SAND2015-4969PE

Characterization of Aging and Degradation of Reactor Materials in Extreme Environments

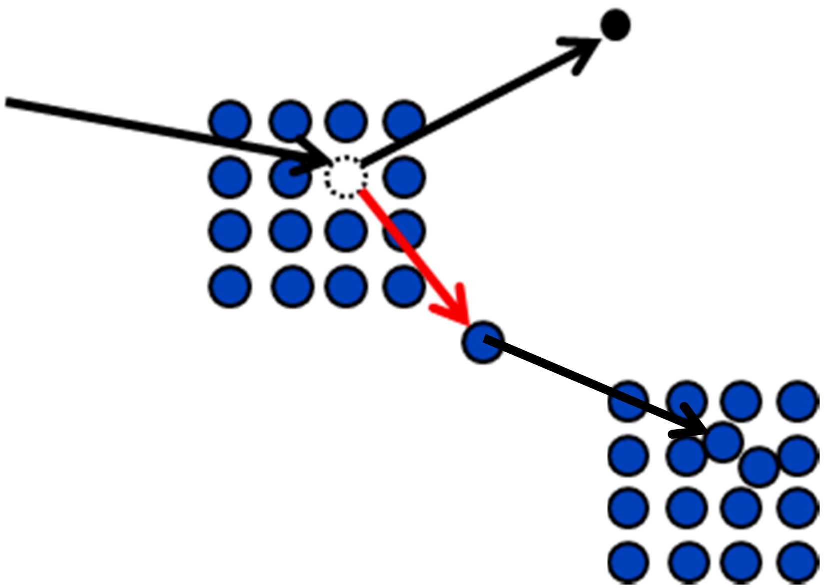
By MIDN 1/C Christian D. Herrmann, USN
In collaboration with Dr. Khalid Hattar,
Dr. Brittany Muntifering,
& Dr. Daniel Bufford

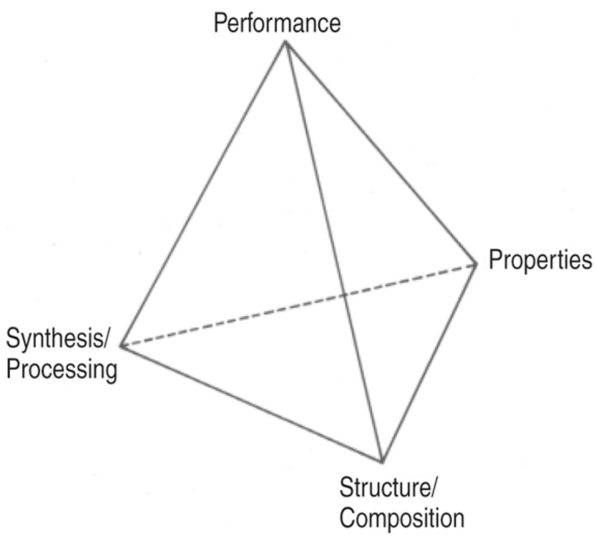
Presentation for MAC Program Use Only

Problem Definition

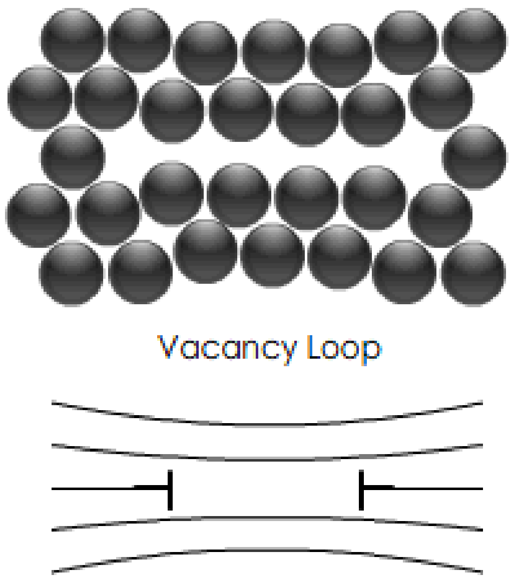
- Understanding reactor material behaviors in extreme environments
  - Necessary to develop new materials for future reactor designs
  - Helpful in extending current reactor operating lifetimes

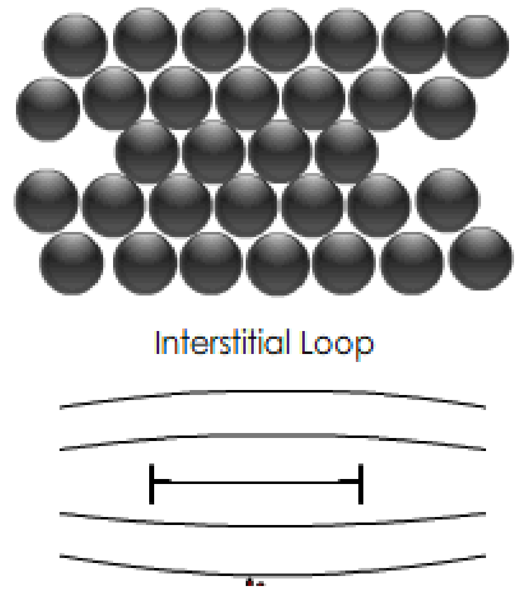
What Happens In a Reactor and Why Do We Care?



