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

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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| 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
HFIR
Designed for isotope production, equipped for neutron scattering

- Completed in 1965 to meet national need for production of transuranic isotopes
  - Peak thermal flux: \( \sim 3 \times 10^{15} \text{ neutrons/cm}^2/\text{s} (\text{n/cm}^2/\text{s}) \), 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: $5 \times 10^{15} \text{n/cm}^2/\text{s}$)
- 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

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**Major Facilities for Materials Research and Related Disciplines**

Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, DC, 1983

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 Ugradps) calls for upgrades to HFBR and HFIR

1997
ORNL’s bid for SNS accepted
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

<table>
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<tr>
<th>Neutron scattering</th>
<th>Isotope production</th>
<th>Materials irradiation</th>
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</thead>
<tbody>
<tr>
<td>• Cold source</td>
<td>• Californium-252 for industrial, defense, medical, and research uses (80% of world demand)</td>
<td>• Materials under extreme conditions</td>
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<tr>
<td>– Small-angle neutron scattering (SANS)</td>
<td>• Unique source of heavy actinides for research, including discovery of element 117 (tennessine)</td>
<td>• Fusion energy: Radiation damage testing (30-year collaboration with Japan)</td>
</tr>
<tr>
<td>– Cold triple-axis spectroscopy</td>
<td>• Plutonium-238 for powering satellites and deep space exploration</td>
<td>• Fission energy: Support for next-generation power reactors, including accident-tolerant fuel and reactor materials</td>
</tr>
<tr>
<td>– Neutron imaging</td>
<td>• Ac-227, Sr-89, W-188 for cancer treatment, Se-75 for NDT on infrastructure</td>
<td>• National security: Neutron activation analysis for nonproliferation</td>
</tr>
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<td>– Quasi-Laue diffractometer</td>
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High-flux research reactors today

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<tr>
<th>Reactor</th>
<th>Location</th>
<th>Initial operation</th>
<th>Power (MW)</th>
<th>Fuel</th>
<th>Reflector</th>
<th>Peak thermal flux (10^{15} \text{n/cm}^2\text{s})</th>
<th>Mission and capabilities</th>
</tr>
</thead>
</table>
| 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\(_2\)O | 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\(_2\)O | 0.8 (0.5 fast)                  | • Neutron scattering (23 instruments)  
|         |          |                   |            |      |           |                                 | • Isotopes |
| CARR    | China    | 2010              | 60         | LEU  | D\(_2\)O | 0.8 (0.6 fast)                  | • Neutron scattering (6 instruments)  
|         |          |                   |            |      |           |                                 | • Isotopes  
|         |          |                   |            |      |           |                                 | • Materials testing |
| NBSR    | US (NIST)| 1967              | 20         | HEU  | D\(_2\)O | 0.4                            | • Neutron scattering (17 instruments) |
| OPAL    | Australia| 2007              | 20         | LEU  | D\(_2\)O | 0.4                            | • Neutron scattering (13 instruments)  
|         |          |                   |            |      |           |                                 | • Isotopes |
• 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

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Location</th>
<th>Status</th>
<th>Power (MW)</th>
<th>Fuel</th>
<th>Reflector</th>
<th>Peak thermal flux ($10^{15}$ n/cm$^2$/s)</th>
<th>Mission and main capabilities</th>
</tr>
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</table>
| 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

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<th>Pulsed accelerator sources</th>
<th>Steady-state reactors</th>
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<tr>
<td>Highest peak neutron intensities</td>
<td>Highest steady-state neutron fluxes (more neutrons)</td>
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<tr>
<td>Superior for many aspects of neutron scattering</td>
<td>Superior for isotope production and materials irradiation as well as selected aspects of neutron scattering</td>
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<tr>
<td>Superior for studying phenomena across broad spatial and temporal regions</td>
<td>Superior at focusing on phenomena at specific length and time scales</td>
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<td>SNS is the world’s most powerful spallation source; the Second Target Station will significantly advance SNS science capability</td>
<td>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</td>
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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$_2$O reflector to further increase neutron scattering performance
- A second guide hall to expand the number of world-class scattering instruments
Discussion