INL/CON-18-45026-Revision-1

Radioactivity Calculator for Research and Test Reactor Neutron-Activated Materials

Brenden Heidrich , Kaecee Holden

August 2018

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Radioactivity and Neutron Damage Calculators for Research and Test Reactor Neutron-Activated Materials

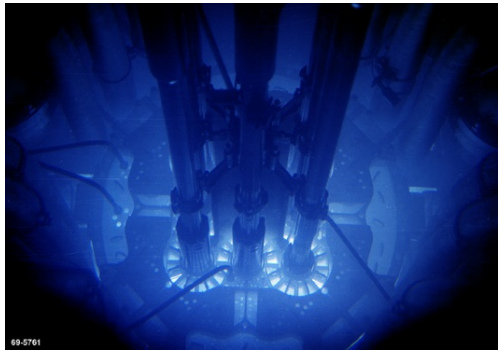
Brenden Heidrich, KaeCee Holden, and Kelley Verner

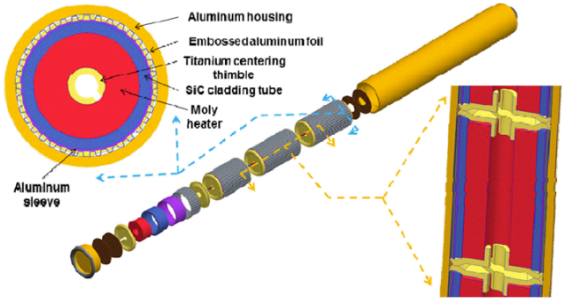
NSUF Nuclear Science User Facilities

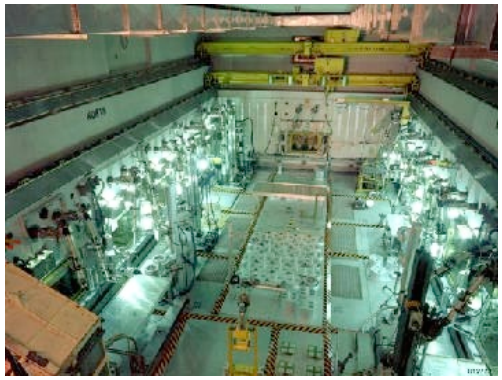
INL/CON-18-45026R1

Nuclear Science User Facilities (NSUF)

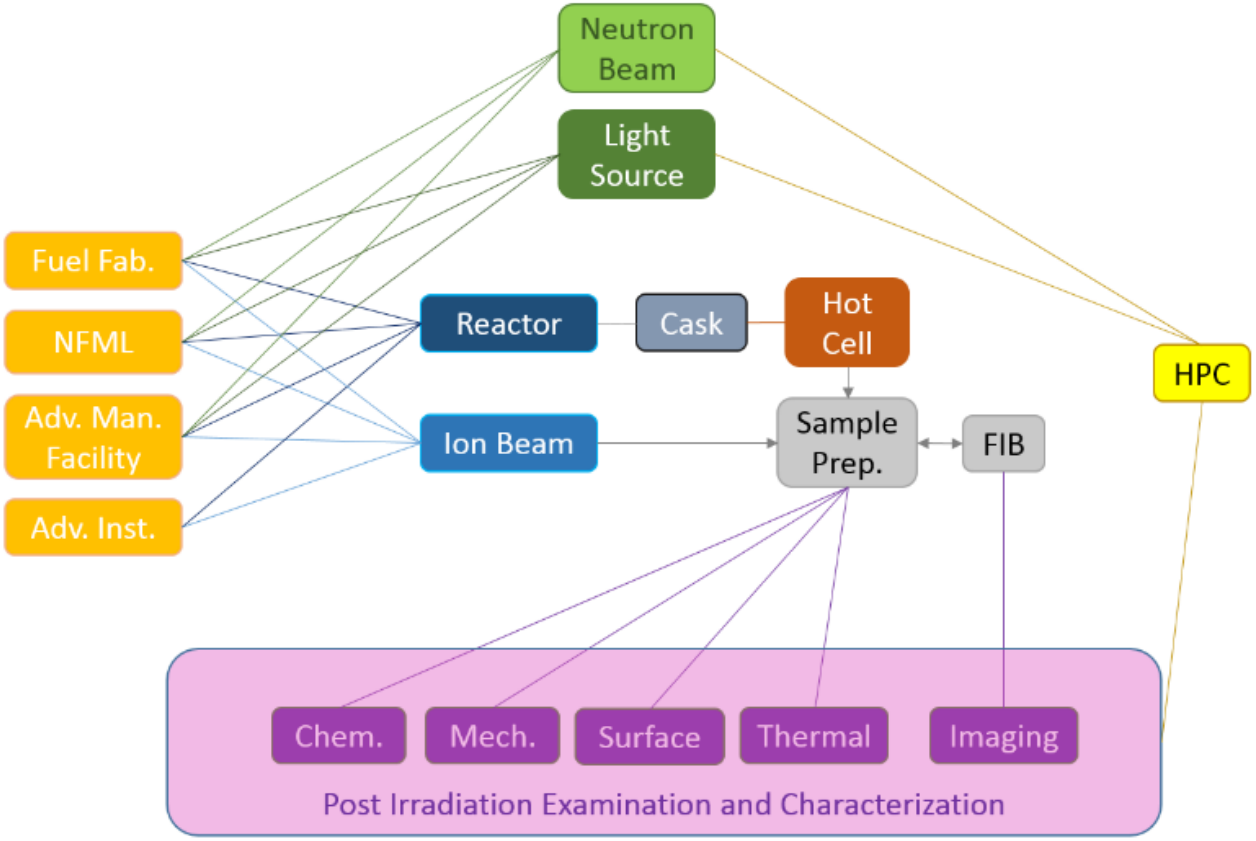
- NSUF offers unparalleled research opportunities for nuclear energy researchers.
- Users are provided access to:
  - world-class nuclear research facilities,
  - technical expertise from experienced scientists and engineers, and
  - assistance with experiment design, assembly, safety analysis and examination.
- Access is awarded through a competitive peer-reviewed process.
- 369 total projects awarded ($216MM)
  - 69 large CINR projects
  - 300 smaller RTE projects







