Role of radioactive beams in stockpile stewardship science

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Nuclear science contributions to national security

- *Radiochemistry* – nuclear forensics, stockpile stewardship, NIF nuclear diagnostics

- *Nuclear Theory* – fission, fusion, nuclear reactions

- *Nuclear Experiment* – cross sections, diagnostics, detectors

- *Nuclear Data* – cross section evaluations, computational models

And *the scientists* who willing and able to take on the challenges presented by a changing world
RIA and Stockpile Stewardship – August 26th, 2003

Scientific Challenge: Determine the neutron flux in regions of enormous instantaneous neutron intensities (interior of stars, nuclear weapon tests, and NIF experiments) from remnant long lived nuclei.

• Accurate neutron cross sections on short lived isotopes essential for accurate flux determination

• Most of the neutron cross sections on the relevant short-lived states have never been measured due to production limitations. RIA changes all that.

• Improved physical understanding of unstable nuclei allows more accurate calculations of cross sections where measurements are not possible.
What has changed?

The challenge of measuring reactions on short lived nuclear states remains an important goal.

RIA became FRIB and has been approved by DOE.

A tremendous effort has gone into exploiting “indirect” methods for measuring neutron reactions on relevant states.

Theory is starting to become an important contributor to providing information on reactions.

Nuclear Forensics has become an important notion in nuclear security.
An example of stock pile radiochemistry

Count $^{95}$Zr activity: infer ~ $N$ atoms
- Expected Fraction ~ $f$
- Total # of $^{95}$Zr atoms produced = $N/f = N_{\text{tot}}$
- Total # of fissions $F = N_{\text{tot}}/0.06 \sim M$ fissions
- NOTE: 0.06 is the percentage of the total fragment distribution that is assumed to decay along the $A=95$ mass chain into $^{95}$Zr. IT ASSUMES NO BURN IN OR OUT OF THE CHAIN.
- Energy release from fission ~ $FY \times 10^{23}$ fissions/kt

TOTAL FISSION YIELD = $F / A \times 10^{23}$ kt

235,238U, 239Pu

IY(fs) > 0.5%
Our knowledge of the reaction networks is incomplete

Measure the ratio $^{88}\text{Y}/^{89}\text{Y}$ compare to expectation
## Unstable nuclei of interest to stockpile stewardship

<table>
<thead>
<tr>
<th>Loaded Element</th>
<th># of isotopes and isomers</th>
<th># with half-life &gt; 10y</th>
<th># with half-life &lt; 1d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti</td>
<td>14</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Cr</td>
<td>11</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fe</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>11</td>
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</tr>
<tr>
<td>Zr</td>
<td>10</td>
<td>3</td>
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</tr>
<tr>
<td>Nb</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Eu</td>
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<td>7</td>
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<td>2</td>
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<td>14</td>
</tr>
<tr>
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<td>2</td>
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</tr>
<tr>
<td>Ir</td>
<td>21</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Au</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bi</td>
<td>7</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

**After fragment separator**

- Proton dripline
- Neutron dripline

**Stockpile relevant isotopes**

- $^{108}_{51}$Fm
- $^{116}_{51}$Fm
- $^{126}_{51}$Fm
- $^{130}_{51}$Fm
Isotope harvesting

Estimated target mass as a function of isotope half-life and isotope production rates. The solid lines are calculated for an A=150 nucleus for 4 different target masses, as indicated. A further assumption limits the isotope collection time to the shorter of 10 days or 3 half-lives.
Additional interest in fission

$^{239}\text{Pu}(n,\text{Fission})$

![Graph showing data for $^{239}\text{Pu}(n,\text{Fission})$]
Proposed to develop new detector – “Fission TPC” to push to new precision and accuracy
Additional information from the TPC will expand fission measurements, e.g. fragment distribution.
The NIF – National Ignition Facility

Hot/Dense

\[ k_p T = 1\text{-}20 \text{ keV} \]

\[ 10^{35} \text{ cm}^{-2}\text{s}^{-1} \]

\[ \rho \approx 10\text{-}1000 \text{ g/cm}^3 \]

\[ 10^{36} \text{ e/cm}^2\text{s} \]

High Neutron Flux

\[ \approx 10^{30\text{-}35} \text{ cm}^{-2} \text{s}^{-1} \]

(fluence=\(10^{21\text{-}24} \text{ cm}^{-2}\))

Radiochemical activations are used on NIF to measure yield, and there are proposals for an expanded diagnostics program.

Proposed radiochemistry diagnostics of ICF capsule mix

\[ ^{127}{\text{I}}(d,2n)^{127}{\text{Xe}} \text{ production} \]
Theory may be the only way of providing “precision” cross section information of interest to NIF

\[ n + ^3H \]

\[ E_n = 14 \text{ MeV} \]
The nuclear science workforce continues to be an issue… but data does not exist to track trends

Ph.D Production

Nuclear Physics

average = 84/yr

51/yr in 2010

Nuclear- and Radio-chemistry

average = 11/yr

5/yr in 2010
Additional concerns regarding the fate of small facilities which produce the majority of PhDs

Experimental Nuclear Physics Ph.D. production from Facilities

- DOE report
- total facility
- RHIC
- Jlab
- ANL/Atlas
- NSCL
- BATES
- HRIBF
- ORELA
- 88"
- BEVALAC
- Low Energy
- Notre Dame
- TAMU
- total experimental
- CENPA
- TUNL
- WNSL-Yale
Conclusions half-way to FRIB…

- The need for nuclear data and a skilled nuclear science workforce are increasingly important to nuclear security.
- The development of technique, detectors, simulation and theory are necessary in preparation for FRIB experiments.
- The nuclear science workforce pipeline continues to be a concern.
- “Small” nuclear science facilities will play an essential role in all these areas before and after FRIB first beam.