los Alamos NATIONAL LABORATORY EST.1943



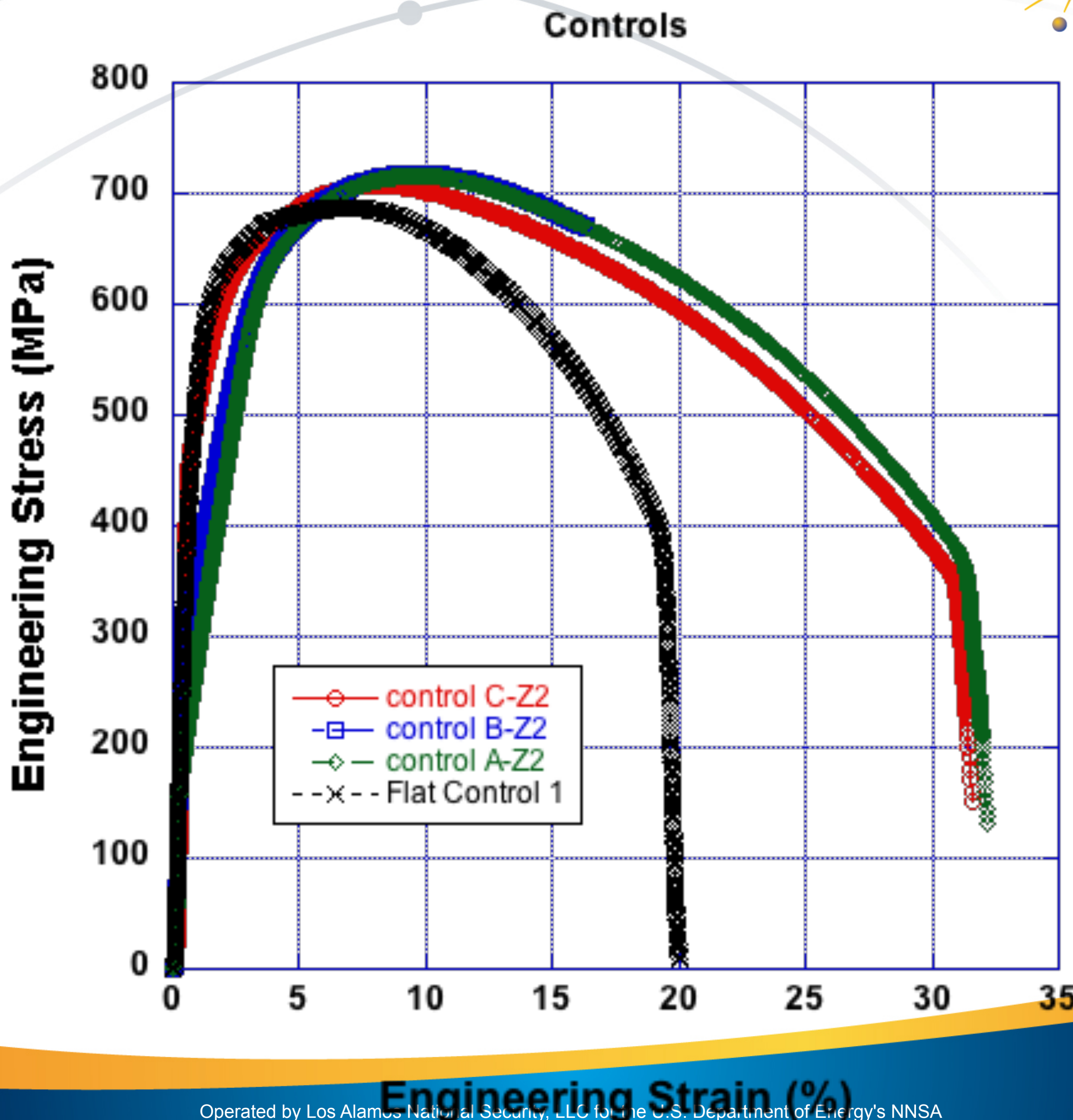


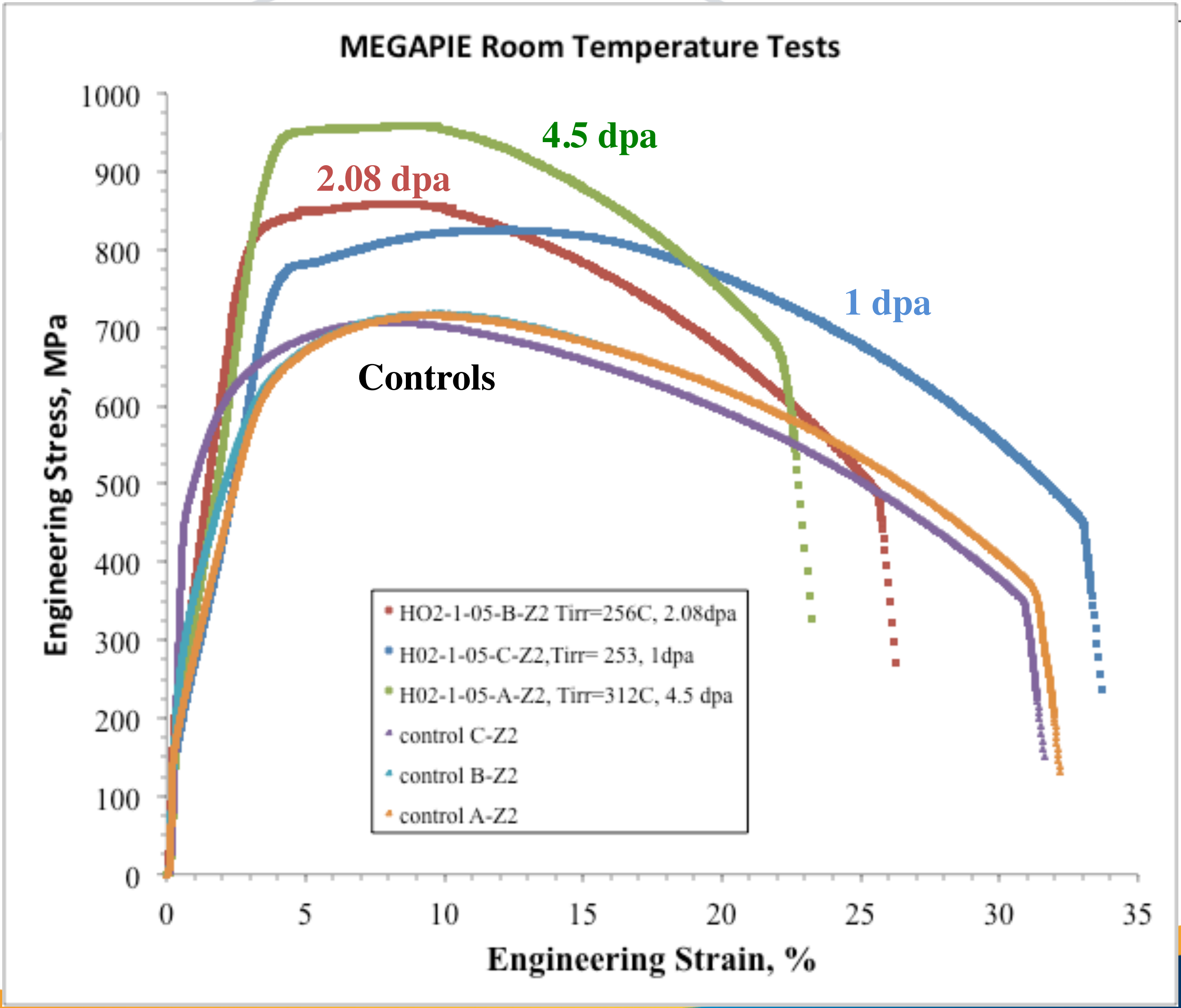
Test Set-up – Testing Conditions

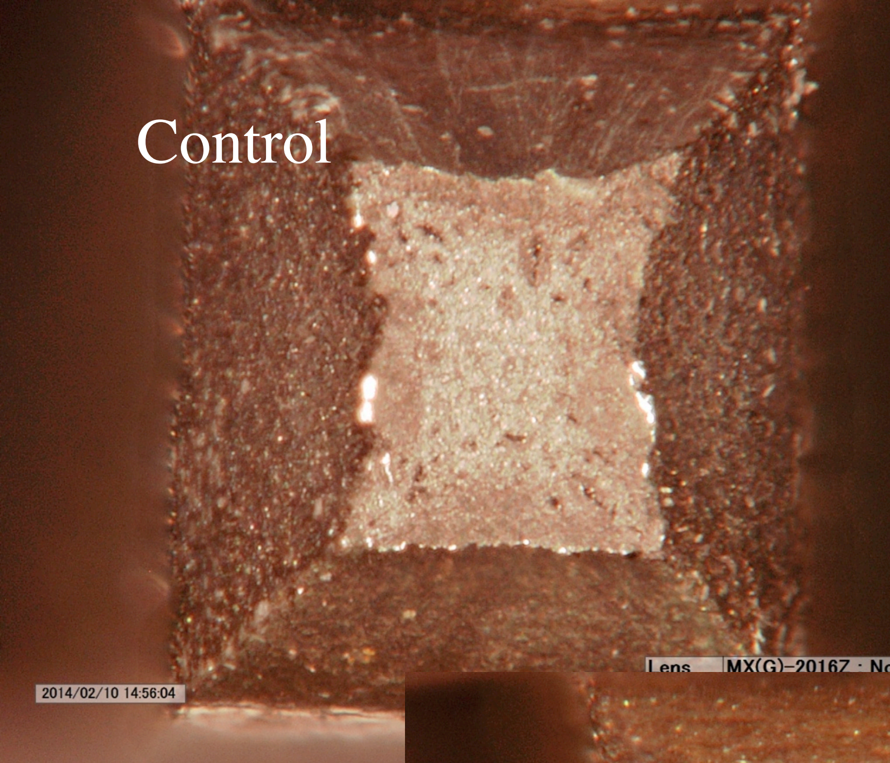
- Testing performed at RT
- Strain rate = 5 x 10^{-4}/s
- Compliance tests performed to remove machine compliance from stress/strain curves.

