The High Flux Isotope Reactor: Historical Context and Current Landscape

Presented to the
Basic Energy Sciences
Advisory Committee

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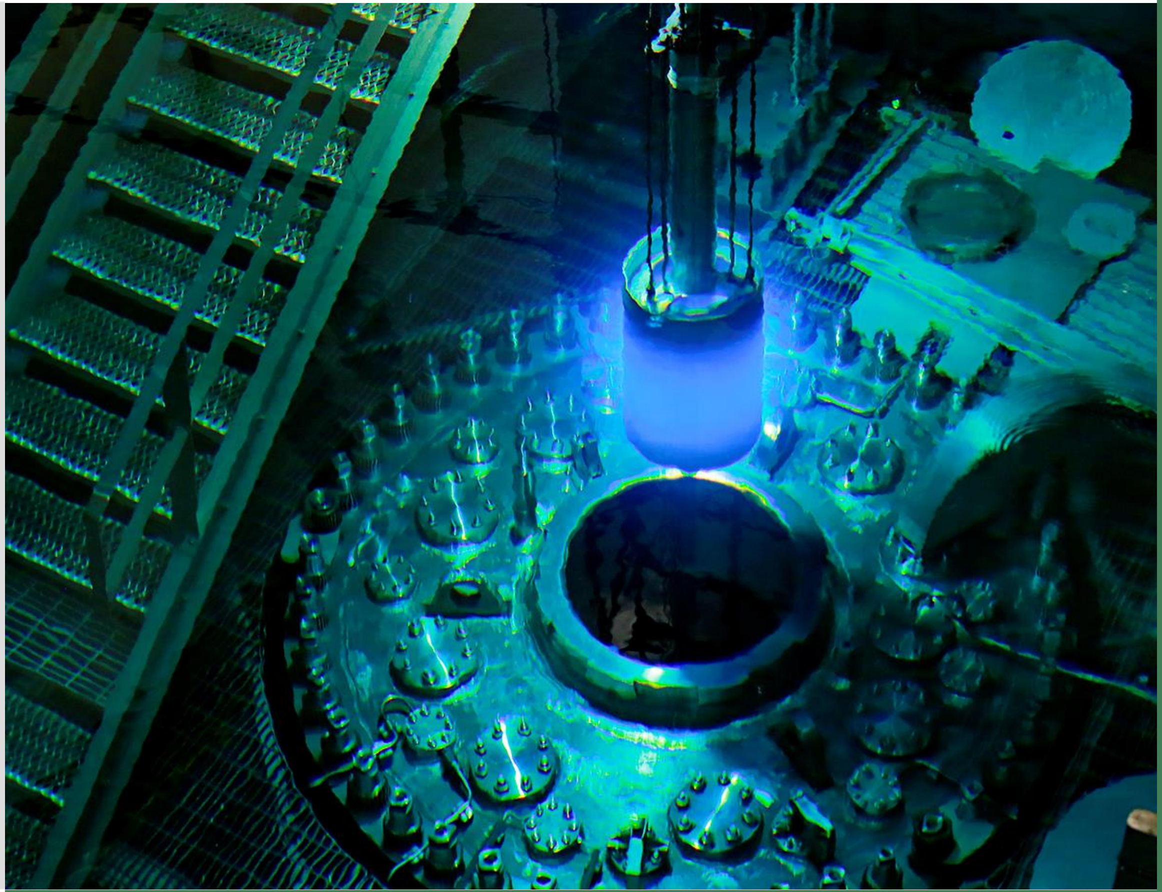
The High Flux Isotope Reactor (HFIR)

- Historical context
- The Advanced Neutron Source
- Current landscape
- HFIR going forward



Historical context

1960s

New reactor facilities: US leads in neutron scattering

- High Flux Beam Reactor (HFBR) at Brookhaven
- High Flux Isotope Reactor (HFIR) at ORNL

1972

Europeans complete ILL

- High-flux reactor optimized for neutron scattering with a large cold source and neutron guides

1976

NAS panel recommends more instruments at HFBR and HFIR

1980

DOE Brinkman panel reiterates NAS panel findings

1984

NAS Seitz-Eastman panel priorities:

1. 6-GeV synchrotron (later APS)
2. Advanced steady-state neutron facility (ANS)
3. 1–2 GeV synchrotron (ALS)
4. High-intensity pulsed neutron source (later SNS)

1985

NIST reactor upgraded (only US guide hall until HFIR in 2007)

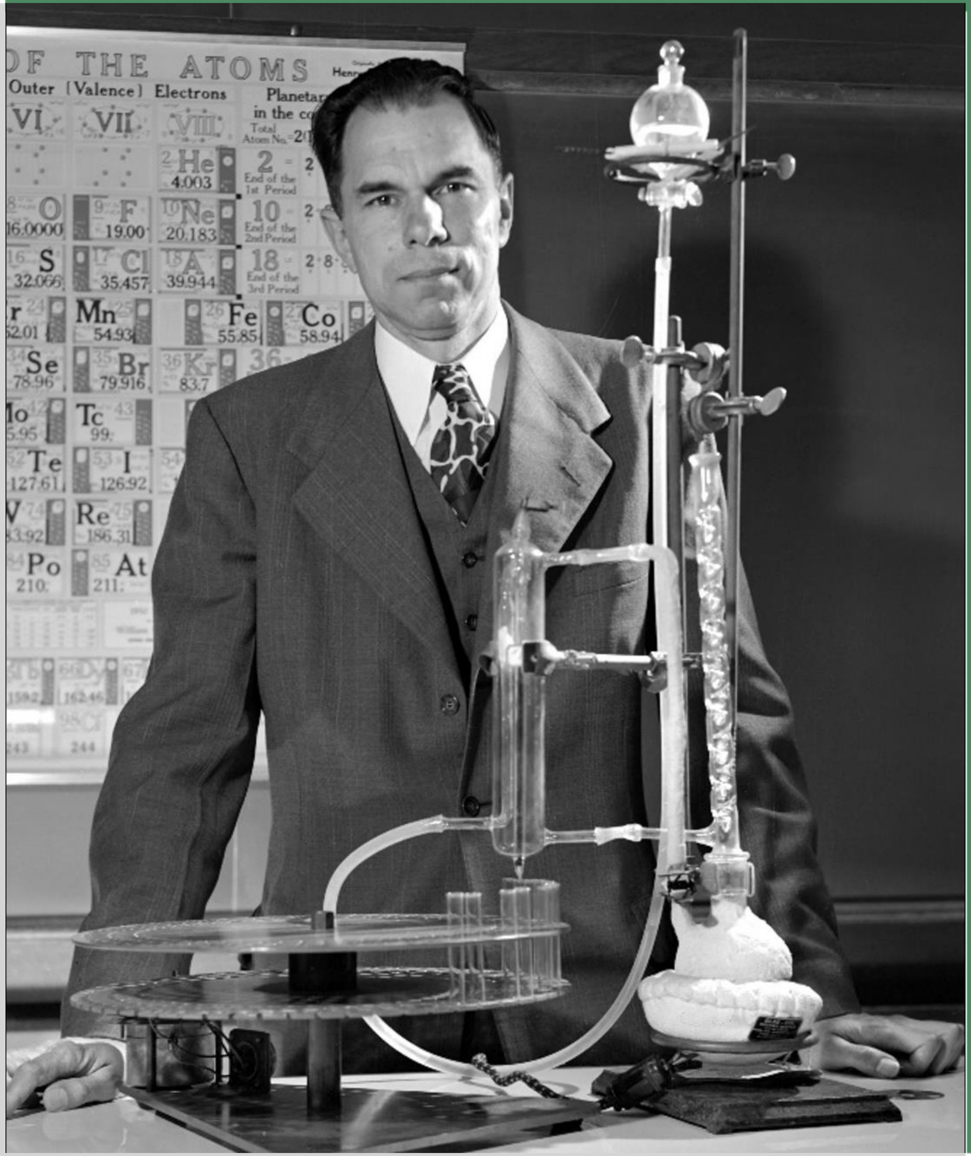
1995

ILL reactor vessel replacement

Seaborg's vision:
A "very high flux reactor" for heavy element production

Letter to AEC Chairman Lewis Strauss,
October 24, 1957

- Future progress in "the field of new transuranium elements" requires production of "substantial weighable quantities (say milligrams) of berkelium, californium, and einsteinium"
- With support from Seaborg, HFIR became this **"very high flux reactor,"** and more