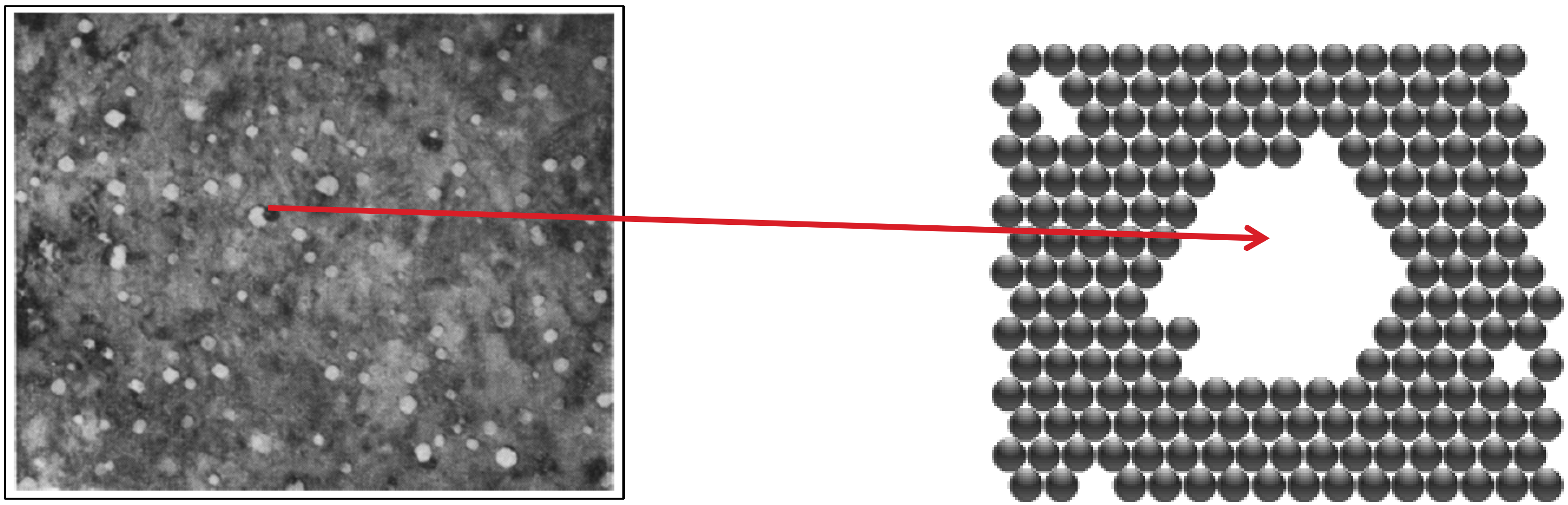


Background: Dislocation Loop

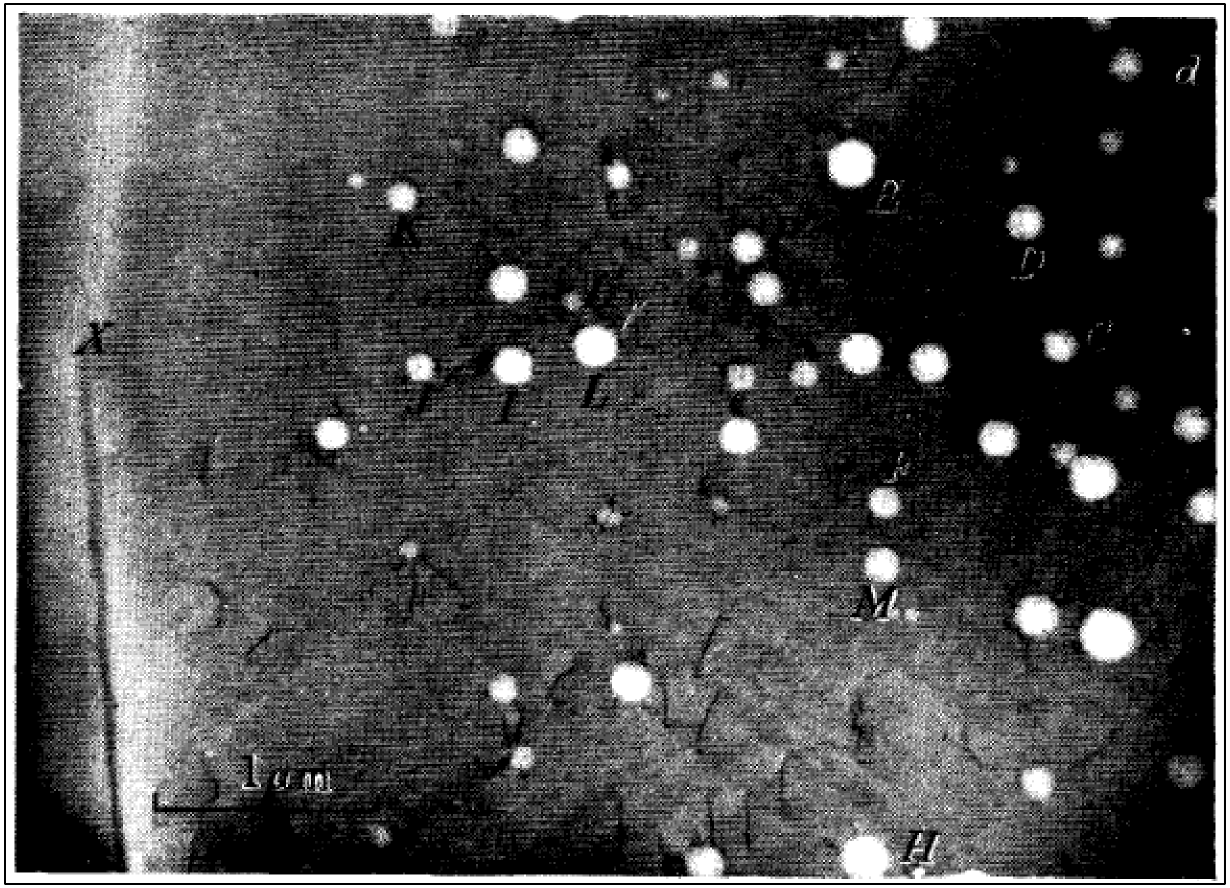




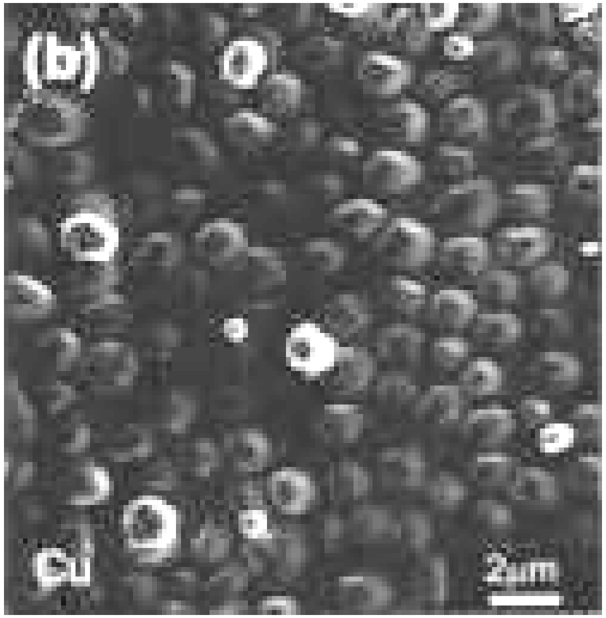
Background: Void

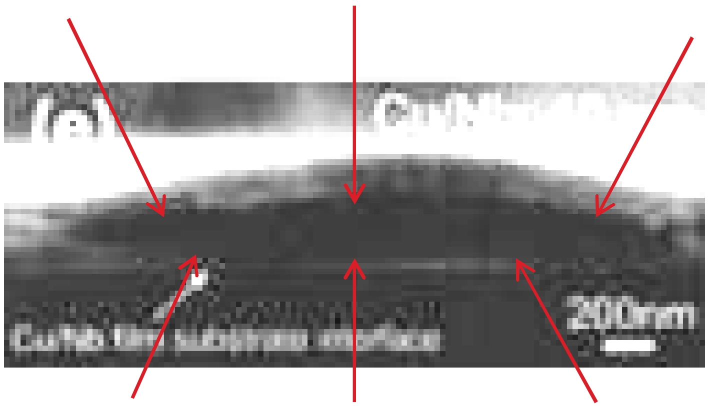


Background: Bubbles



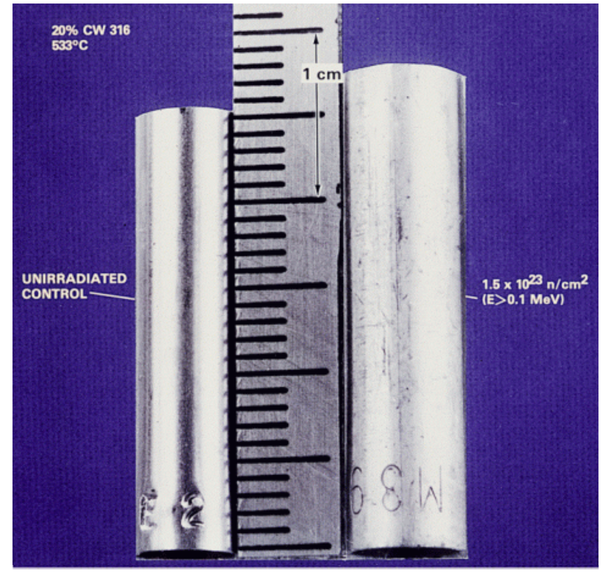
Background: Blistering

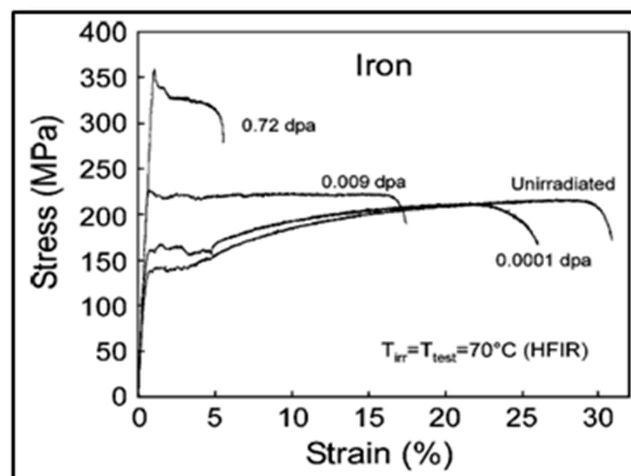




Why Is This Relevant?

- Radiation induced damage (along with temperature and induced-stress) can alter physical structure and chemical properties of a material
- May cause reduction in ductility and increase embrittlement
- Ultimately leads to failure of reactor components





Eldrup et al. (2002)