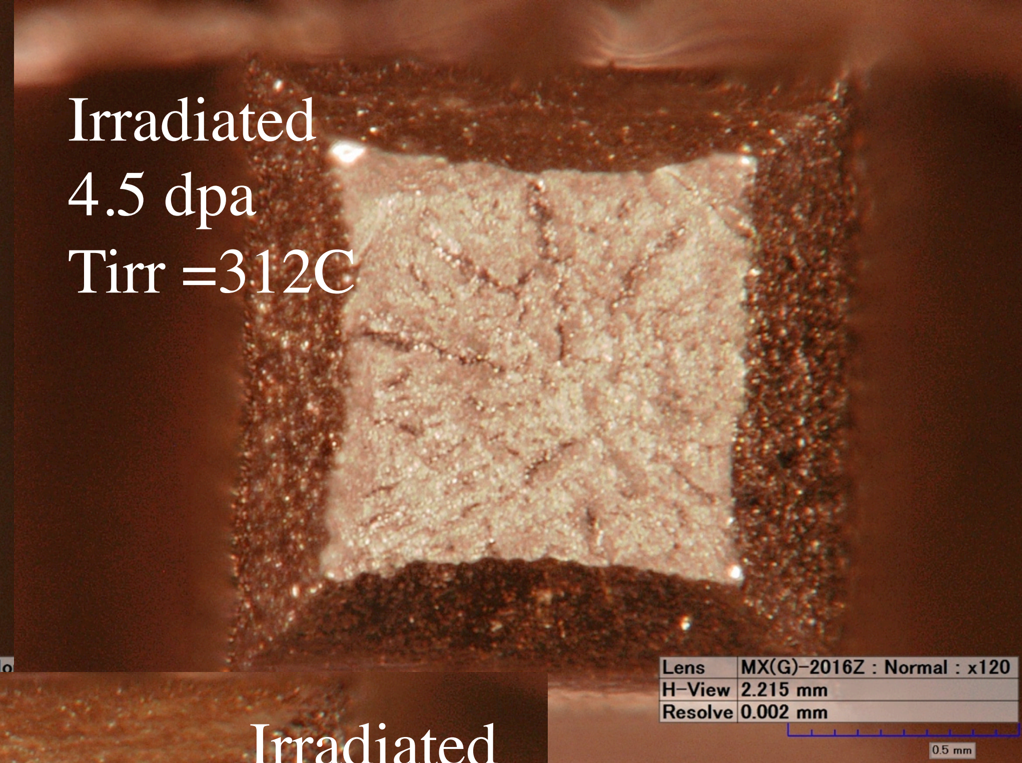


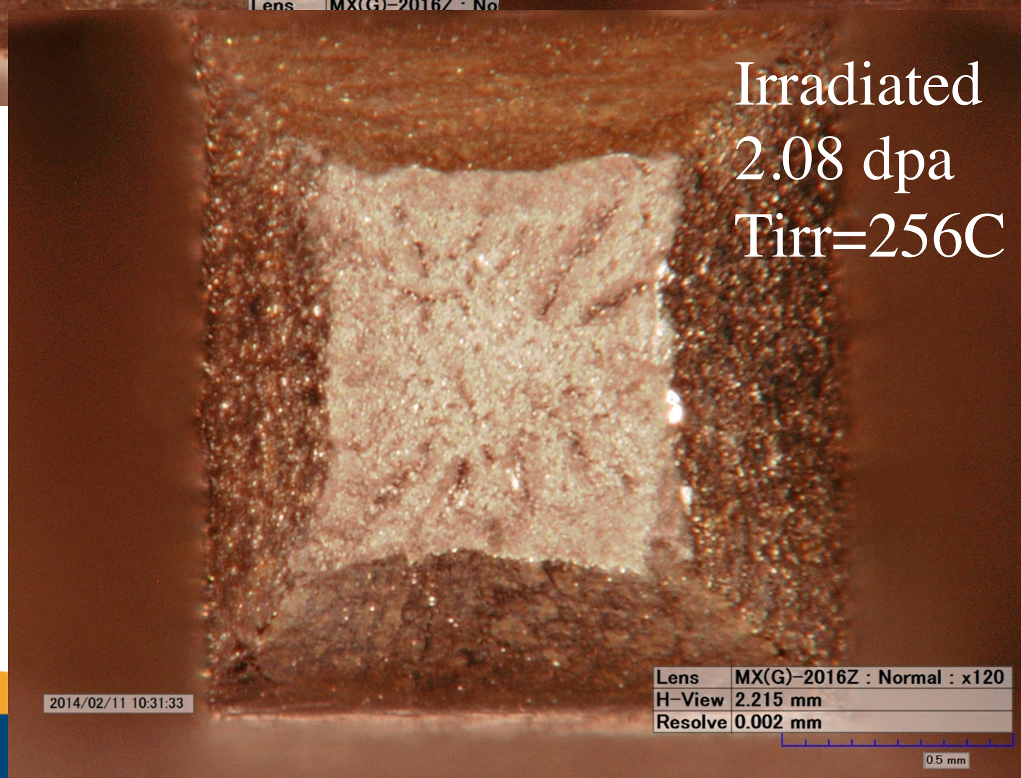
Mechanical Tests


Controls
Engineering Stress (MPa)
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
Engineering Strain (%)
control C-Z2
control B-Z2
control A-Z2
Flat Control 1