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HFIR

Designed for isotope production, equipped for neutron scattering

- Completed in 1965 to meet national need for production of transuranic isotopes
  - Peak thermal flux: ~3×10^{15} neutrons/cm^2/s (n/cm^2/s), highest in the western world
  - 4 horizontal beam tubes added at insistence of ORNL director, Alvin Weinberg
- Primary missions today
  - Thermal and cold neutron scattering (12 instruments in user program serving >400 unique users)
  - Isotopes: Heavy actinides (80% of world's Cf-252), Pu-238 for NASA deep space missions, medical isotopes (Ac-227, Sr-89, W-188)
  - Materials: Exceptional resource for irradiation and neutron activation analysis

1980s: ORNL proposes the Advanced Neutron Source (ANS) based on Seitz-Eastman recommendations

User requirements

- Useful neutron flux at experiment locations at least 5 times ILL (minimum thermal neutron flux: 5×10^{15} n/cm^2/s)
- Isotope production and materials irradiation capabilities equal to or greater than HFIR

Facility characteristics

- 330 MW heavy-water cooled and moderated reactor with containment dome
- Fuel plate design comparable to HFIR and ILL using highly enriched fuel
- 14 cold and 7 thermal beam lines, 37 scattering instruments
- Materials irradiation, isotope production, and nuclear science capabilities

Major Facilities for Materials Research and Related Disciplines

Major Materials Facilities Committee
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, DC 1984

Seitz-Eastman report, 1984

Evolution of the ANS project

Mid-1980s
Planning for ANS begins at ORNL, consistent with Seitz-Eastman major facility recommendations

1989
National Steering Committee (Rush Committee) for ANS established, provides community input

Early 1990s
ANS cost estimate continues to rise, driven by scientific scope and cost of reactor containment

1993
CDR completed, DOE Kohn panel confirms top priority for ANS (also calls for upgrades at HFBR and HFIR)

1993
(SSC cancelled)