Proposal of the Project

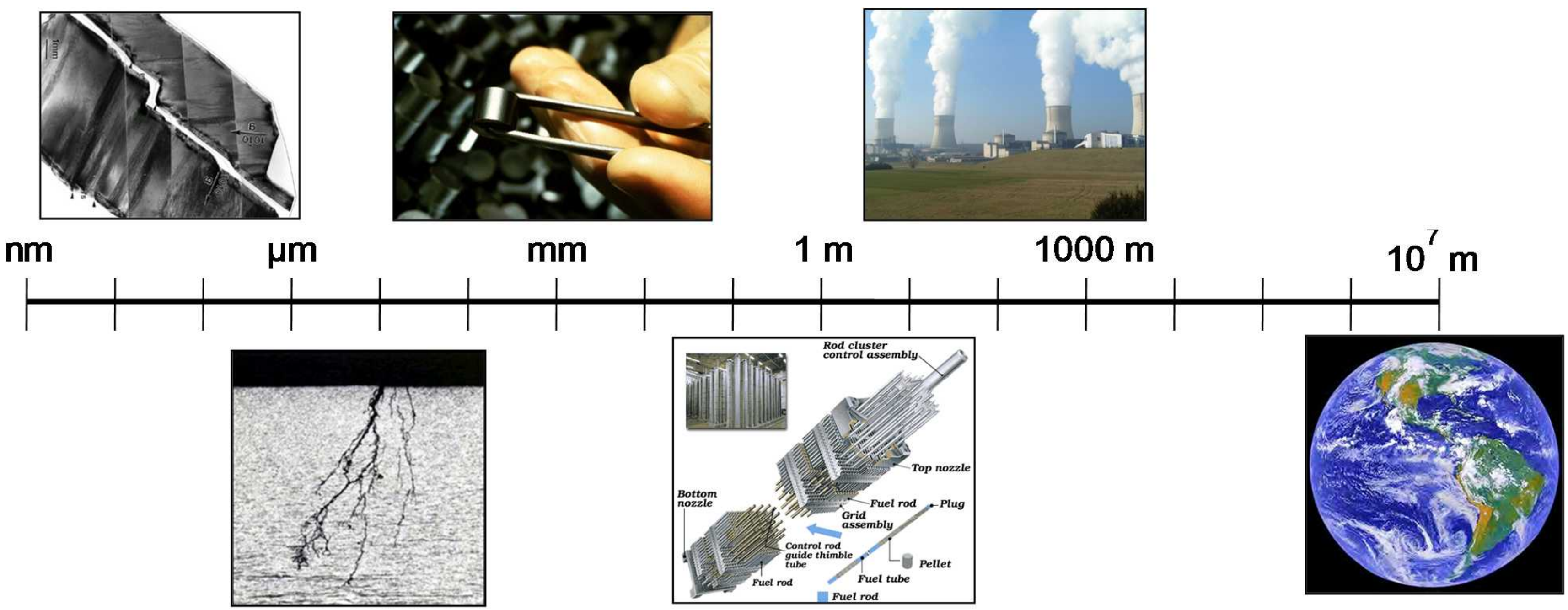
- Through use of experimental techniques, including use of a transmission electron microscope and ion beam, predict the effects of the following have on the macroscopic behavior of a specified material:
  - Irradiation
  - Temperature
  - Stress
- Prepare and use zirconium alloys and high chromium martensitic steels (such as 316 series) samples, expose to in-situ experiments while examining them under a TEM

Why a TEM? How do we use it?

- A TEM is a form of microscopy that allows the visualization of aforementioned defects on a small scale, not obtainable by regular/ traditional optics
- However for our purposes it does require the use of 100 nm or thinner samples
  - Electrons must pass through sample to create an image

Why a TEM? How do we use it?

- For scale:



Why Do We Use Ions in the Lab?

- Able to simulate years/decades of neutron damage in only a few hours or days
- Neutrons are expensive (and hazardous to health)
- Can perform multiple types of experiments in conjunction with using ions (ie heat a sample)
- Creates little/no residual radioactivity

Sample Preparation Process

- Zirconium templates were cut smaller

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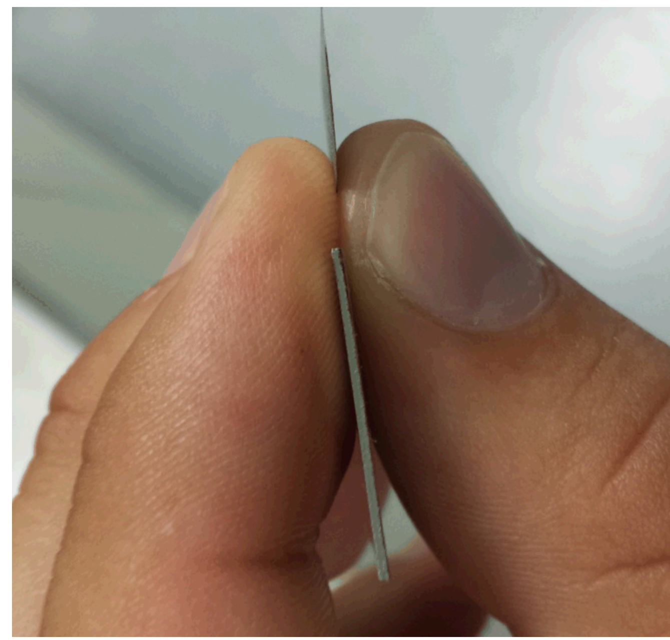
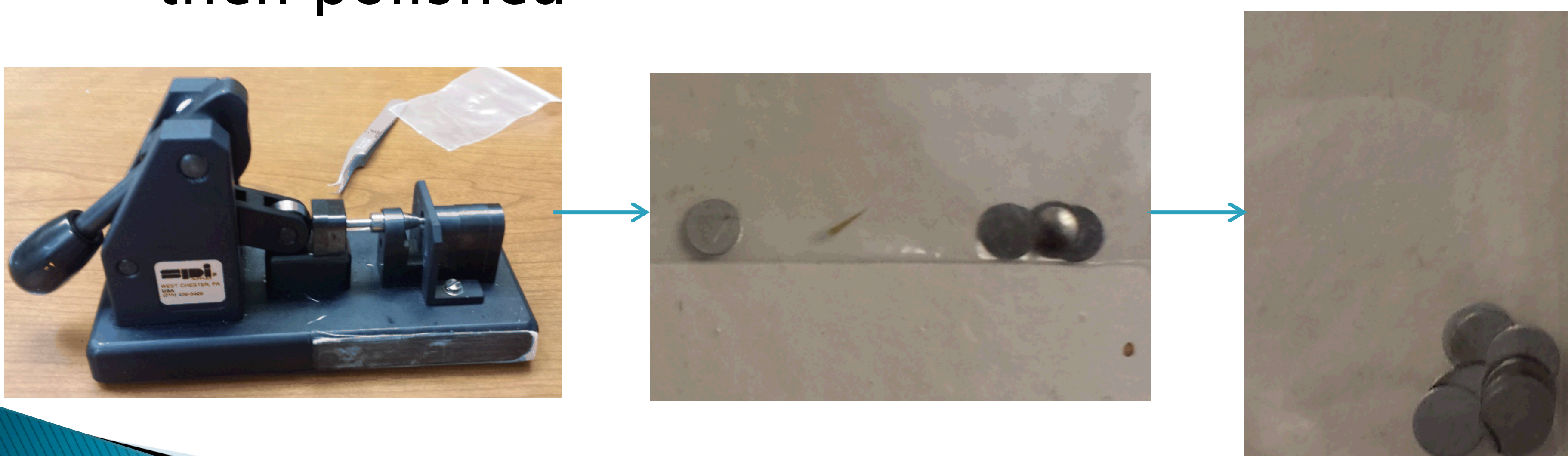
- Samples were grinded until desired thickness was achieved