Experiment Process



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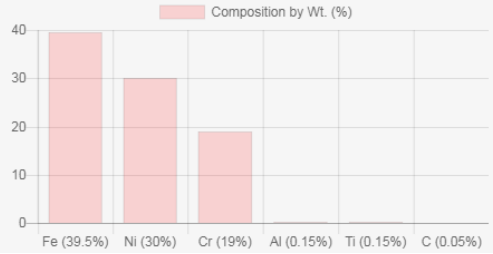
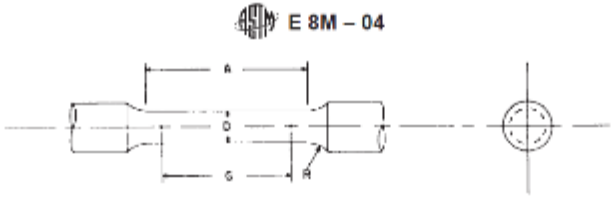
Is Approved	True
Project	Irradiation Test Plan for the Advanced Test Reactor National Scientific User Facility/University of Wisconsin Pilot Project
Reactor	ATR
Reactor Position	East Flux Trap
Sample Id Code	024-08-331
Capsule	Capsule 1
Packet	500 LO A
Material Code	N5
Material Name	800H
Material Description	Austenitic SS
KGT Num	276
Specimen Type	TEM
Dimensions (mm)	3d x .2
Number Of Samples	4
Specimen Availability	Yes
Availability Date	November 26, 2014
Certification	Yes
Storage Facility	Hot Fuel Examination Facility
Notes	only 1 tensile specimen each for 800H and 800H-TMP per irradiation condition
Planned Temp (°C)	500.00
Planned Dose (DPA)	3
Planned Flux (n/cm²s)	9.7E+13
Planned Environment	Helium/Argon
As Run Total Dose (DPA)	4.64
As Run Total Fluence (...	1.51E+22
Composition by Wt. (%)	Fe-30Ni-19Cr-0.15Al-0.15Ti-0.05C
Keyword Tags	Metallic Alloy, Alloy, Metal, Austenitic Alloy, Steel, Stainless Steel, INCOLOY Alloy, Ferrous, Control Rods, High Temperature Gas Reactor



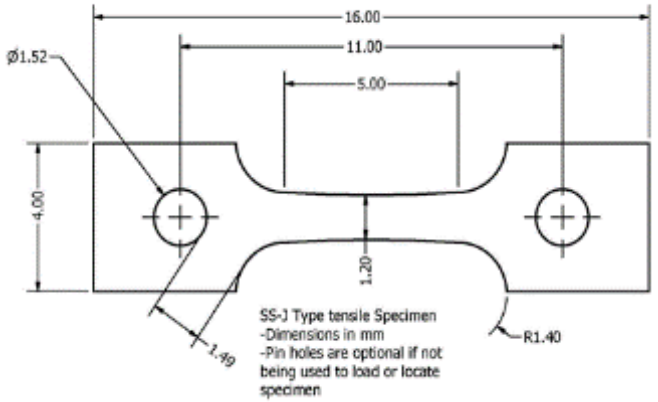
Small Specimen Tensile Testing Challenge

- Tensile testing has long been an important method for determining the material properties of different structural steel components.
- The effect of irradiation on these steel components is of particular interest to the nuclear power industry.
- The large (E8) specimens typically used are not efficient for test reactor irradiations. They also usually require a hot cell for performing post-irradiation examination.
- Research into using small-scale tensile specimens has been of great interest in the nuclear industry for quite some time.