1995
ANS cost projection approaches $3B, OMB and SC remove funding from budget request, project cancelled

1996
Birgeneau Committee (BESAC Panel on Research Reactor Upgrades) calls for upgrades to HFBR and HFIR

1997
ORNL's bid for SNS accepted

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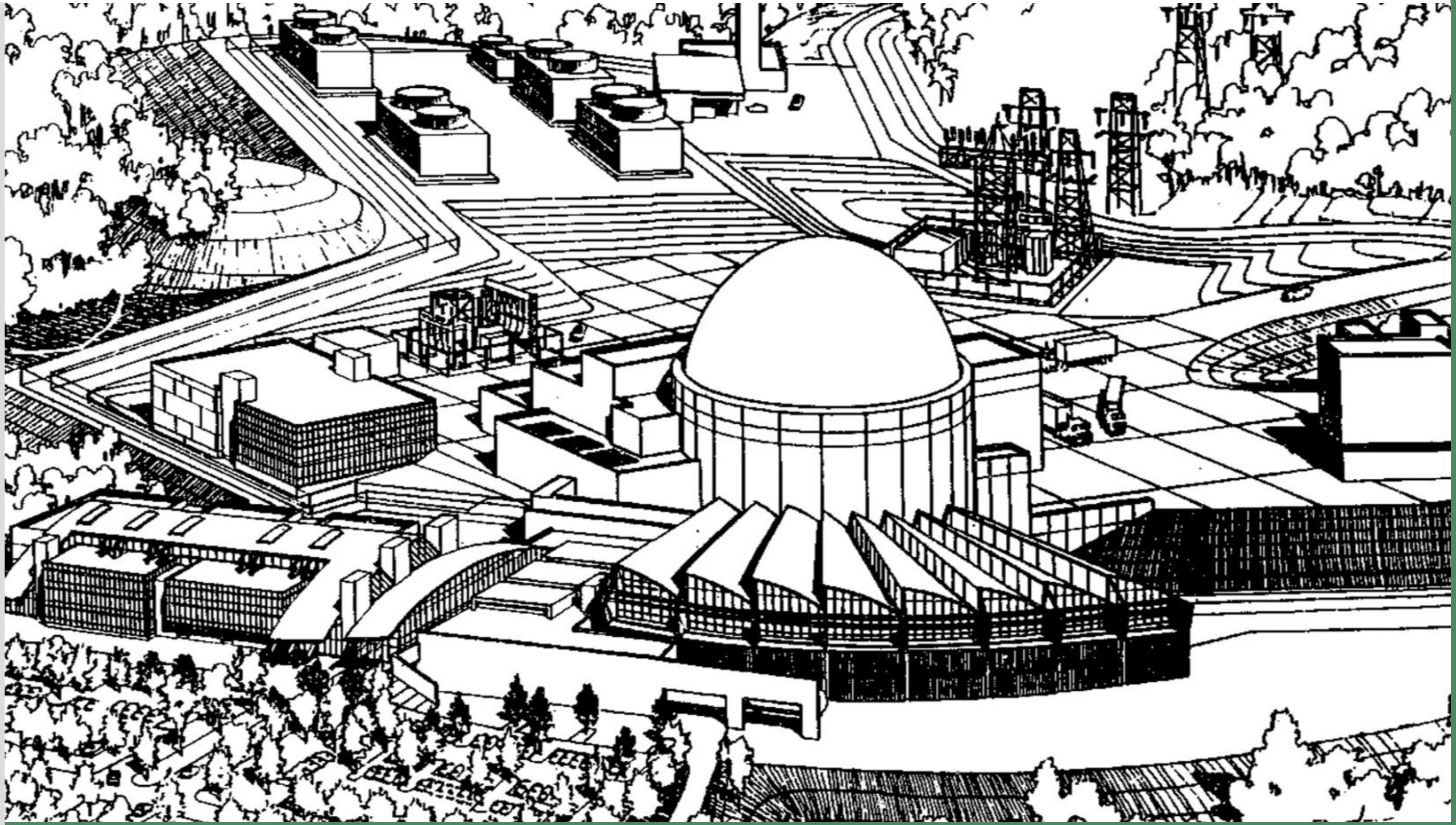
What went wrong

- Costs grew to unsupportable levels
- Unresolved HEU/LEU debate
- Neutron community alignment (some preferred that the spallation option be constructed first)



ORNL depiction of the Advanced Neutron Source (1993)

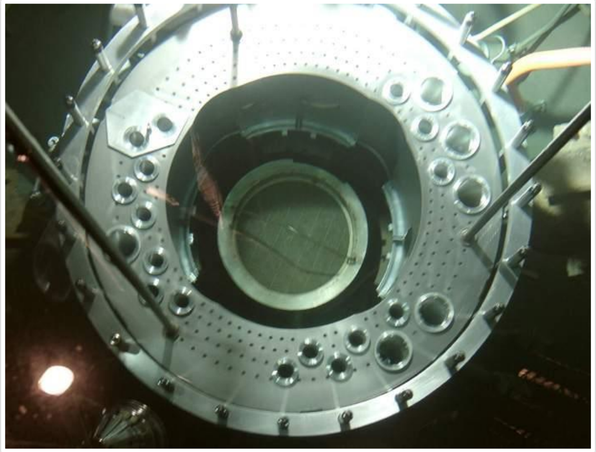
2007: Major HFIR refurbishment completed

Neutron scattering upgrades

- New guide hall
- New and upgraded instruments
- New cold neutron source with brightness comparable to the world's best
- Thermal neutron fluxes comparable to world's best

New infrastructure

- Beryllium reflector
- Cooling tower, etc.