Sample Preparation Process

- Zirconium templates were cut smaller
- Samples were grinded until desired thickness was achieved
- Smaller discs were punched from sample and then polished

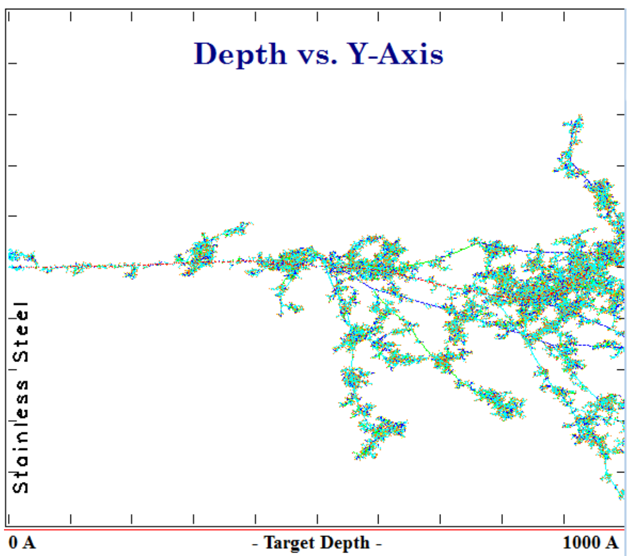


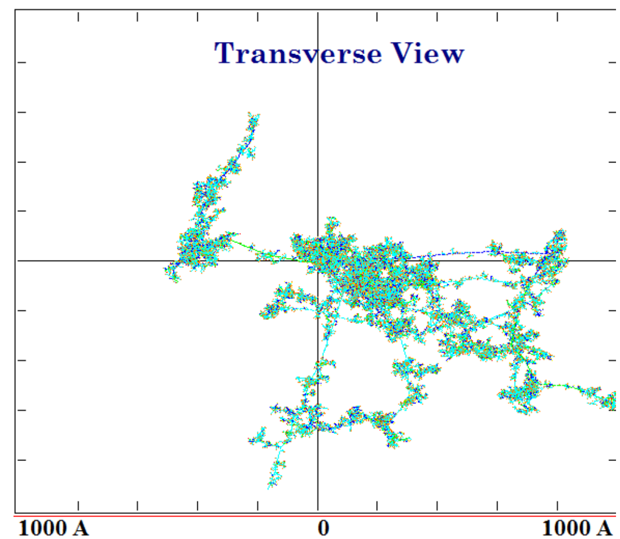
Sample Preparation Process

- Zirconium templates were cut smaller
- Samples were grinded until desired thickness was achieved
- Smaller discs were cut from sample and then polished
- Discs were sent off to an outside facility for further electrochemical processing

Analyzing Process

- Use of 316 Series Stainless Steel
- Predict likely damage accumulation using The Stopping and Range of Ions in Matter (SRIM) software

