INL/CON-22-66711-Revision-0

Pu-238 Production Calculator and Estimation Tool in the Advanced Test Reactor

May 2022

Changing the World's Energy Future

Demi Weaver, Andrew John Zillmer

INL/CON-22-66711-Revision-0

Pu-238 Production Calculator and Estimation Tool in the Advanced Test Reactor

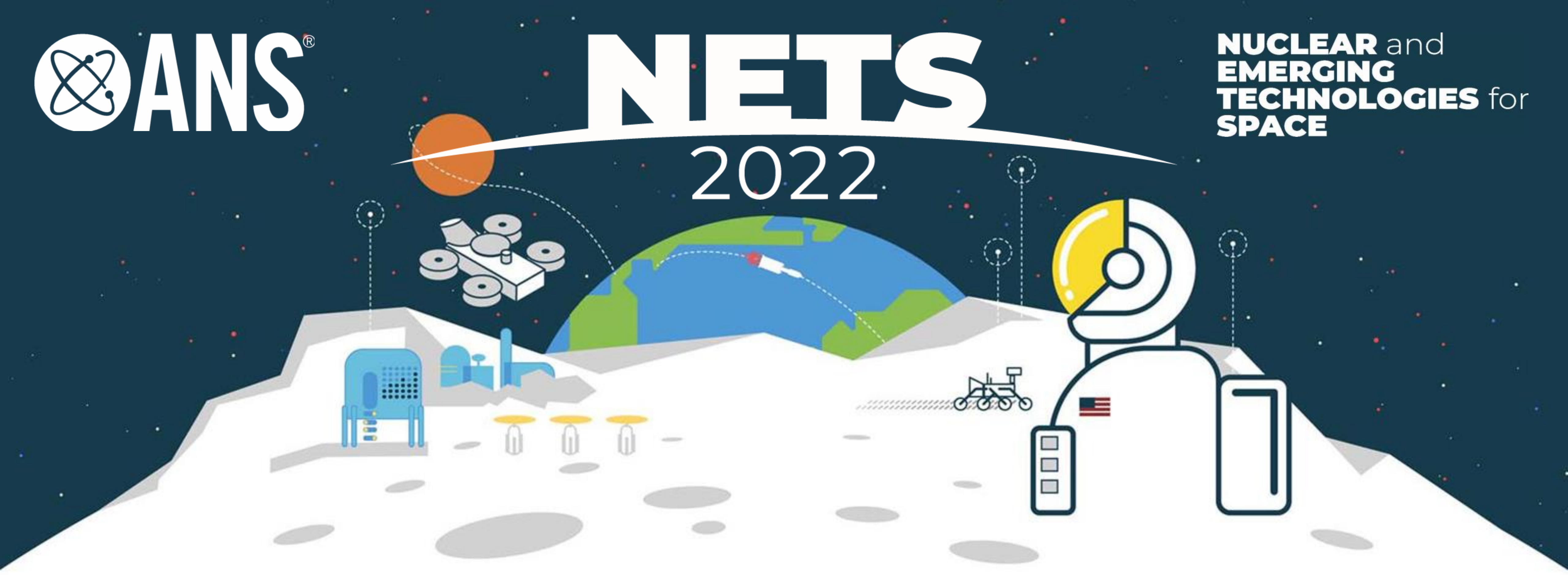
Demi Weaver, Andrew John Zillmer

May 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517



Pu-238 Production Calculator and Estimation Tool in the Advanced Test Reactor

Demi Weaver

ORISE DOE Scholars Intern
Angelo State University

Andrew Zillmer

Deputy Division Director of Space Nuclear Power and Isotope Technologies

Angelo State University
INL

Summary

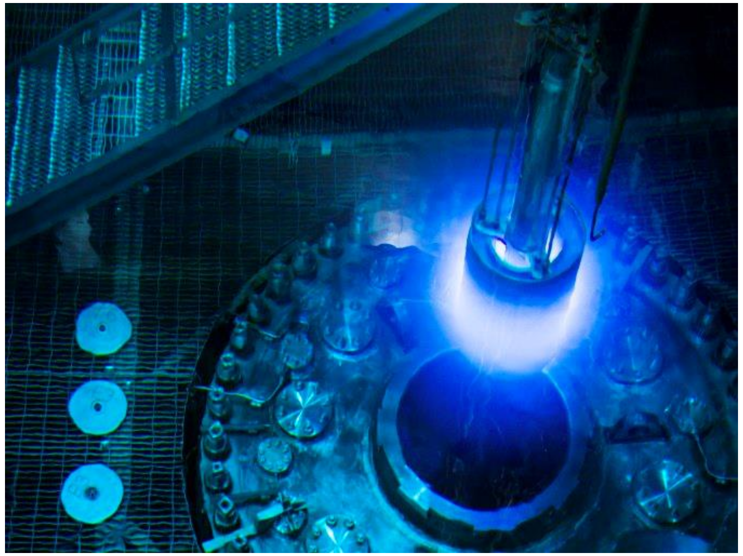
- Project Overview
- Project Goals
- Irradiation Target Information
- Target Design
- ATR and HFIR Loading Positions
- Example Production Results
- Conclusions