Alloy	Dose Rate		6 dpa
	T=0	T=365	
SA 508	112	97	R/hr @ 30cm
625	75	28	
718	6.2	0.13	
690	1.5	0.10	
316L	3.8	0.10	
Grade 91	2.3	0.09	
304L	3.8	0.09	

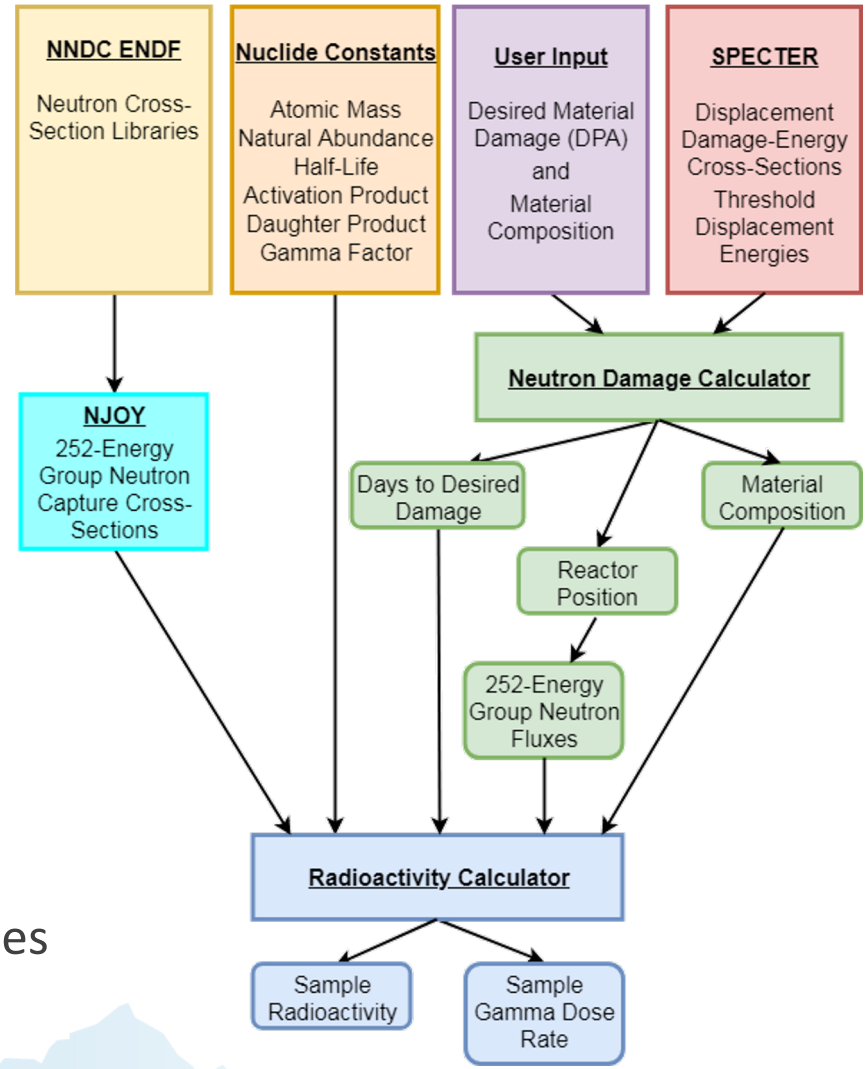


	Dimensions, mm				
	Standard Specimen	Small Size Specimens Proportional To Standard			
	12.5	9	6	4	2.5
G—Gage length	62.5 ± 0.1	45.0 ± 0.1	30.0 ± 0.1	20.0 ± 0.1	12.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1	4.0 ± 0.1	2.5 ± 0.1
R Radius of fillet, min	10	8	6	4	2
A—Length of reduced section, min (Note 2)	75	54	36	24	20



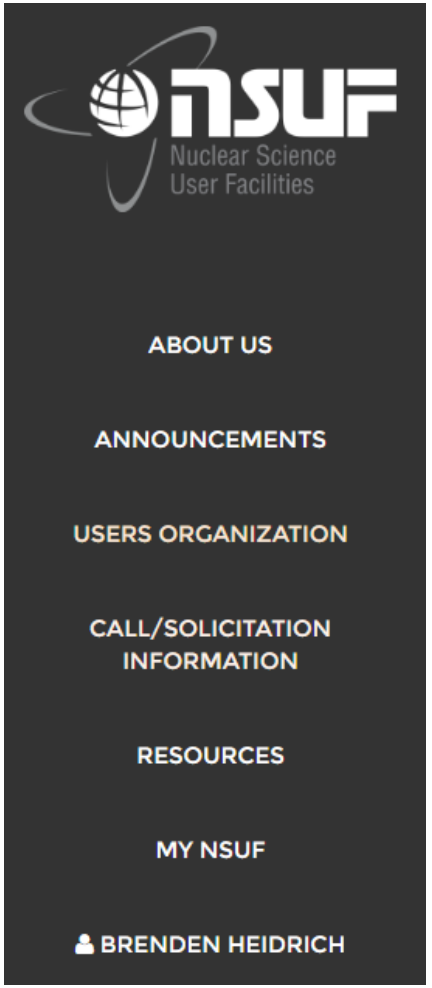
Calculator Data Flow

- Neutron Damage Calculator
  - Input
    - Desired DPA
    - Material Composition
  - Output
    - Days to desired DPA
    - Reactor Positions
- Radioactivity Calculator
  - Input
    - Irradiation time
    - Material composition
  - Output
    - Radioactivity at set decay times
    - Gamma Dose Rate