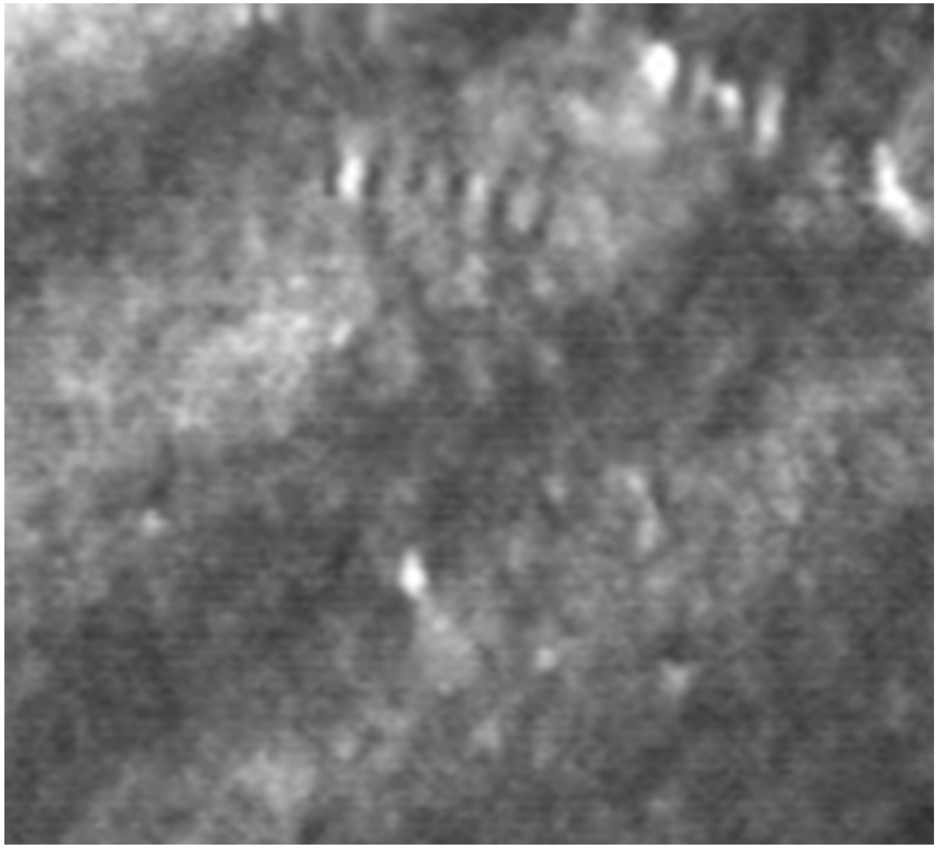




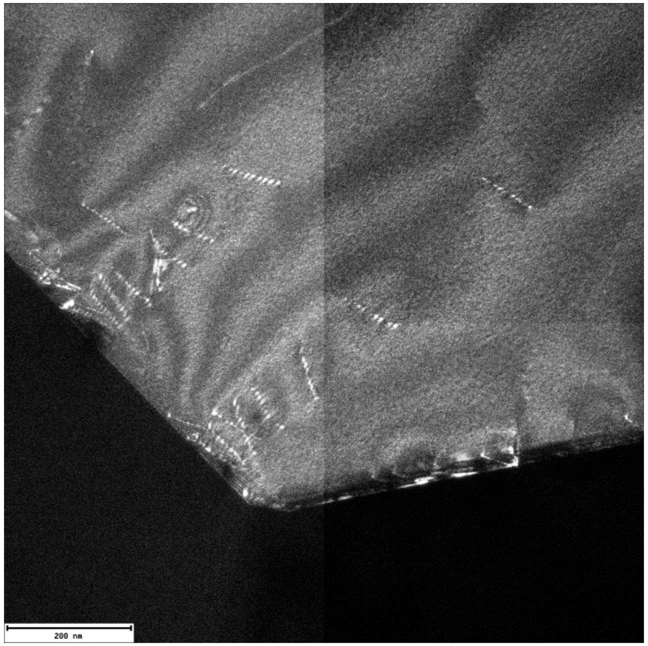
Analyzing Process

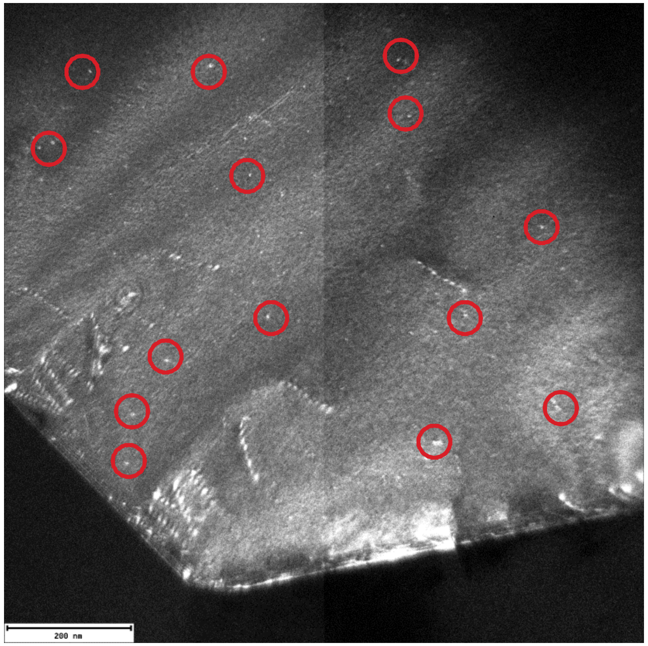
- Use of 316 Series Stainless Steel
- Predict likely damage accumulation using The Stopping and Range of Ions in Matter (SRIM) software
- In situ TEM observation was performed:
  - Heating and Mechanical Testing
  - Ion irradiation and He implantation
  - Load vs displacement