Today, HFIR's world-class capabilities serve a variety of national missions

Neutron scattering

- Cold source
  - Small-angle neutron scattering (SANS)
  - Cold triple-axis spectroscopy
  - Neutron imaging
  - Quasi-Laue diffractometer
- Thermal beams
  - Triple-axis spectroscopy
  - Powder diffraction
  - Single-crystal diffraction
  - Residual stress diffraction

Isotope production

- Californium-252 for industrial, defense, medical, and research uses (80% of world demand)
- Unique source of heavy actinides for research, including discovery of element 117 (tennessine)
- Plutonium-238 for powering satellites and deep space exploration
- Ac-227, Sr-89, W-188 for cancer treatment, Se-75 for NDT on infrastructure

Materials irradiation

- Materials under extreme conditions
- Fusion energy: Radiation damage testing (30-year collaboration with Japan)
- Fission energy: Support for next-generation power reactors, including accident-tolerant fuel and reactor materials
- National security: Neutron activation analysis for nonproliferation

High-flux research reactors today

Reactor	Location	Initial operation	Power (MW)	Fuel	Reflector	Peak thermal flux (10^{15} n/cm^2/s)	Mission and capabilities
SM-3	Russia	1961	100	HEU	Be	2.5 (1.0 fast)	• Materials testing • Isotopes (heavy actinides)
HFIR	US (ORNL)	1965	85	HEU	Be	2.5 (1.0 fast)	• Neutron scattering (12 instruments) • Isotopes (heavy actinides) • Materials testing
ILL	France	1972	58	HEU	D_2O	1.5	• Neutron scattering (33 instruments)
BR-2	Belgium	1962	100	HEU	Be	1.0 (0.7 fast)	• Materials testing • Isotopes
ATR	Idaho	1967	250	HEU	Be	1.0	• Materials testing • Isotopes
FRM-2	Germany	2005	20	HEU	D_2O	0.8 (0.5 fast)	• Neutron scattering (23 instruments) • Isotopes
CARR	China	2010	60	LEU	D_2O	0.8 (0.6 fast)	• Neutron scattering (6 instruments) • Isotopes • Materials testing
NBSR	US (NIST)	1967	20	HEU	D_2O	0.4	• Neutron scattering (17 instruments)
OPAL	Australia	2007	20	LEU	D_2O	0.4	• Neutron scattering (13 instruments) • Isotopes

HFIR provides unique resources for DOE and the Nation

- Highest steady-state thermal neutron flux
- High-end aspects of isotope production (heavy actinides, specialty medical isotopes), neutron scattering, and materials irradiation
- Adjacent Radiochemical Engineering Development Center (REDC) provides unique capabilities for radioisotope separations (>400 isotope shipments annually to universities, hospitals, industry, and other research institutions)
- The HFIR/REDC complex is essential to DOE missions and unique in the world

Research reactors under construction

Reactor	Location	Status	Power (MW)	Fuel	Reflector	Peak thermal flux (10^{15} n/cm^2/s)	Mission and main capabilities
PIK	Russia	Completed in 2011, full power in 2019?	100	HEU	Be	4.5	• Neutron scattering • Isotopes (transuranics) • Materials testing
JHR	France	Under construction, operation in 2021	100	HEU (LEU)	Be	0.6 (1.0 fast)	• Reactor technology • Materials testing • Commercial isotopes
MBIR	Russia	Under construction, operation in 2020?	150	MOX	Sodium cooled	NA 5.5 (fast)	• Fast reactor testing

PIK reactor near St. Petersburg, Russia, is (if successful) the only emerging competition in HFIR's mission space

Accelerator and reactor-based neutron sources are complementary

Pulsed accelerator sources	Steady-state reactors
Highest peak neutron intensities	Highest steady-state neutron fluxes (more neutrons)
Superior for many aspects of neutron scattering	Superior for isotope production and materials irradiation as well as selected aspects of neutron scattering
Superior for studying phenomena across broad spatial and temporal regions	Superior at focusing on phenomena at specific length and time scales
SNS is the world's most powerful spallation source; the Second Target Station will significantly advance SNS science capability	HFIR is a world-leading steady-state neutron source; pressure vessel and reflector upgrades will extend and expand HFIR's distinctive science capabilities well into the future

HFIR going forward

Continued leadership

- High-flux applications of steady-state neutron scattering
- Isotope production
- Materials irradiation

Growing importance of isotopes

- HFIR/REDC (>400 shipments annually to research institutions, hospitals, and industry

Considerations for the future

- HFIR life extension to ensure continued US science capability at the highest neutron fluxes
- A D_2O reflector to further increase neutron scattering performance
- A second guide hall to expand the number of world-class scattering instruments

Discussion