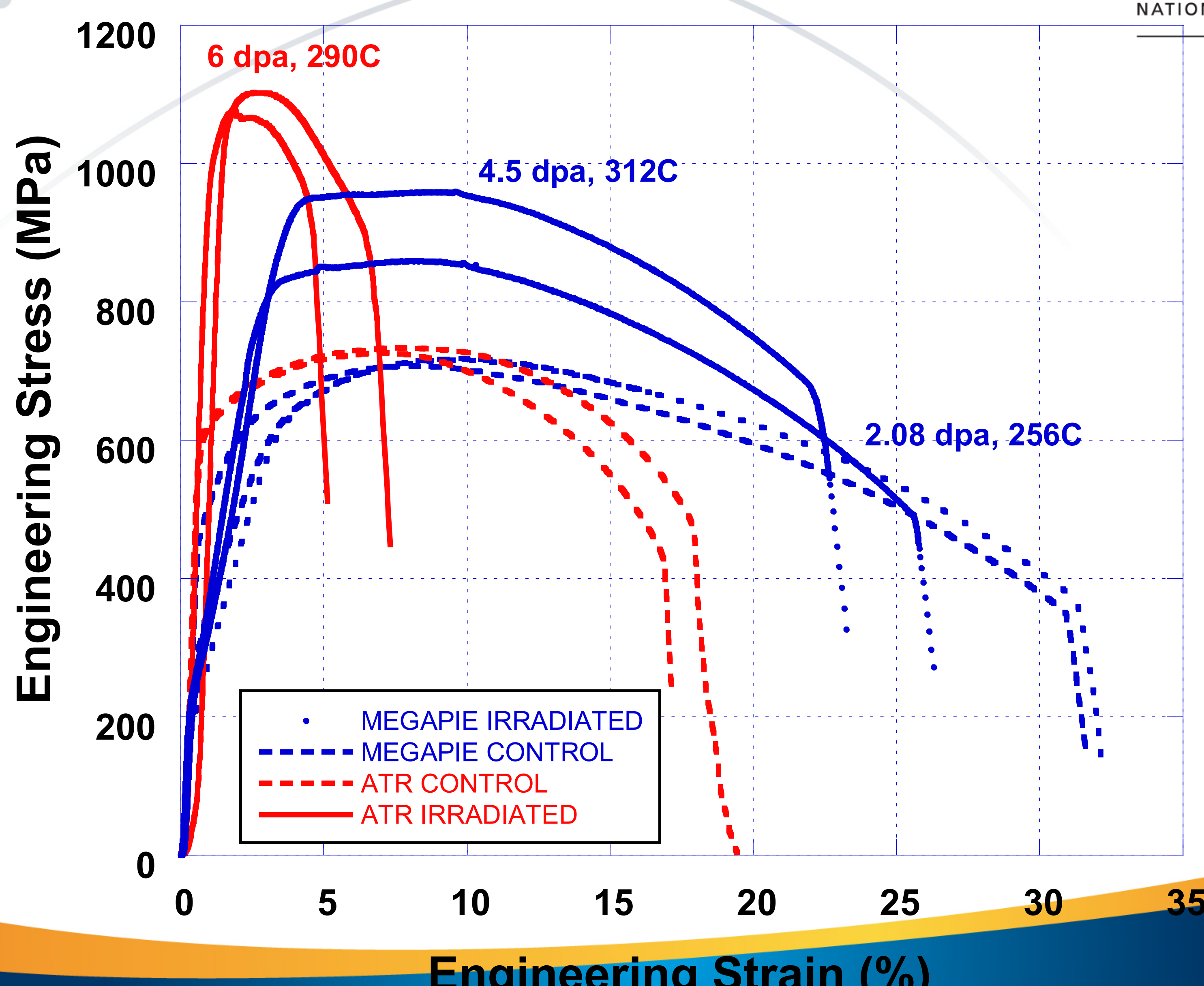

MEGAPIE Room Temperature Tests
4.5 dpa
2.08 dpa
1 dpa
Controls
Engineering Stress, MPa
Engineering Strain, %
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
HO2-1-05-B-Z2 Tirr=256C, 2.08dpa
H02-1-05-C-Z2,Tirr= 253, 1dpa
H02-1-05-A-Z2, Tirr=312C, 4.5 dpa
control C-Z2
control B-Z2
control A-Z2

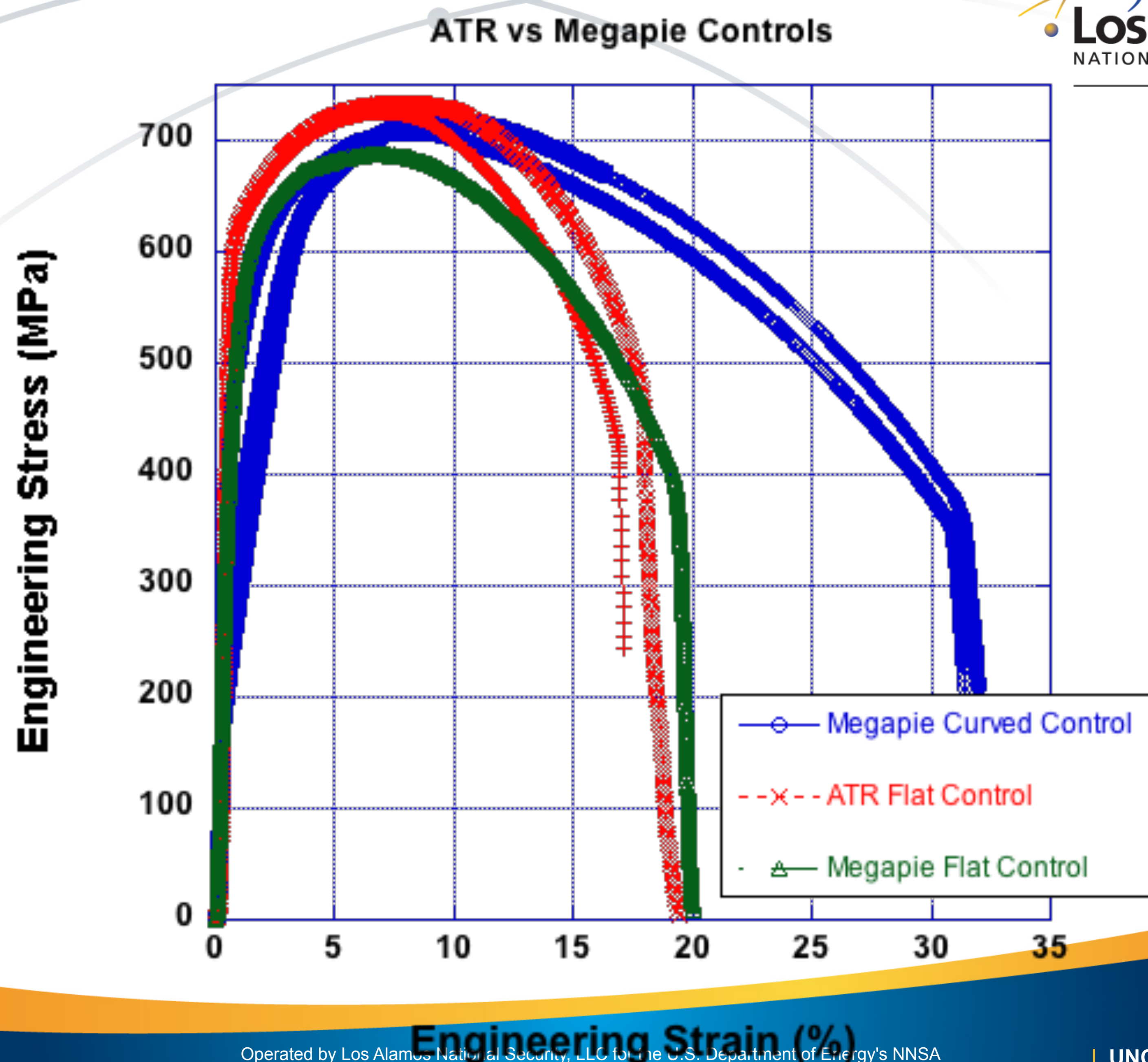

Control
2014/02/10 14:56:04


Irradiated
4.5 dpa
Tirr =312C
Lens MX(G)–2016Z : Normal : x120
H–View 2.215 mm
Resolve 0.002 mm
0.5 mm