Analyzing Process



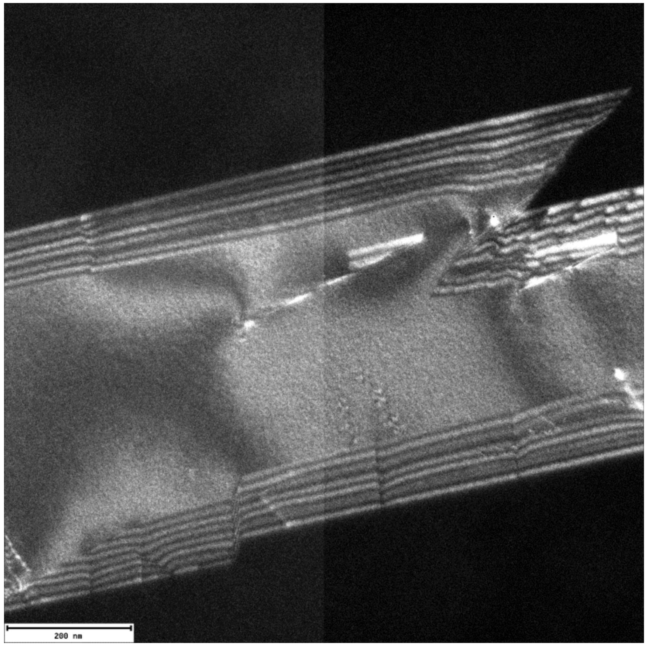
Results

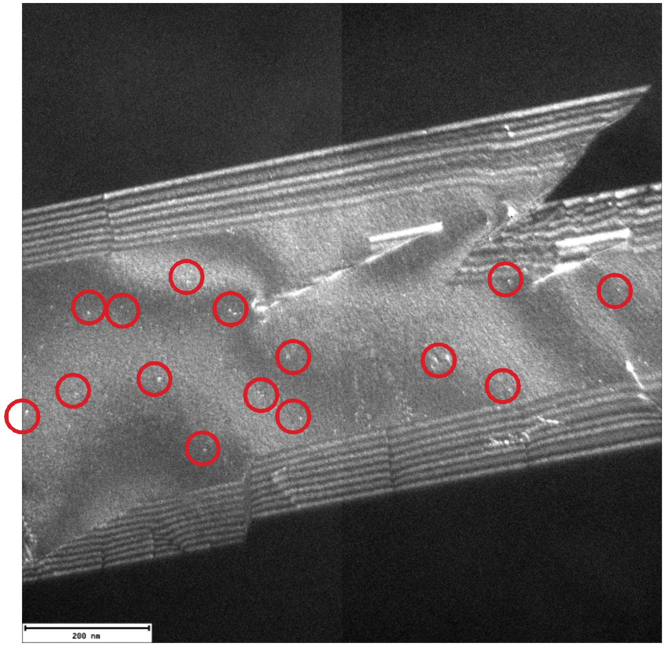




SS Irradiated with Au

Results





SS Irradiated with
He then Au

File		Area	Mean	Min	Max	Number of Defects	Density	Time (s)
7	1	728417.4	104.765	0	255			0
35	2	819594.9	125.856	0	255	6	7.32069E-06	128
40	1	793052.1	114.781	0	255	15	1.89143E-05	256
44	1	772632.2	113.224	0	255	31	4.01226E-05	512
47	1	795222.6	101.375	0	255	66	8.29956E-05	1020
51	1	809173.2	123.748	0	255	109	0.000134705	2040
57	1	879411.4	100.159	0	255	142	0.000161472	4260

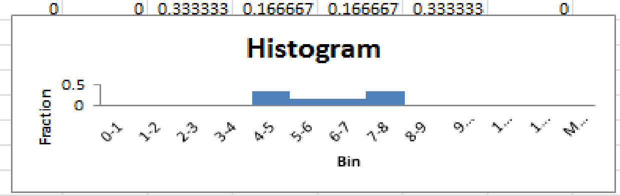
Measurements

AuinSS35

						Defect Size
1	0.897	241.952	193.143	255	-63.435	3.325
2	2.051	189.88	132	254.649	35.754	7.771
3	2.051	201.084	156.079	245.278	17.241	7.793
4	0.961	228.543	161.778	255	-26.565	3.475
5	1.09	193.975	136.333	247.5	39.806	4.065
6	1.666	235.945	164.657	255	-161.565	6.405

Defect Categorization

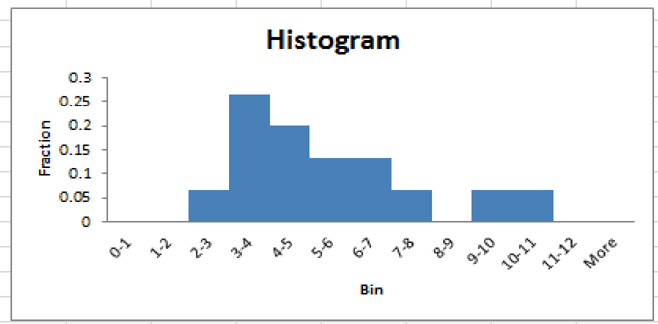
0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11		
0	0	0	0	2	1	1	2	0	0	0		6
0	0	0	0	0.333333	0.166667	0.166667	0.333333	0	0	0		



AuinSS40

						Defect Size
1	1.777	199.915	140.099	251.719	-21.801	6.782
2	2.601	210.756	146	255	0	10.076
3	1.332	206.616	162.111	238.367	30.466	5.041
4	1.332	208.185	163.667	254.12	26.565	4.959
5	0.761	175.259	147	216.143	55.008	2.889
6	1.65	211.747	168	255	36.87	6.247
7	1.142	222.994	151.111	250.319	-17.354	4.248
8	0.825	191.005	158.667	237.321	-28.61	3.004
9	0.508	186.464	159.596	215.347	15.945	1.809
10	1.142	222.298	142	254.25	17.354	4.248
11	0.952	213.396	163.494	255	102.995	3.425
12	0.825	147.016	105	196	-26.565	3.004
13	1.459	238.267	181.667	255	13.392	5.539
14	0.952	178.703	118.925	236.061	74.055	3.506
15	1.903	225.951	138.703	255	-1.909	7.396

0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
0	0	1	4	3	2	2	1	0	1	1	
0	0	0.066667	0.266667	0.2	0.133333	0.133333	0.066667	0	0.066667	0.066667	15