Overview

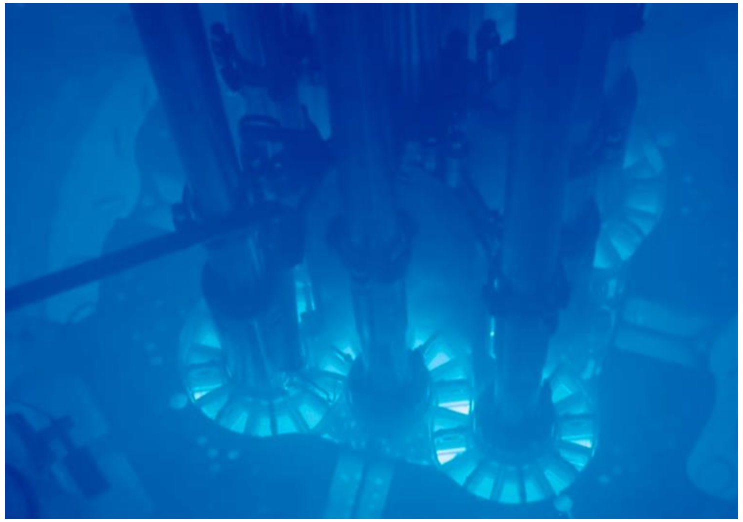
Excel tool was created to…

- Track Pu-238 production across the DOE complex
- Track and estimate Np-237 feedstock use
- Estimate production scenarios
- Coordinate planning for shipments
  - Project number of targets per shipment
  - Identify potential shortfalls in target production

[1]



[3]

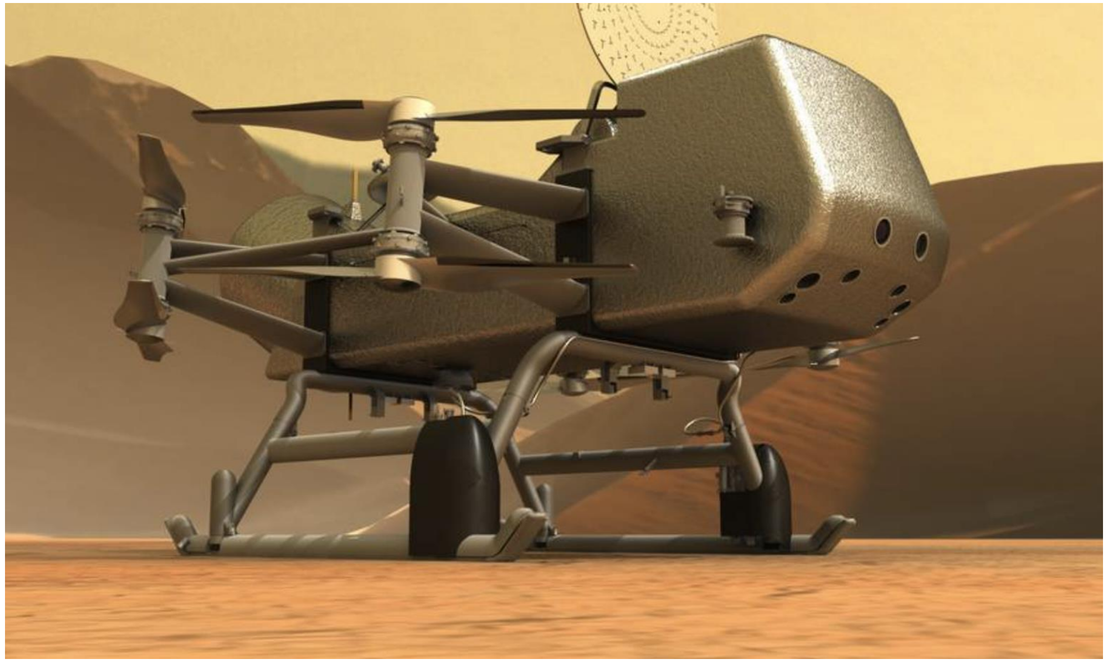


Application

INL and ORNL are producing heat source material to provide heat and power for NASA space missions.