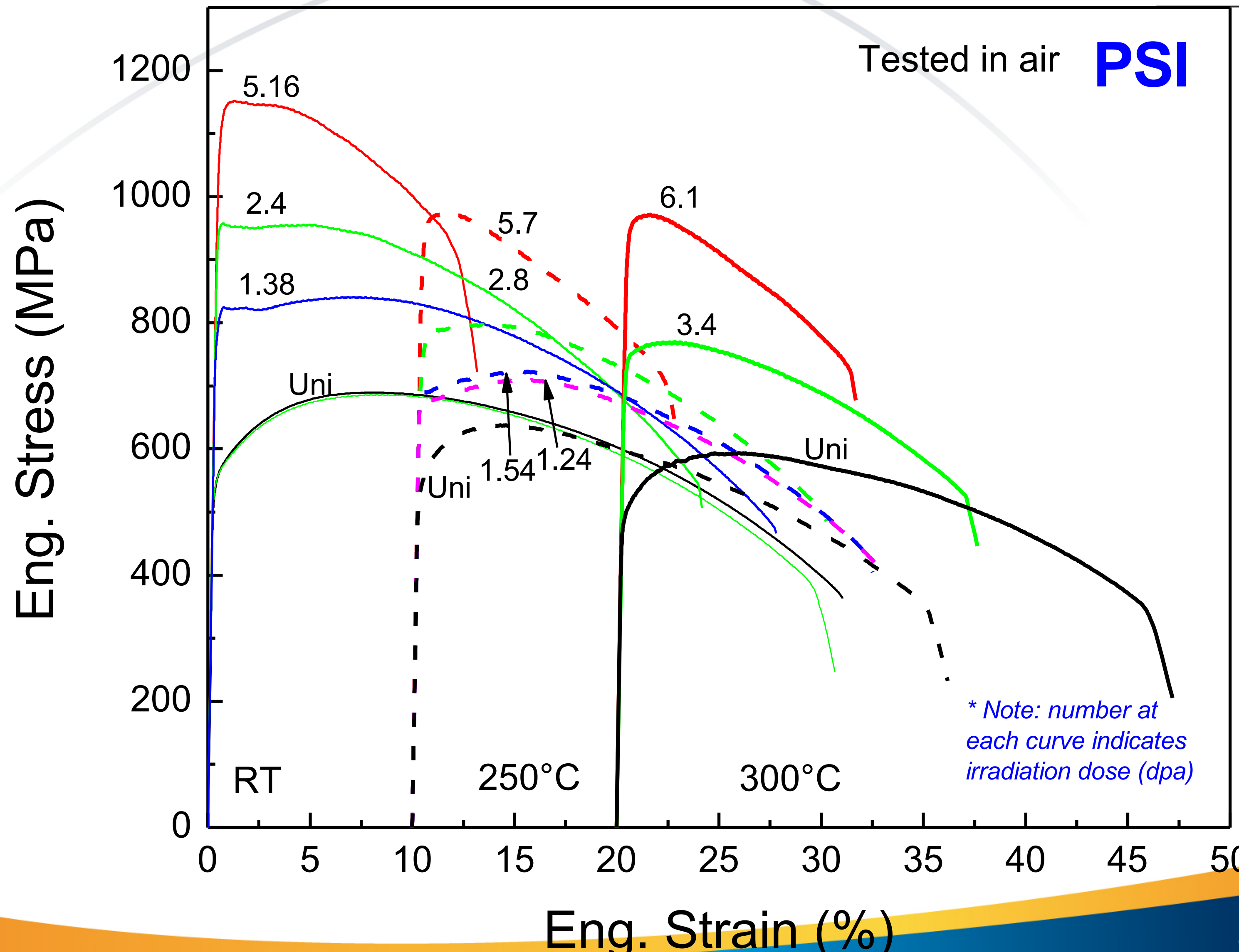

Irradiated
2.08 dpa
Tirr=256C
2014/02/11 10:31:33
Lens MX(G)–2016Z : Normal : x120
H–View 2.215 mm
Resolve 0.002 mm
0.5 mm