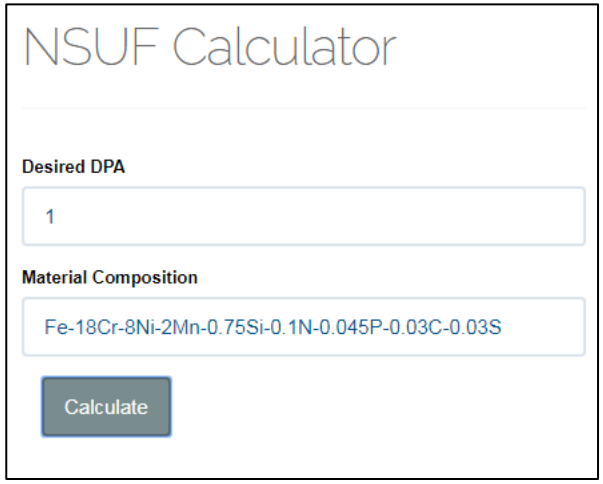


Web Application Development

- Neutron Damage Calculator (Python) and Radioactivity Calculator (MATLAB) converted to C#
- Cross-sections and constant database created
- Calculators will be available on nsuf.inl.gov



Web Application – Position Selection



- Representative reactor positions for:
  - INL ATR
  - ORNL HFIR
  - MITR-II (coming soon!)
  - BR-2
  - OSURR
  - NCSU Pulstar

Select a row to calculate radioactivity and gamma dose rate:

Select	Reactor	Position	Diameter (cm)	Days	Cycles	Years	Thermal Fluence	Fast Fluence
○	ATR	A1	1.6	68.2	1.2	0.2	3.73e+020	3.10e+020
○	ATR	A13	1.6	77.9	1.4	0.2	3.55e+020	2.92e+020
○	ATR	B1	2.2	123.9	2.3	0.3	6.06e+020	3.16e+020
○	ATR	B9	3.8	402.5	7.3	1.1	8.35e+020	3.81e+020
○	ATR	I1	12.7	8024.7	145.9	22	1.26e+021	4.18e+020
○	ATR	I3	8.3	8227.6	149.6	22.5	1.75e+021	3.85e+020
○	ATR	I5	8.3	9833.6	178.8	26.9	1.76e+021	3.26e+020
○	ATR	I21	3.8	6699.3	121.8	18.4	3.96e+021	4.33e+020

Web Application – Final Results

Your sample contains **Fe-9.6Cr-0.03Y-0.01C-0.003N**

ATR

Position	B1
Diameter (cm)	2.2
Days	123.9
Cycle	2.3
Years	0.3
Thermal Fluence	6.06e+020
Fast Fluence	3.16e+020

The activity of your sample is as follows:

after 0 days: 2.47E+11 Bq/g or 6.66 Ci/g

after 30 days: 5.42E+10 Bq/g or 1.47 Ci/g

after 60 days: 2.64E+10 Bq/g or 0.714 Ci/g

after 90 days: 1.33E+10 Bq/g or 0.359 Ci/g

after 180 days: 2.67E+09 Bq/g or 0.0723 Ci/g

after 3098 days: 1.87E+08 Bq/g or 0.00505 Ci/g

The effective gamma dose rate of the sample at 30cm:

after 0 days: 882 mrem/hr/g

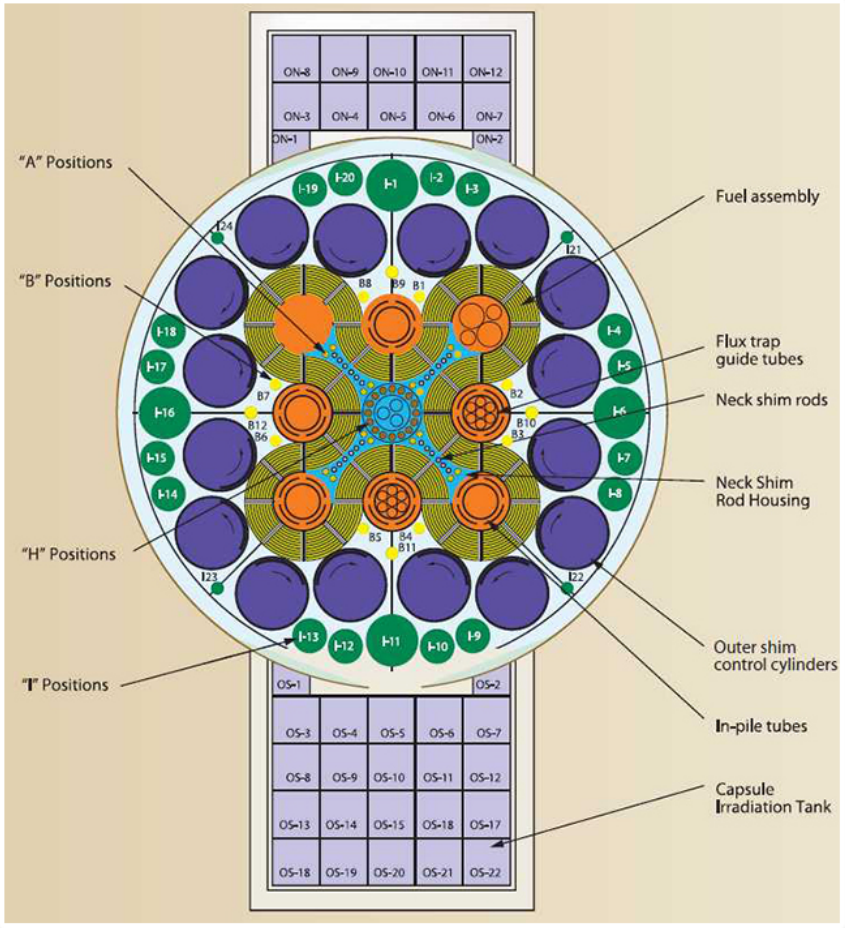
after 30 days: 431 mrem/hr/g

after 60 days: 213 mrem/hr/g

after 90 days: 107 mrem/hr/g

after 180 days: 14.8 mrem/hr/g

after 3098 days: 0.000901 mrem/hr/g

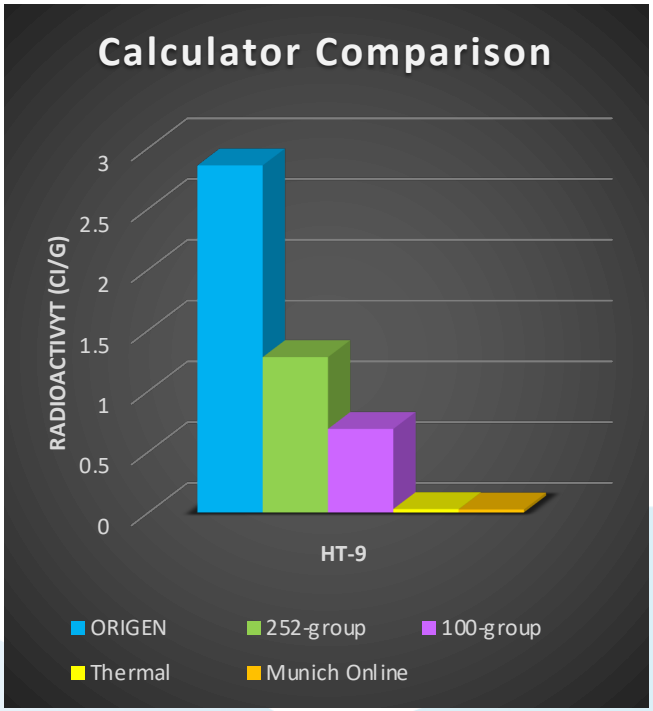


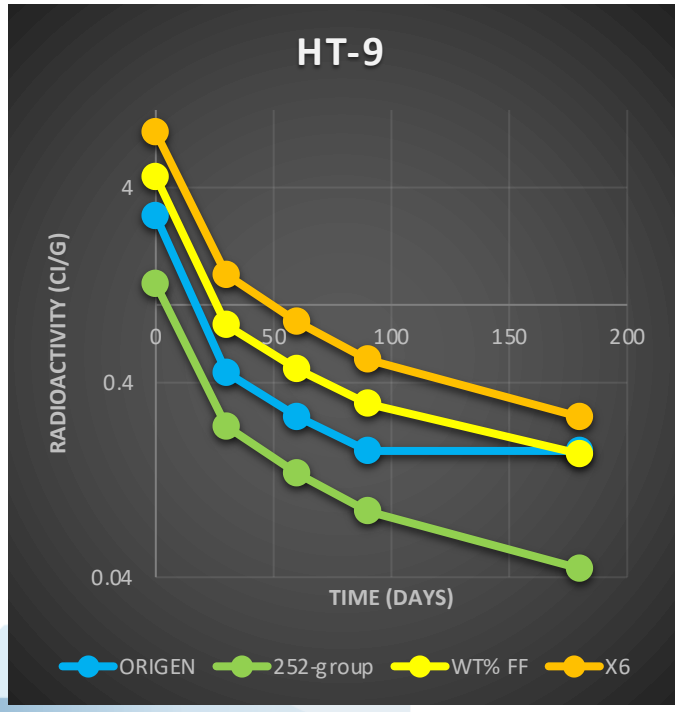
Select a different position

Radioactivity Calculator Validation

- Utilizes 252-energy group neutron flux and activation cross-sections (JEFF)
- Improvement over available online calculators and previous calculator iterations

- Added a **safety factor** to improve accuracy.
- Only neutron activation/capture reaction included
- Meta-stable states not included