- **Dragonfly**
  - Scheduled to launch: June 2027
  - Advance the search for the building blocks of life

[6]



Initial Goals

- Track targets through the irradiation process at the Advanced Test Reactor (ATR)
- Estimate…
  - production yields from irradiated targets in various positions for each cycle
  - production from current and future target designs based on data from numerical modeling
- Provide past, current, and future year quantities of Np-237 & Pu-238 at ATR
- Calculate the amounts of Np-237 & Pu-238 shipped to & from INL to ORNL.

Target Information

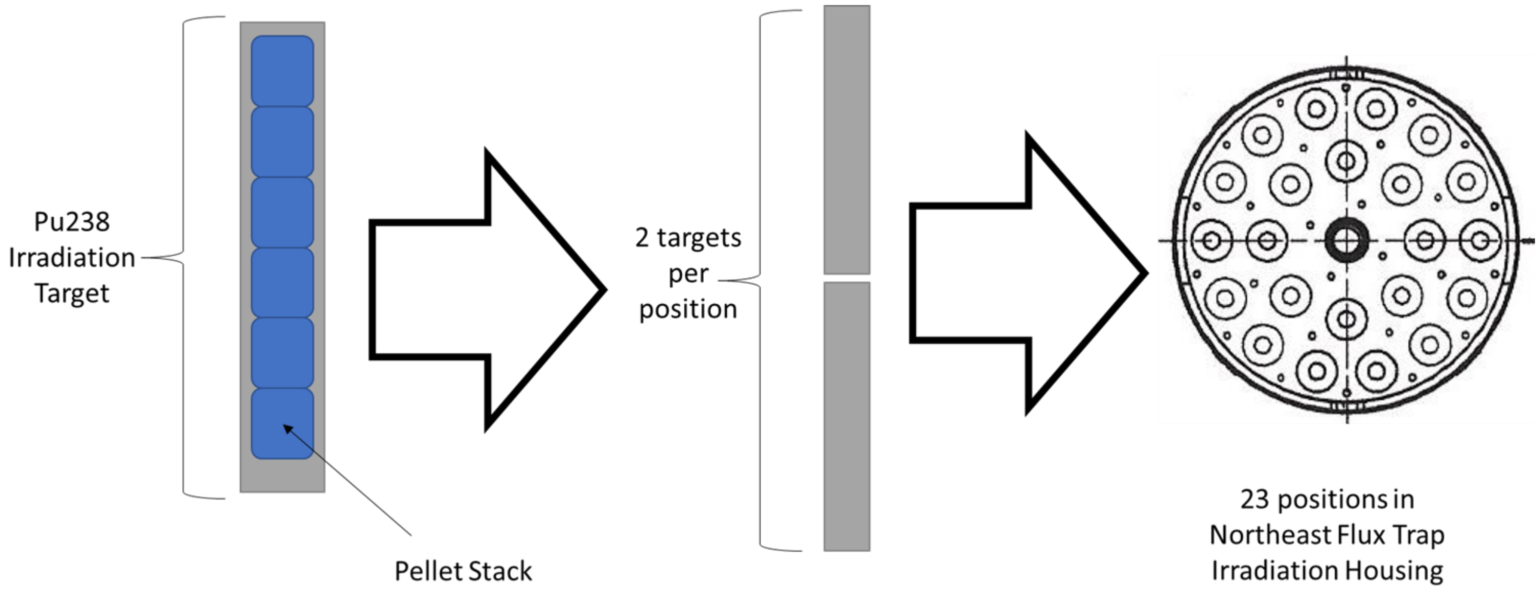
- Target name
- Number of pellets per target
- Initial Np mass
- Final Np mass
- Initial Pu-238 mass
- Final Pu-238 mass
- Final Pu-238 Oxide mass
- Assay %
- Equivalent Heat Source Material

Cycle	Start Date	Target Type	# Targets	Pellets	Initial Np	Final Np [g]	Initial Pu-238 [g]	Final Pu-238 [g]	Final Pu-238 Oxide [g]	Assay [%]	HS Material [g]