ATR vs MEGAPIE T91

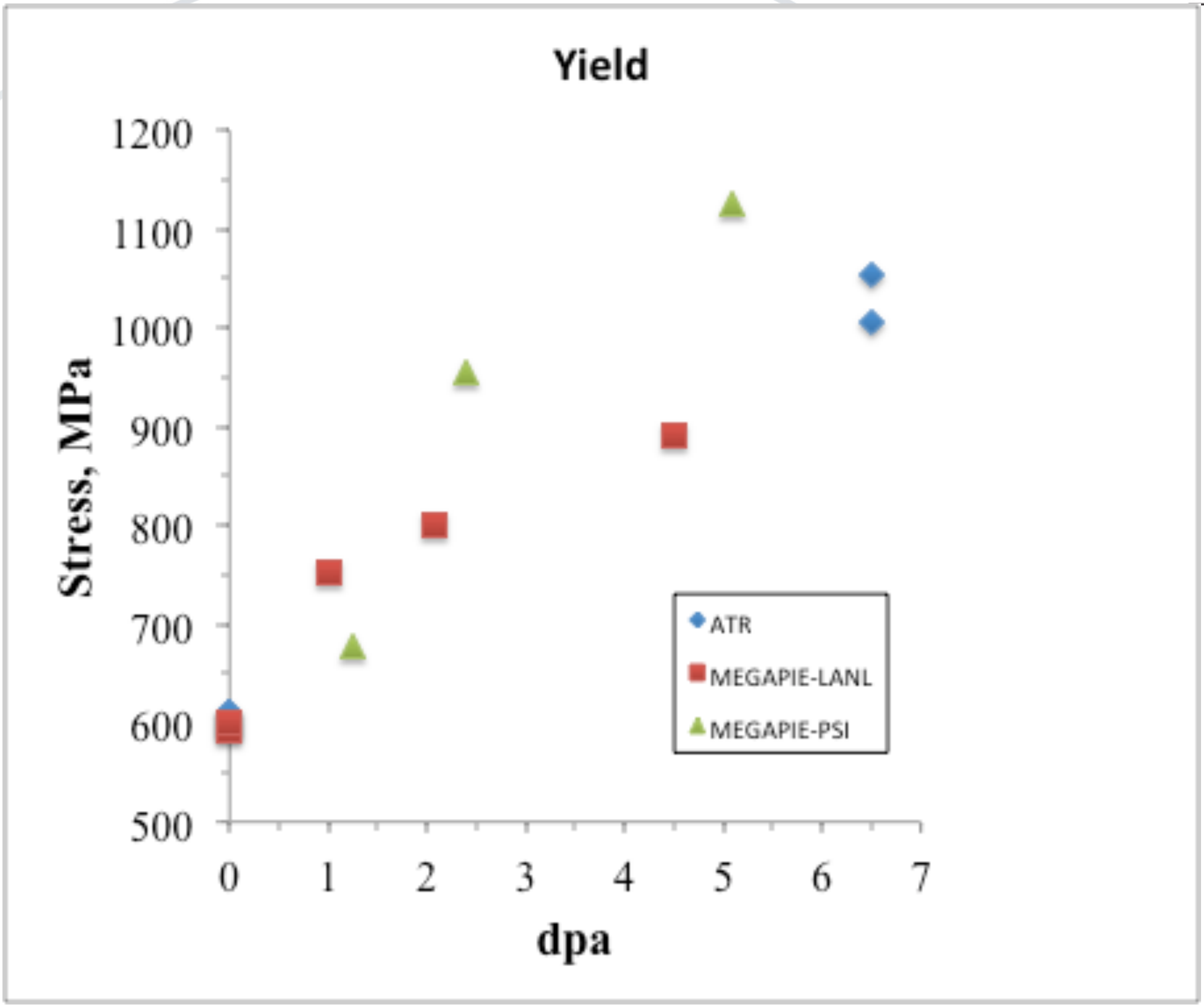


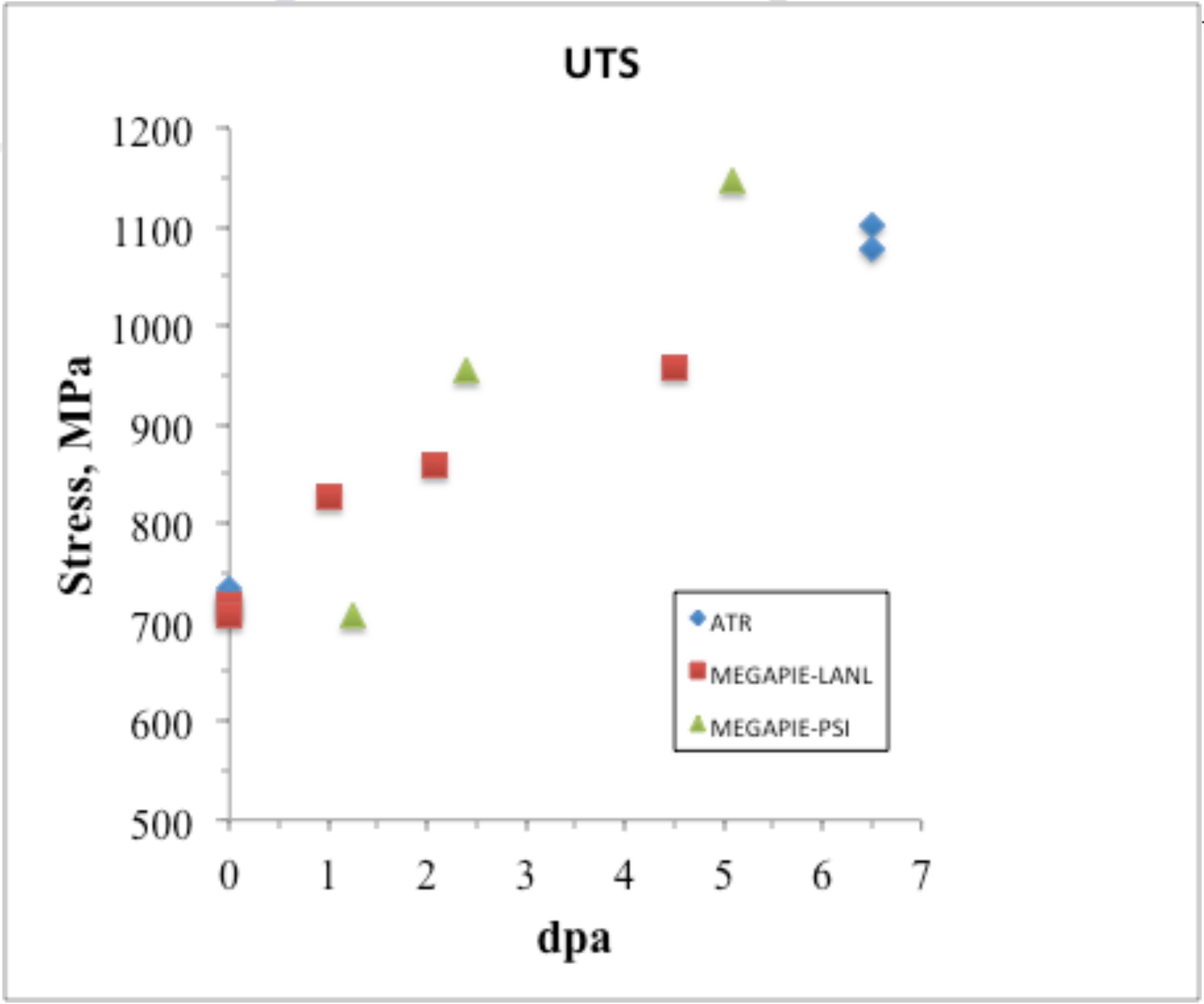

ATR vs Megapie Controls
Engineering Stress (MPa)
0
100
200
300
400
500
600
700
0
5
10
15
20
25
30
35
Engineering Strain (%)
Megapie Curved Control
ATR Flat Control
Megapie Flat Control

Eng. strain-stress tensile curves of specimens of MEGAPIE T91 Calotte



	Sample	Yield MPa	UTS MPa	UE %	TE %		Sample
MEGAPIE	Control A	598	716	5.7	29.9	Megapie LANL	Control A Z2
MEGAPIE	Control B	592	718	5.85	*	Megapie LANL	Control B Z2
MEGAPIE	Control C	600*	707	7.05	30.5	Megapie LANL	Control C Z2
MEGAPIE	Tirr, 251C, 1dpa	752	826	7.9	30.9	Megapie LANL	H02-1-05-C-Z2, Tirr = 253C, 1dpa
MEGAPIE	Tirr=256C, 2.08dpa	800	859	7.8	26.5	Megapie LANL	HO2-1-05-B-Z2 Tirr=256C, 2.08dpa
MEGAPIE	Tirr=312C, 4.5 dpa	890	959	5.9	19.3	Megapie LANL	H02-1-05-A-Z2, Tirr=312C, 4.5 dpa
	Tirr=309C, 5.1 dpa	1125	1146	2.3	12.4	Megapie PSI	Tirr=309C, 5.1 dpa
	Tirr=273C, 2.4dpa	955	956	3.3	24	Megapie PSI	Tirr=273C, 2.4dpa
	Tirr=260C, 1.24dpa	677	706	5.8	23.1	Megapie PSI	Tirr=260C, 1.24dpa
ATR	Control 1c	610	734	7.28	17.5	ATR LANL	Control TA#1c
ATR	Control 2c	610	726	6.32	16.4	ATR LANL	Control TA#2c
ATR	Tirr= 290C, 6 dpa	1055	1102	1.07	5.7	ATR LANL	Irradiated TA04 Tirr= 290C, 6 dpa
ATR	Tirr =290C, 6dpa	1005	1078	0.9	3.8	ATR LANL	Irradiated TA05 Tirr =290C, 6dpa
	High Temperature Tests						
MEGAPIE	Control A-Z3 Test temp =250C	543	624	3.9	25.3	Megapie LANL	CONTROL A Z3
MEGAPIE	Control A-Z1 Test Temp = 300C	534	614	4.1	25	Megapie LANL	CONTROL A Z1


Yield
Stress, MPa
1200
1100
1000
900
800
700
600
500
0
1
2
3
4
5
6
7
dpa
ATR
MEGAPIE-LANL
MEGAPIE-PSI


UTS
Stress, MPa
1200
1100
1000
900
800
700
600
500
0
1
2
3
4
5
6
7
dpa
ATR
MEGAPIE-LANL
MEGAPIE-PSI

Conclusions

- Hardening and yield behavior consistent with previous runs of irradiated T91 and other MEGAPIE tests, some irregularities to explore in continued testing.

- Continued testing (bend and high temp tension) and examination of specimens.

Finite Element Simulation of a Curved Bend Test

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Geometry

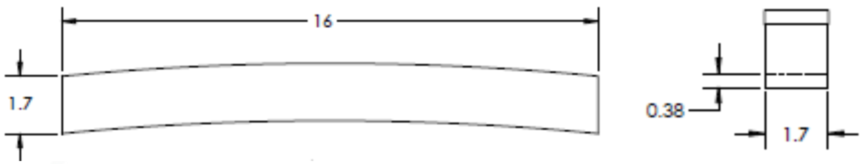
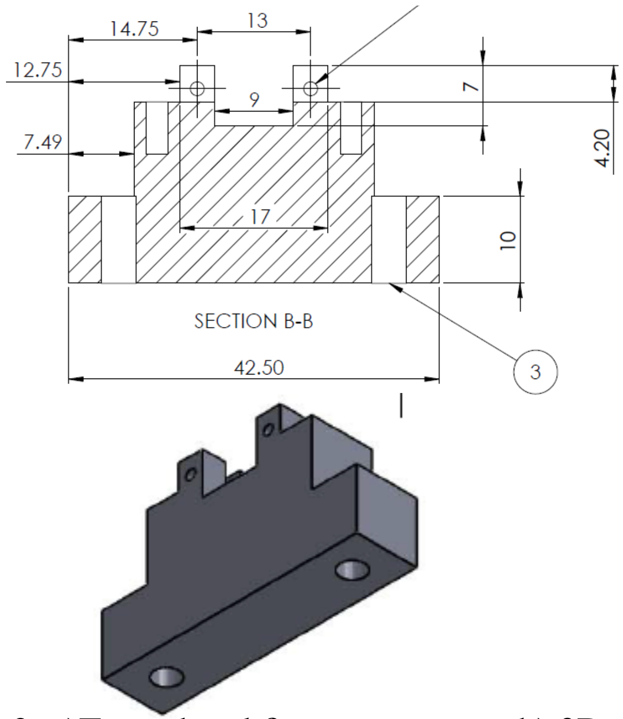


Figure1: Curved bend sample geometry. Units in mm.