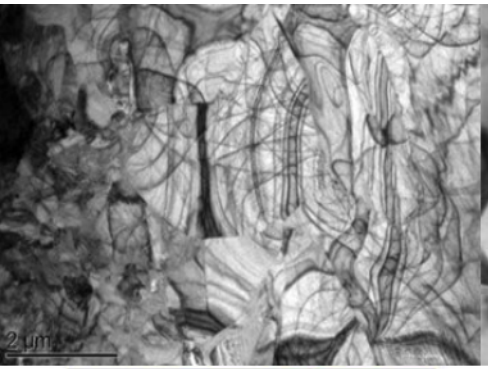


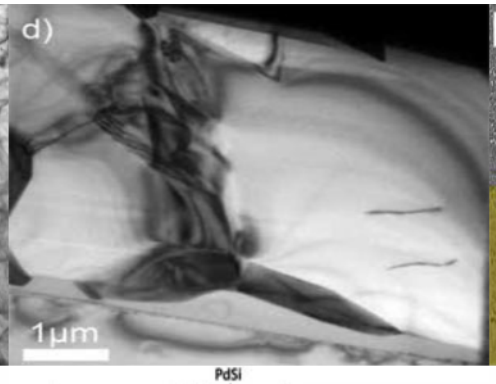


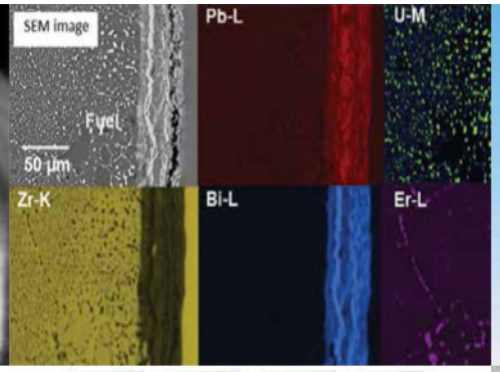
Technical University of Munich, "Calculate Activation," https://webapps.frm2.tum.de/intranet/activation/ (2017).

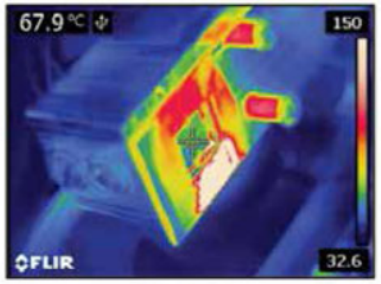
Desired Impact

1. Provide an easily accessible, user-friendly calculation tools for DPA and Radioactivity
2. Inform researchers and technical staff of experiment requirements and time frames
3. Flag any potential safety issues

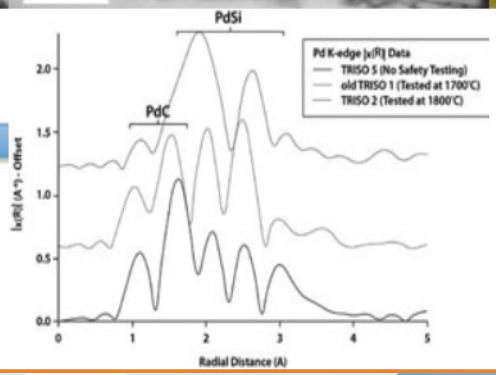


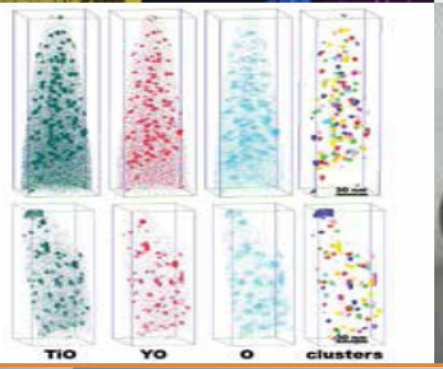






Ion irradiation at ATLAS





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Questions?