Target information is generated by high fidelity models, and averages are loaded into the tool as Target Information

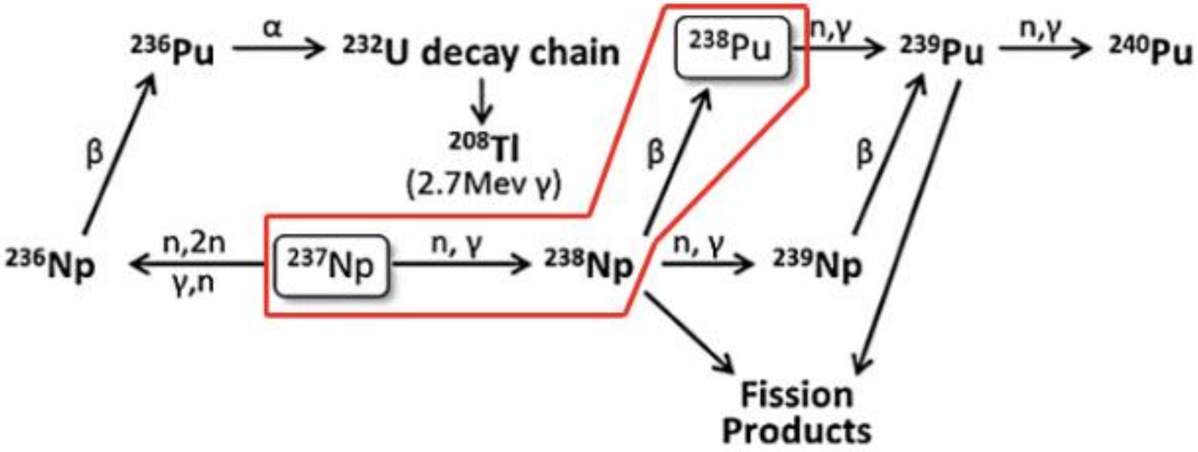
Nomenclature

- **Position** – the position in the reactor
- **Slot** – the number of locations in a reactor position that can have targets loaded
- **Type** – the model of the irradiation target; for example a HFIR Gen II target has one target per slot, and the ATR Gen I target has two targets per slot



Production Chain of Pu-238 from Np-237 Feedstock

- Primary reaction is Np-237 feedstock absorbing a neutron to make Np-238, which then decays to Pu-238.
- Several other reactions can occur when the Np-237 is irradiated, including (n,2n), beta decay, and fission.