A



B

Figure2: a)Tester bend fixture geometry b) 3D view of the bend fixture. Units in mm.

- A unique test fixture was designed in A2 Tool Steel hardened to 55RC to accommodate the curved bend sample.
- All dimensions in mm.

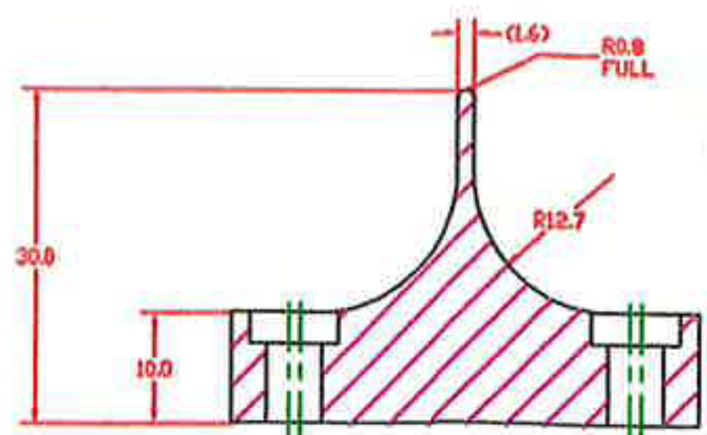


Figure 3: Upper loader pin. Units in mm.

Finite Element simulation

- Abaqus 6-14, Standard
- Elastic-plastic material model
- Contact algorithm between all surfaces.
- Friction coefficient of 0.3, between all contact surface.

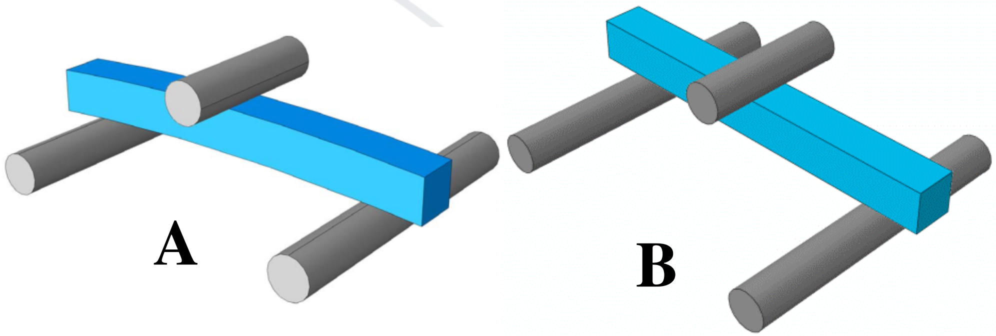


Figure 5: FE assembly a) Curved sample assembly and b) Flat sample assembly

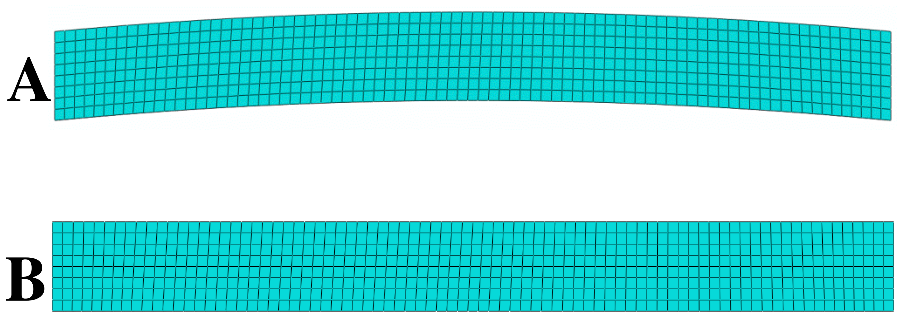
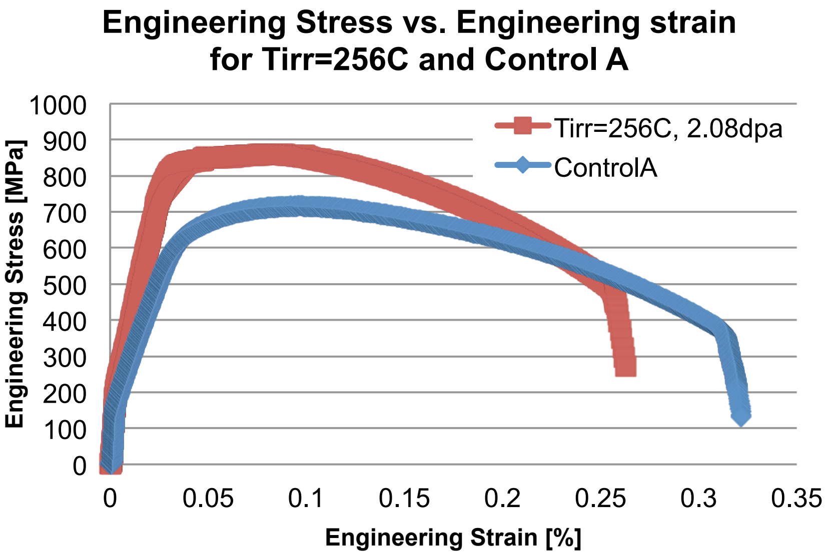


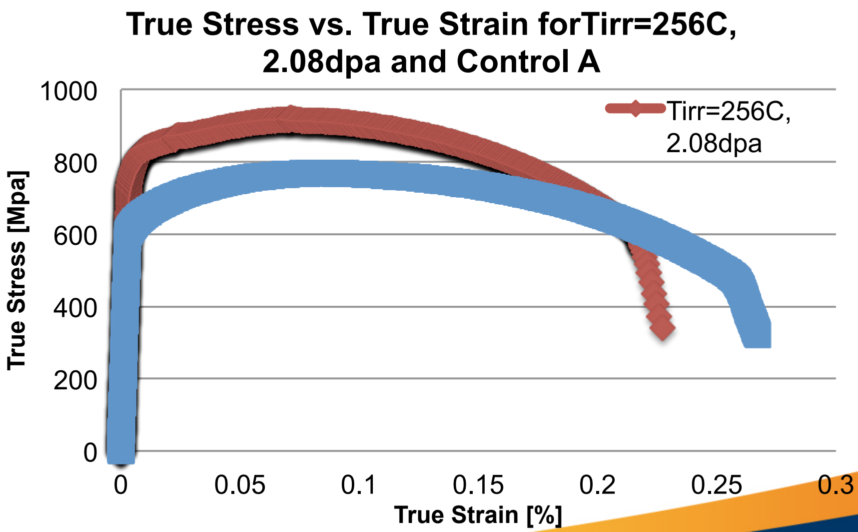
Figure 6: X-Y View of the sample mesh a) Curved sample and b)Flat sample.