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Extra Slides

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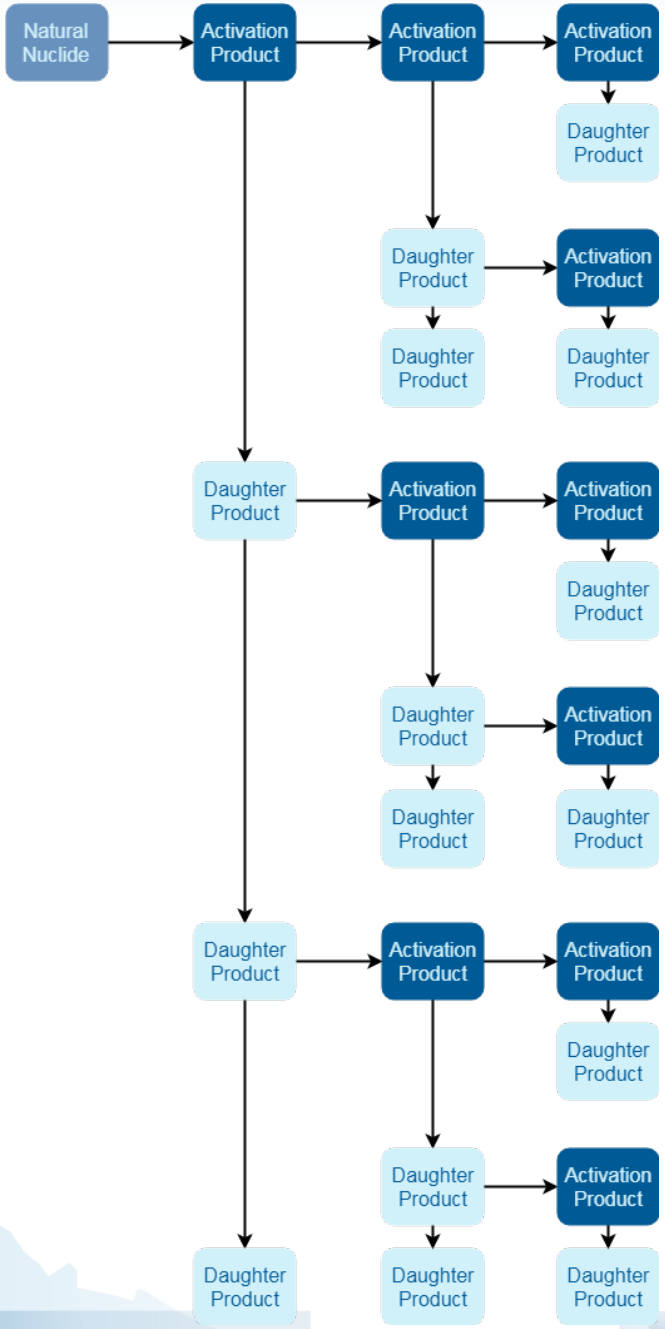
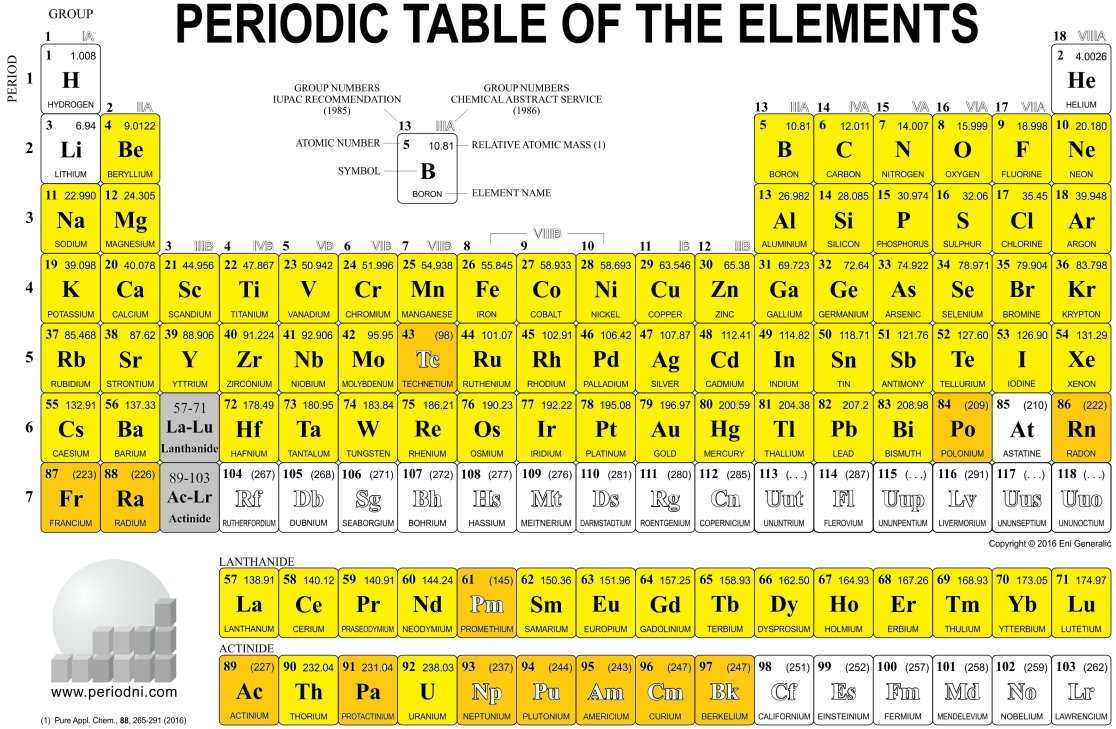
Activation-Decay Chain

- Only daughter products with highest branching ratio were included
- Calculator does not include meta-stable states or spontaneous fission