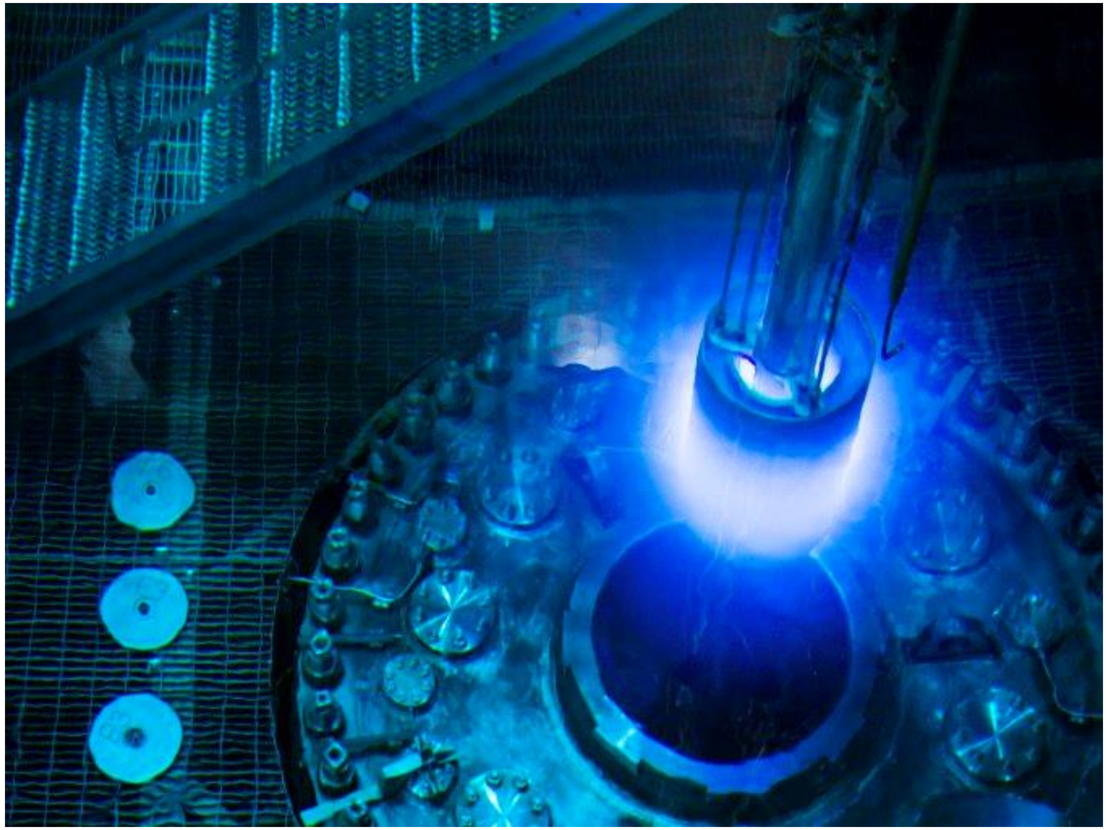


[5]

HFIR Gen I Target

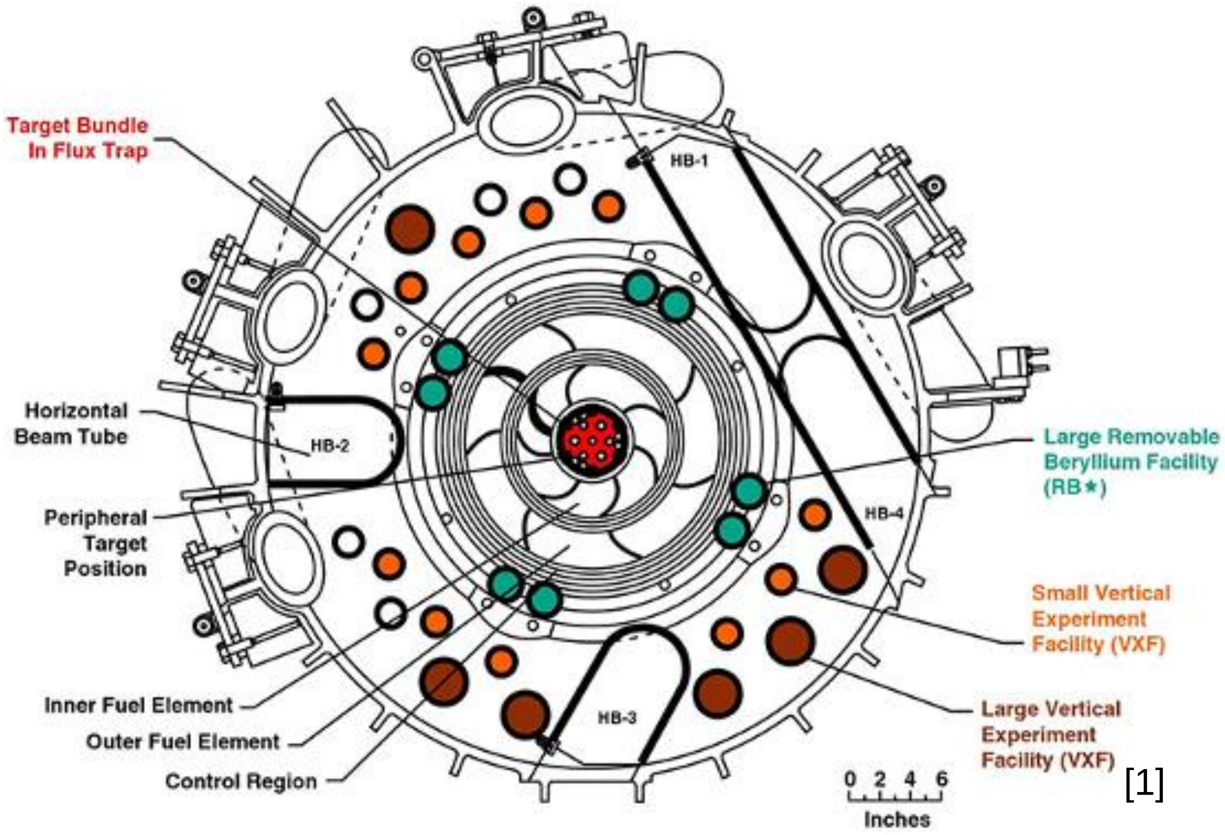
- Originally developed at ORNL for the HFIR reactor
- Provided initial data for target qualifications
- Was not used for production