	Element Type	Number of Elements	Material
Pin	C3D4R	9180	A2 Tool Steel
Load Fixture	C3D4R	2040	A2 tool steel
Specimen flat/ curved	C3D8R	46240	T91

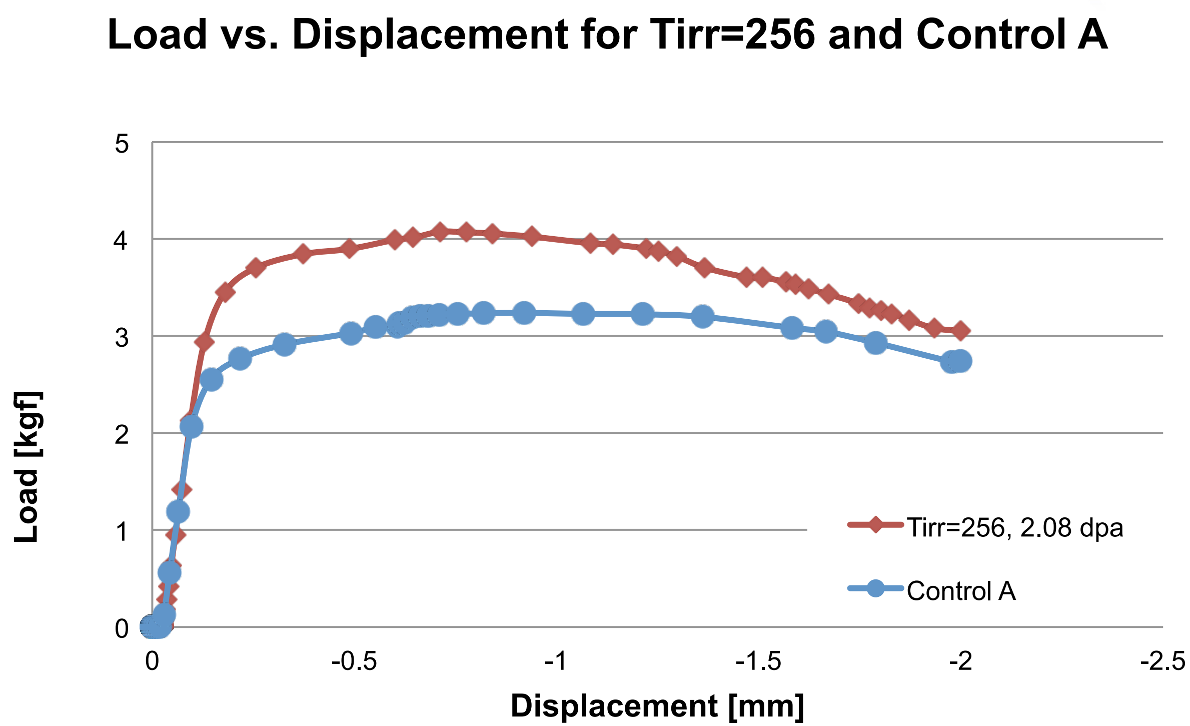
Mechanical Properties

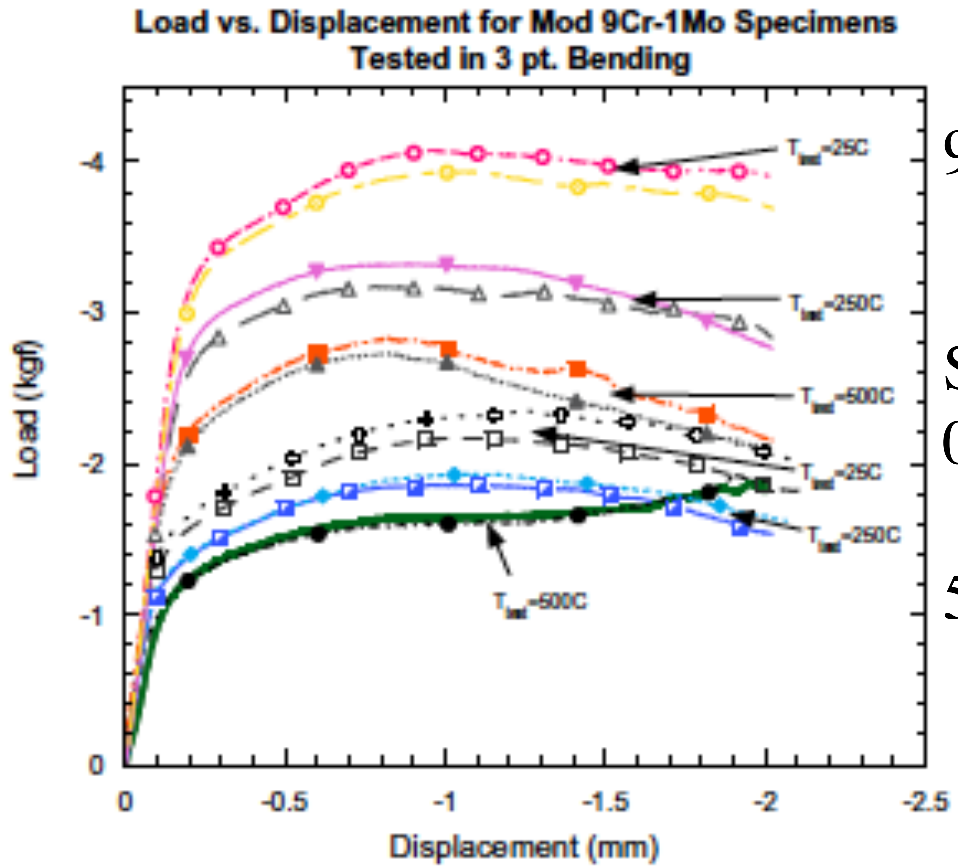
	Elastic Modulus [GPa]	Poisson Ratio	Yield Strength [MPa]	UTS [MPa]
Tirr=256 C, 2.08 dpa	207	0.28	740	859
Control A Z2	207	0.28	598	716





Load Vs Displacement Bend Test for Tirr=256 2.08 dpa and Control A





9dpa

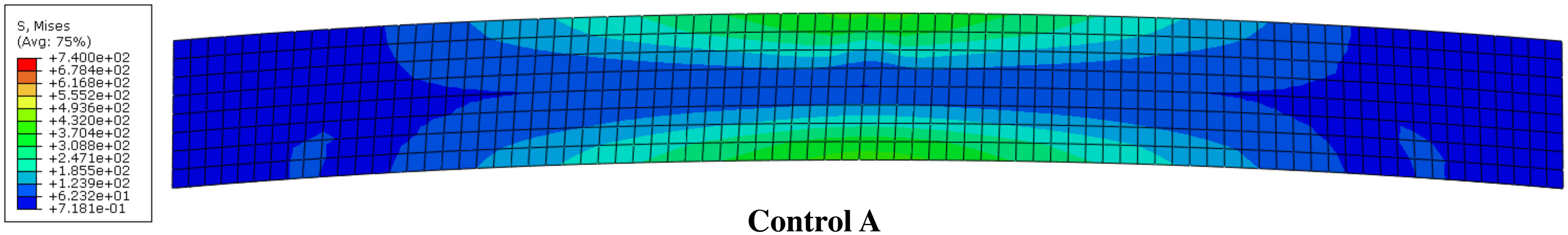
Smaller cross section
0.5x2mm vs 1.7x1.7
Smaller span
5.5mm vs 13mm

Maloy, Journal of Nuclear Materials 343 (2005) 191–196

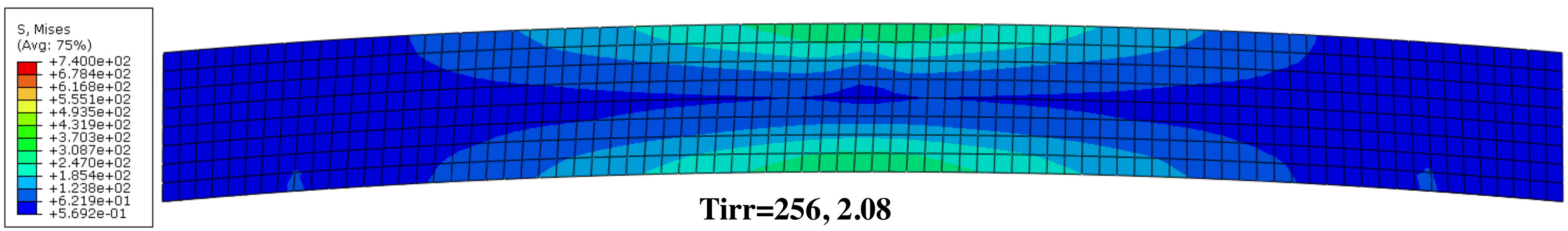
Results: Stress contour plot of Tirr=256, 2.08 dpa and control A