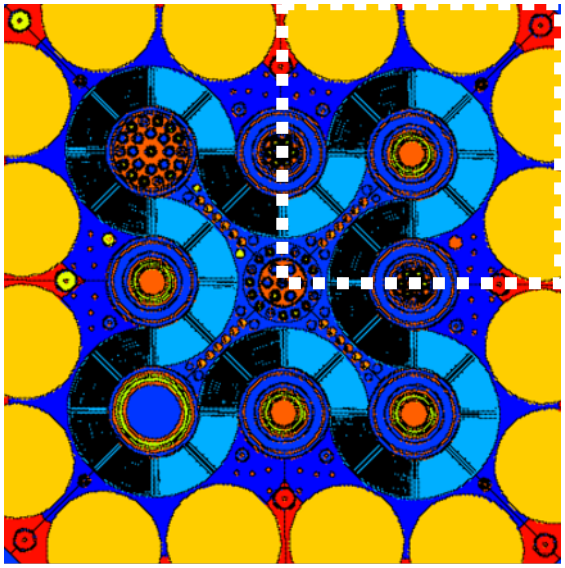


Elements Included

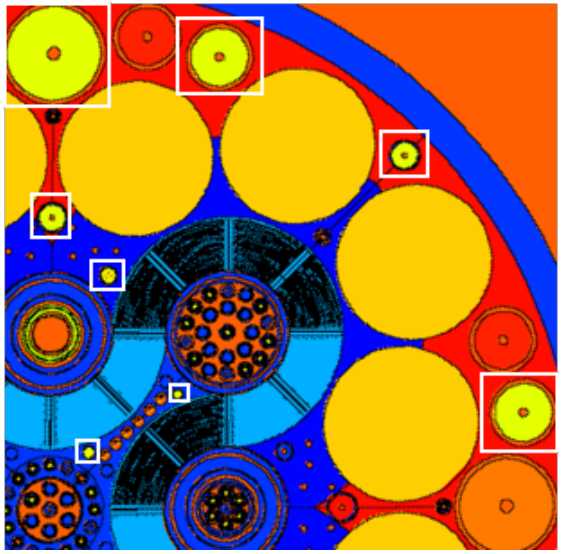
- 92 elements
  - 760 nuclides
- Yellow: all naturally occurring isotopes included, plus any required for any activation-decay chain
- Orange: no naturally occurring isotopes, therefore only those needed to complete any activation-decay chain were included
- White: element not included in the calculator



Reactor Positions - ATR

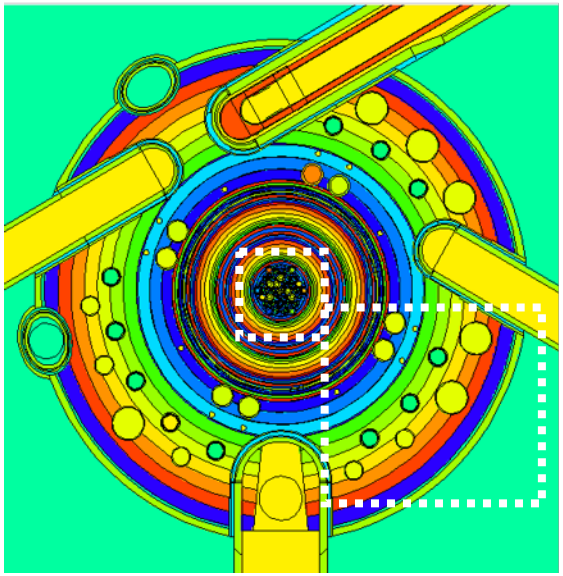


Full Core of ATR

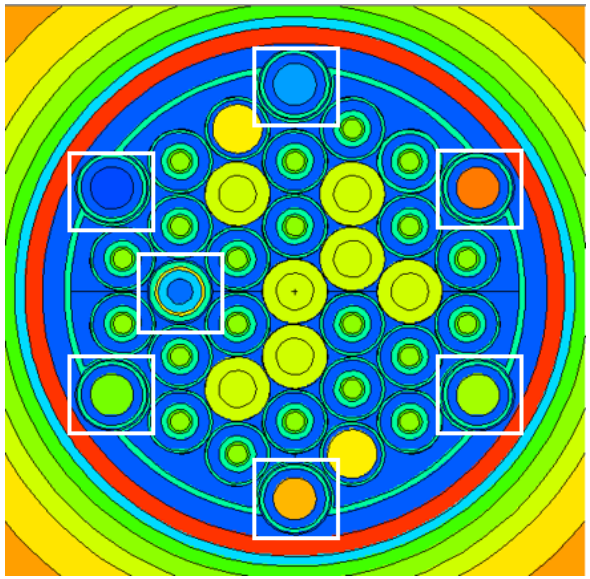


Northeast section of ATR

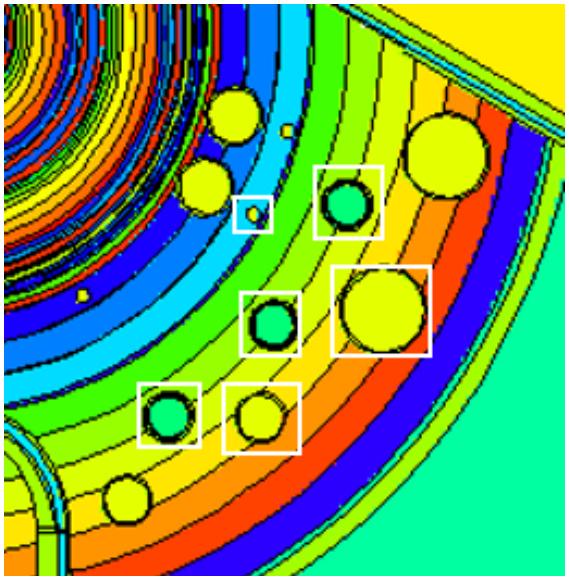
Reactor Positions - HIFR



Full Core of HIFR



Central Core Positions



Outer Core Positions