[1]



HFIR Gen II Target

- Contains a CERMET pellet composed of
  237 and Aluminum.
- Designed by ORNL
- Used in HFIR and ATR
  - Full height of HFIR core
  - Half height of ATR core
    - One target per ‘slot’ in ATR
    - Provided initial production capacity at ATR



[1]

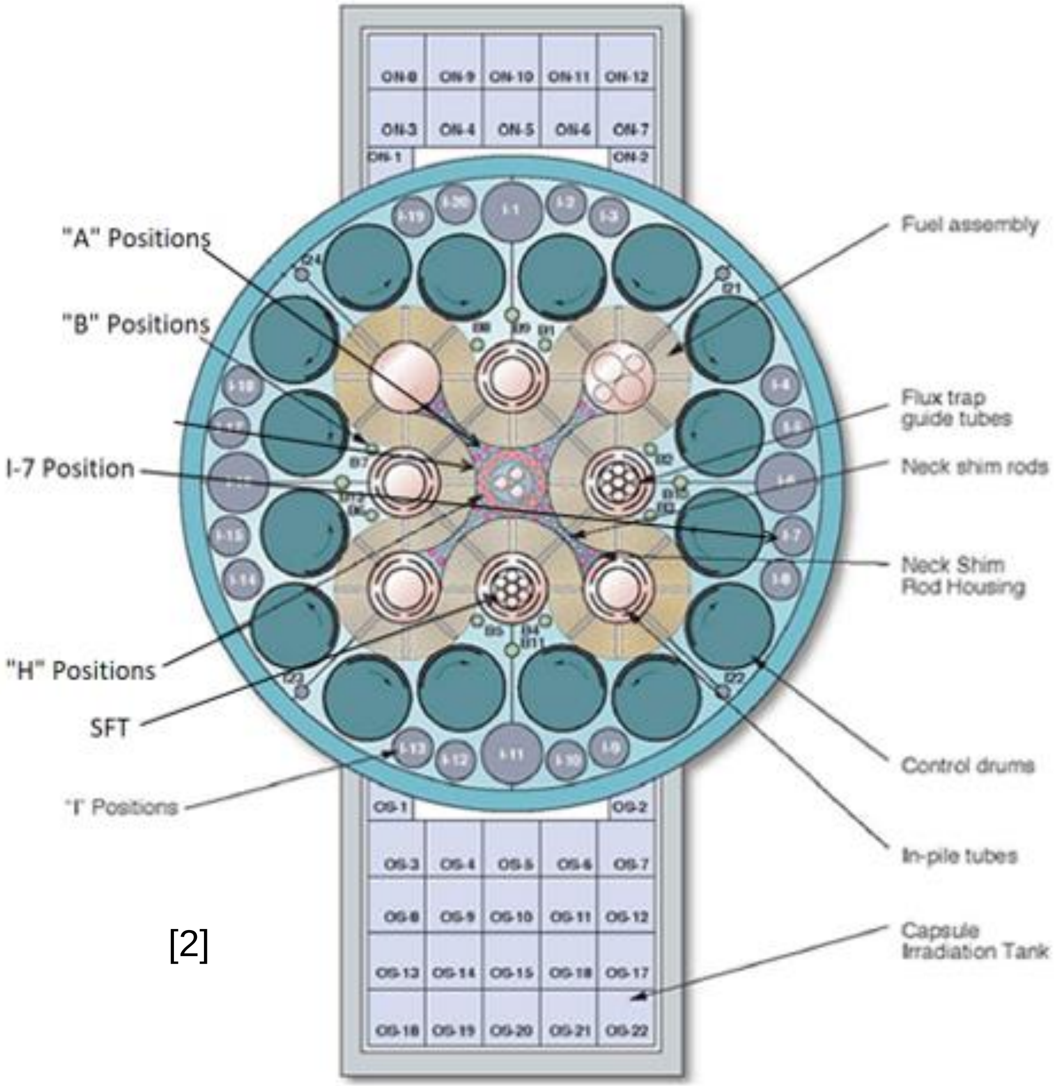
ATR Gen I Target

- Evolution of the HFIR Gen II target
- 2 targets similar to HFIR Gen II targets are joined with a Samarium spacer
  - Allows use of full length ATR core
  - Samarium spacer reduces impact of mid plane heating
- 2 targets per slot