elastic response

Displacement 0.05 mm

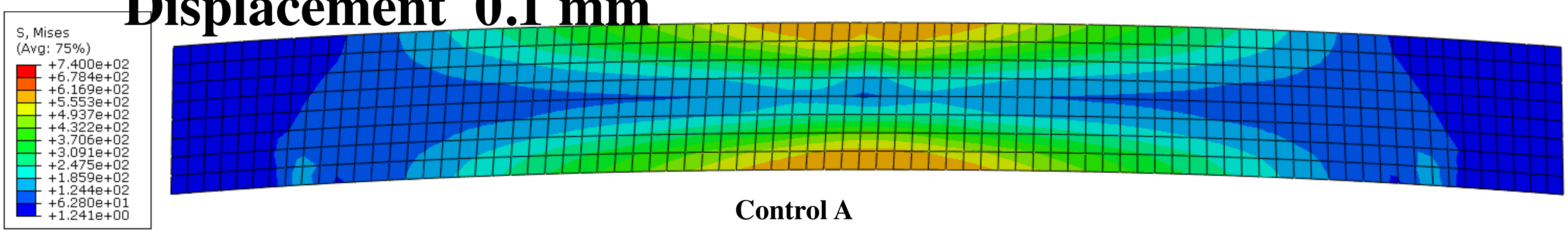


Control A

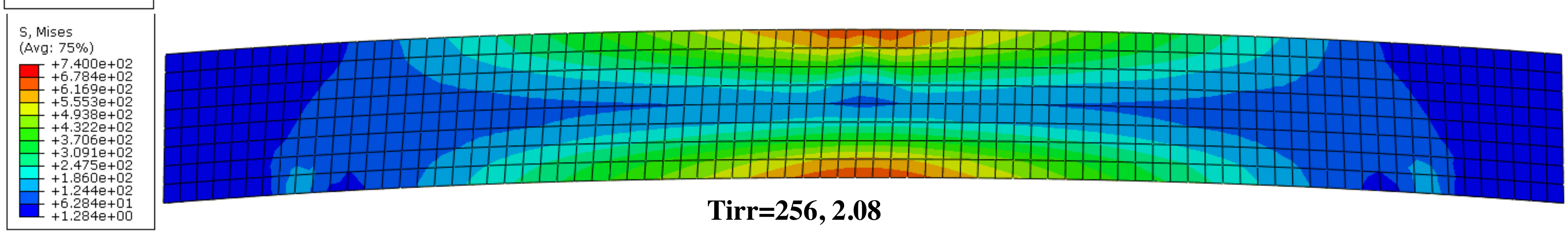


Tirr=256, 2.08 dpa

Displacement 0.1 mm



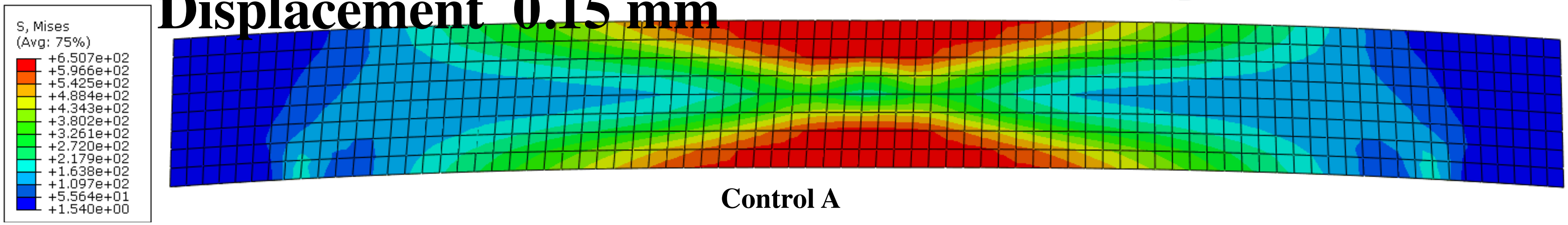
Control A



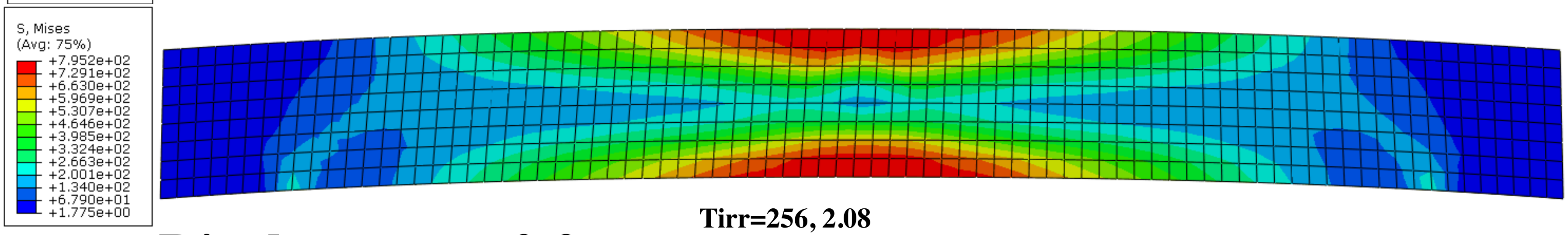
Tirr=256, 2.08 dpa

Results: Stress contour plot of Tirr=256, 2.08 dpa and control A

Displacement 0.15 mm

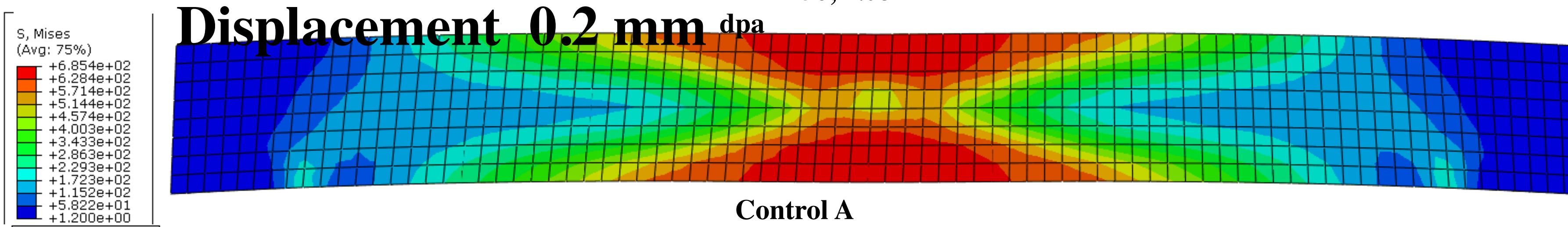


Control A

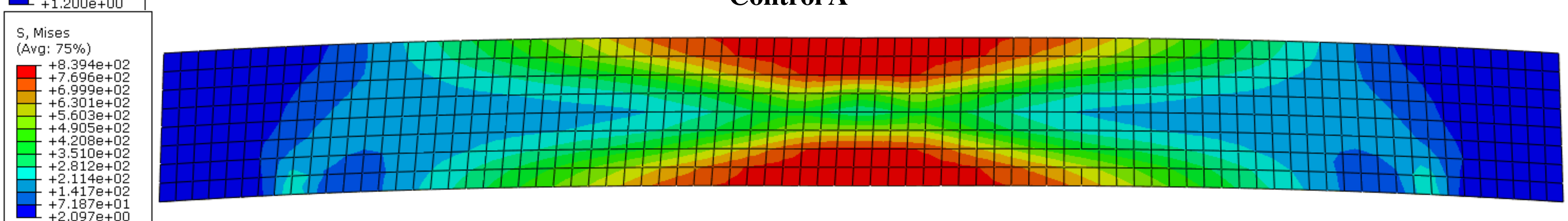


Tirr=256, 2.08 dpa

Displacement 0.2 mm



Control A



Tirr=256, 2.08 dpa

Future Work

- Comparison between curved test of bend sample and previous geometries.
- Addition of damage and irradiation parameters to the material model.