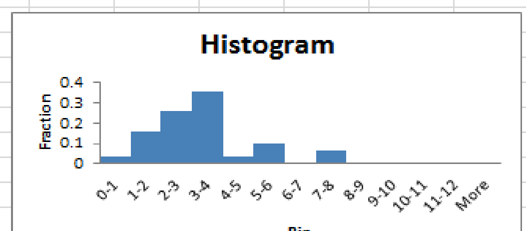


AuinSS44

						Defect Size
1	1.456	107.885	38	150.727	-84.806	5.557
2	0.57	213.667	181	247	90	2.013
3	0.506	198.352	163.918	255	-33.69	1.814
4	0.57	210.481	159.556	254.444	-97.125	2.04
5	0.38	198.218	149	233.387	-153.435	1.209
6	0.57	172.537	153	186.333	33.69	1.956
7	0.443	163.82	132	185.778	-30.964	1.5
8	0.823	162.843	118.333	243.556	-128.66	3.093
9	0.443	137.683	107	162.444	-135	1.423
10	0.696	181.241	129.453	209.716	-122.005	2.419
11	0.696	208.503	174.058	246.333	-126.87	2.419
12	1.139	211.869	170.025	252.612	-151.928	4.203
13	0.253	162.701	145.481	192.333	-135	0.75
14	0.949	220.992	159	255	-33.69	3.628

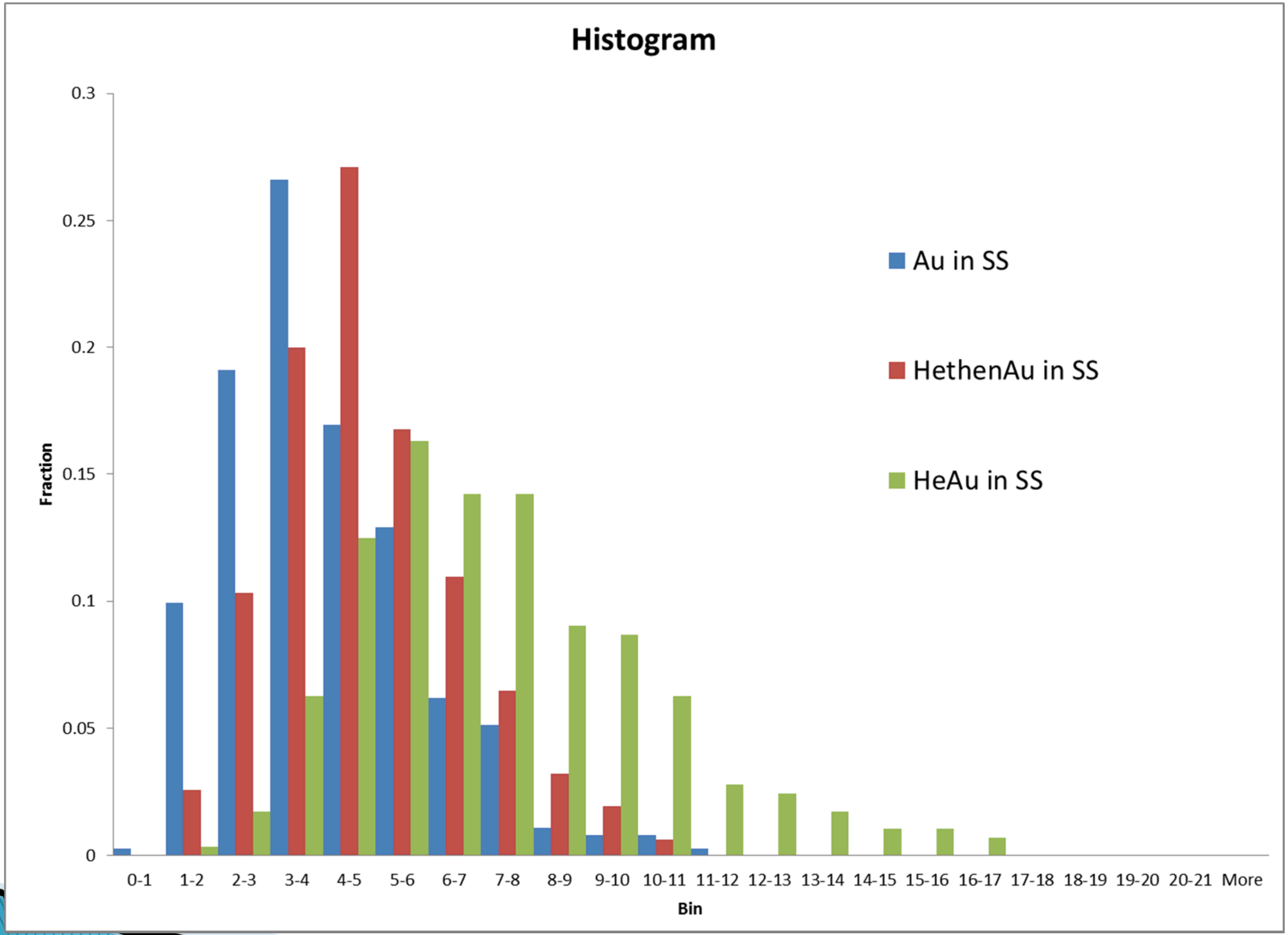
Defect Categorization

0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
1	5	8	11	1	3	0	2	0	0	0	
0.032258	0.16129	0.258065	0.354839	0.032258	0.096774	0	0.064516	0	0	0	31



AuinSS | HeAuinSS | HethenAuinSS | Other Final Time Step 4 15 15

Results



Histogram
Fraction
0.3
0.25
0.2
0.15
0.1
0.05
0
0-1 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12 12-13 13-14 14-15 15-16 16-17 17-18 18-19 19-20 20-21 More
Bin
Au in SS
HethenAu in SS
HeAu in SS

Conclusions

- Was able to observe how fundamental issues can affect macroscopic properties
- Characterized how defects appear under certain imaging conditions
- Data gathered from experimentation can be useful in future modeling software

Take-Aways Of the Summer

- Organization is key to task accomplishment
- Understanding your equipment prior to experimentation is crucial to time management
- Have realistic expectations of yourself with the time you are given
- WEAR SUNSCREEN

Questions?

One team, one fight