ATR Core Loading Locations

Potential irradiation locations:

- North East Flux Trap
- South Flux Trap
- East Flux Trap
- Inner A positions (A1 through A8)
- H positions (H1 through H 16)
- Small I positions
- Medium I positions
- Large I positions

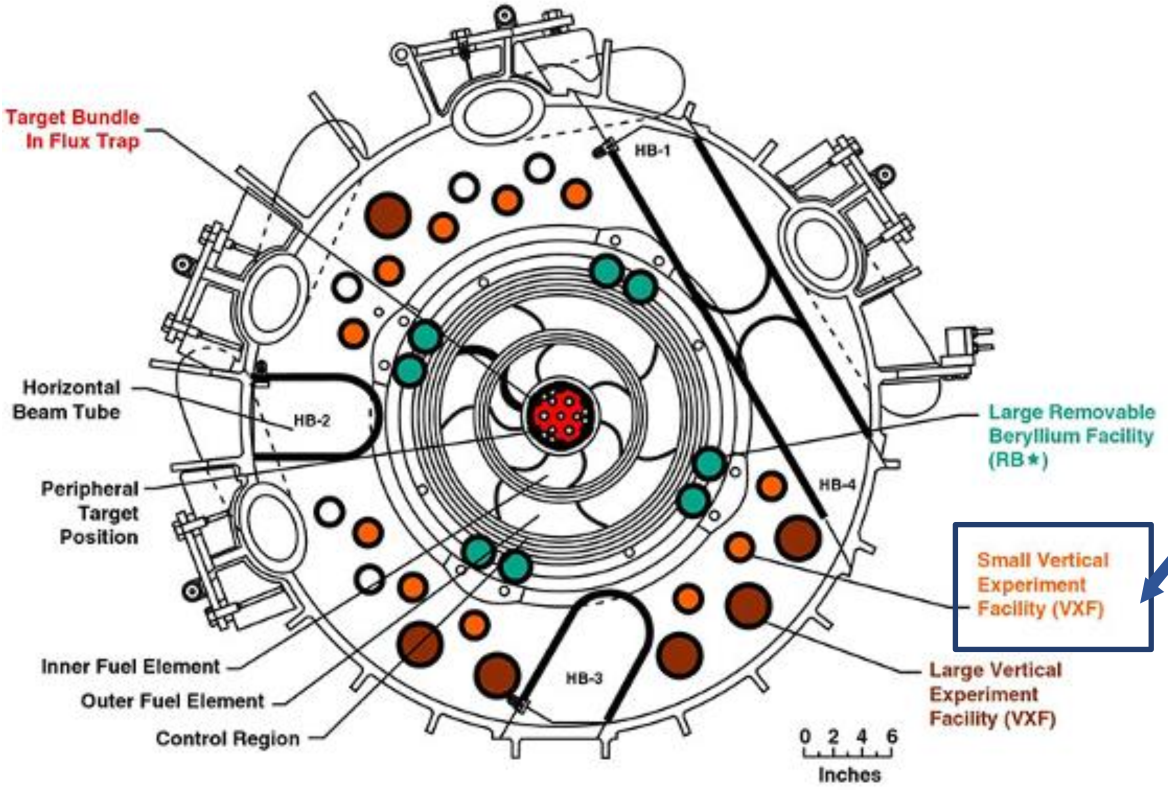


[2]

HIFR Core Loading Locations

Potential irradiation locations:

- Small Vertical eXperiment Facility (VXF) positions



[1]

Target Loading Matrix

- Identifies loading positions, slots per position, other information
- Loading is used to produce production results

		CY22						CY23									CY24					
		171A			173A			173B			175A			175B			177A			177B		
Position Type	Position Location	Slots	# Targets	Type	Slots	# of Targets	Type	Slots	# of Targets	Type	Slots	# of Targets	Type	Slots	# of Targets	Type	Slots	# of Targets	Type	Slots	# of Targets	Type
FT	NEFT	23	46	ATRGen1													23	46				
FT	SFT	7	7	HFIRGen2																		
A	A1	1	2	ATRGen1	1	2	ATRGen1															
A	A2	1	2	ATRGen1	1	2	ATRGen1															
A	A3																					
A	A4	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1			ATRGen1			ATRGen1			ATRGen1
A	A5	1	2	ATRGen1	1	2	ATRGen1															
A	A6	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
A	A7	1	2	ATRGen1	1	2	ATRGen1															
A	A8	1	2	ATRGen1	1	2	ATRGen1															
A	A9																					
A	A10																					
A	A11																					
A	A12																					
A	A13	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1			ATRGen1	1	2	ATRGen1
A	A14	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
A	A15													1	2		1	2		1	2	
A	A16	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H1	1	2	ATRGen1	1	2	ATRGen1															
H	H2	1	2	ATRGen1	1	2	ATRGen1															
H	H3	1	2	ATRGen1	1	2	ATRGen1															
H	H4	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H5	1	2	ATRGen1	1	2	ATRGen1															
H	H6	1	2	ATRGen1	1	2	ATRGen1															
H	H7	1	2	ATRGen1	1	2	ATRGen1															
H	H8	1	2	ATRGen1	1	2	ATRGen1													1	2	
H	H9	1	2	ATRGen1	1	2	ATRGen1										1	2		1	2	
H	H10	1	2	ATRGen1	1	2	ATRGen1													1	2	
H	H12	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H13	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H14	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H15	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
H	H16	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1	1	2	ATRGen1
I(L)	I1																					
I(M)	I2																			7	14	ATRGen1
I(M)	I3																					
I(M)	I4																					
	Total # of Targets		103			50			22			22			22			68			28	
A			20	ATRGen1		20	ATRGen1		10	ATRGen1		10	ATRGen1		10		ATRGen1	8		ATRGen1	10	
H			30	ATRGen1		30	ATRGen1		12	ATRGen1		12	ATRGen1		12		ATRGen1	14		ATRGen1	18	
NEFT			46	ATRGen1		0	ATRGen1		0	ATRGen1		0	ATRGen1		0		ATRGen1	46		ATRGen1	0	
EFT				ATRGen1			ATRGen1			ATRGen1			ATRGen1				ATRGen1			ATRGen1		
SFT			7	HFIRGen2		0	ATRGen1		0	ATRGen1		0	ATRGen1		0		ATRGen1	0		ATRGen1	0	
I(M)			0			0			0			0			0			0			20	

Example Production Results

- Notional information was used to provide a proof of principle of the tool
- Calculated production data from other analysis will be incorporated when complete

Cycle	Start Date	Target Type	# Targets	Pellets	Initial Np	Final Np [g]	Initial Pu-238 [g]	Final Pu-238 [g]	Final Pu-238 Oxide [g]	Assay [%]	HS Material [g]
171A	5/1/2021	A	20	1040	1000	934.1	0	61	69.2	0.925	74.8
		H	30	1560	1500	1399.8	0	90.6	102.8	0.904	113.7
		NEFT	46	2392	2300	2143.2	0	138	156.6	0.88	177.9
		EFT	0	0	0	0.0	0	0	0.0	0.9	0.0
		SFT	7	364	350	326.1	0	21	23.8	0.88	27.1
		I(M)	0	#N/A	#N/A						
		I(L)	0	#N/A	#N/A						
		Total	103	5356	5150	4803.2	0	310.6	352.4		393.5

Conclusions

- A tool to calculate the number of irradiation targets and estimate production was created
- Can be used to calculate production activities across DOE labs
  - Amount of Pu-238 oxide produced
  - Movement of feedstock through the DOE complex
  - Determining future target production rates

References

1. High Flux Isotope Reactor (HFIR) User's Guide, Revision 2.0. November 2015.
2. J.L. Campbell. "ADVANCED TEST REACTOR User Guide." INL/EXT-21-64328-Rev000. September 30, 2021.
3. Advanced test reactor. INL. (n.d.). Retrieved March 23, 2022, from https://inl.gov/atr/
4. 7 fast facts about the high flux isotope reactor at Oak Ridge National Laboratory. Energy.gov. (n.d.). Retrieved March 23, 2022, from https://www.energy.gov/ne/articles/7-fast-facts-about-high-flux-isotope-reactor-oak-ridge-national-laboratory
5. R. WHAM, L. FELKER, E. COLLINS, D. BENKER, R. OWENS, R. HOBBS, D. CHANDLER and R. J. VEDDER, "Reestablishing the Supply of Plutonium238," in American Institute of Aeronautics and Astronautics Propulsion Energy Conference, Orlando, FL, 2015.
6. Talbert, T. (2020, September 25). Dragonfly launch moved to 2027. NASA. Retrieved April 7, 2022, from https://www.nasa.gov/feature/dragonfly-launch-moved-to-2027