Full-Stack Nuclear
Nuclear hardware and services to provide reliable energy anywhere

- Seattle, Washington
  Global Head Office
- Ottawa, Canada
  Canada Licensing
  Market Development
- Chalk River, Canada
  Commercial Demonstration Project
- U. Illinois Urbana-Champaign, IL
  Test Research Reactor Project
- Washington, DC
  US Licensing, Legal Office
  Government Affairs
- Oak Ridge, Tennessee
  Pilot Fuel Manufacturing Facility
- Salt Lake City, UT
  Advanced Ceramics
  Manufacturing Facility
- Seattle, WA
  USNC-Tech,
  R&D Power System Prototyping Facilities
- Idaho Falls, ID
  Multi-unit Integrated Energy System
  Fuel Qualification (US Campaign)
- Copper Valley Feas. Study
- Manchester, UK
  UK Market Development
  Fuel Qualification (EU campaign)
- Poland
  East Europe Market Development
- France
  West Europe Market Development
- Daejeon, South Korea
  Power Plant Design
- Pretoria, South Africa
  Power Plant Engineering
- Sydney, Australia
  Market Development

- 2011
  Founded
- $140M+
  Private Funding
- 280+
  Employees
Reliable Energy Anywhere – Earth to Space and Beyond

- Family of nuclear energy products and services
- Zero-carbon power with minimal infrastructure required
- From Watts to Megawatts
- All based on Ultra Safe principles & technologies
- Shared design and fabrication resources
The Fuel
TRISO Coated Fuel Particles Embedded inside Silicon Carbide

**Fully Ceramic Microencapsulated (FCM®) Fuel**

- Tristructural isotropic (TRISO) fuel particles embedded inside an impermeable SiC matrix
- Very high fuel loading fraction owing to the unique manufacturing methodology leveraging additive techniques

TRISO and FCM® Manufacturing Process at Ultra Safe Nuclear

1. **Sol-Gel Module**
   - Broth Mixture
   - Droplet Formation
   - Internal Gelation
   - Aging
   - Drying

2. **Conversion Module**
   - Carbothermic Reduction
   - \( \text{UO}_3 + \text{C} \rightarrow \text{UCO} \)

3. **Particle Coating Module**
   - TRISO Loading

4. **Shell Forming Module**
   - SIC Binderjet Printing
   - CAD

5. **Fuel Loading Module**
   - Non-destructive Analysis

6. **Final Densification**
   - (SIC CVI)

**Patent**: U.S. 9,299,464 B2
**Patent application**: U.S. 2020/0156282 A1
3D Printing - BinderJet Additive Manufacturing for SiC

- **BinderJet Process**
  1. Thin layer of powder is laid on top of bed
  2. Specialized inkjet style head applies droplets of binder (glue) in locations of the part being printed
  3. Heat lamp dries layer of binder
  4. Repeats steps until the part bed is completed
  5. Removed printed parts from the bed of loose powder

- Agnostic to the material chemistry – applicable for multiple ceramics including SiC and ZrC
- Ideal with coarse powder that is safe and cost effective
- Allows for ample complexity in the part

[3Dcarbide™](https://www.3dcarbide.com/)

One Stop Shop for Additive & Advanced Ceramics

We offer additive and advanced manufactured components for specialized applications on demand. Choose from 6 different ceramics.

SiC • ZrC • ZrO2 • B4C-SiC • ZrH4 • YH4

Submit Your Part [https://www.3dcarbide.com/](https://www.3dcarbide.com/)
Production Scale TRISO and FCM Manufacturing at USNC PFM

- uranium gelation
- fuel kernel conversion
- TRISO coating
- Final pellet densification
Nuclear Thermal Propulsion (NTP)

Lightweight
NTP engines will use a remarkably low quantity of uranium fuel in roughly 3-ton or smaller engines. The ZrC cerce-fueled, beryllium-moderated reactor core achieves all DOE and NASA goals with sufficient flexibility for commercial variants.
Pylon - Scalable Power for the Emerging Space Economy
Pylon - Small, Transportable Reactor
EmberCore™: Versatile and Affordable Radioisotope Power

The EmberCore technology is a suite of radioisotope solutions, allowing the use of the right isotope for the right mission.

- Unique capabilities in producing radioisotope targets, modeling, and navigating the regulatory farmwork.

Private and government interest for a wide range of applications of EmberCore technology.

- NASA NIAC, Phase 1 Lunar Flashlight
- NASA NIAC, Phase 2 NYX mission
- DIU NAPP, Shadow Runner
- NASA SBIR “Affordable In-Space Demonstration of Dynamic Radioisotope Power Conversion”

X-ray Flashlight
Find Resources on the Moon

Shadow Runner
High Delta-V Propulsion and Power

Nyx
Observe the Universe From Deep Space
<table>
<thead>
<tr>
<th>General Info</th>
<th>Decay Scheme &amp; Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Half-Life</strong></td>
<td><strong>Tm-170</strong></td>
</tr>
<tr>
<td>Half-Life</td>
<td>129 days</td>
</tr>
<tr>
<td>10 Half-Life Decay</td>
<td>3.5 years</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td><strong>69 Tm 170</strong> (127.8 d)</td>
</tr>
<tr>
<td>99.87% $\beta^-$ decays to Yb-170</td>
<td>$\epsilon$ 0.236 MeV, 0.035%</td>
</tr>
<tr>
<td>$\beta_1$ 81.9% 968.1 keV max (323 keV avg)</td>
<td>$\beta^-$ 0.968 MeV, 81.6%</td>
</tr>
<tr>
<td>$\beta_2$ 18.1% 883.8 keV max (290 keV avg)</td>
<td>$\gamma$ 84 keV, 2.48% $\alpha_f$ 6.37</td>
</tr>
<tr>
<td>$\gamma$ 3.25% 84.25 keV</td>
<td>$\gamma$ 78 keV, 0.0035% $\alpha_f$ 7.55</td>
</tr>
<tr>
<td>X-rays: 51, 52, 57, 59 keV</td>
<td>$\beta$ 0.884 MeV, 18.3%</td>
</tr>
<tr>
<td>0.13% $\alpha$ decays to Er-170</td>
<td></td>
</tr>
<tr>
<td><strong>Stable form</strong></td>
<td><strong>68 Er 170</strong> (stable)</td>
</tr>
<tr>
<td>Single oxidation state $\text{Tm}_2\text{O}_3$</td>
<td>$\beta^-$ 0.968 MeV</td>
</tr>
<tr>
<td>Melting point 2614 K</td>
<td>$\gamma$ 84 keV, 2.48% $\alpha_f$ 6.37</td>
</tr>
<tr>
<td><strong>Isotopes</strong></td>
<td><strong>70 Yb 170</strong> (stable)</td>
</tr>
<tr>
<td>100% natural abundance $\text{Tm}_{169}$</td>
<td>$\beta^-$ 0.968 MeV</td>
</tr>
<tr>
<td>$^{169}\text{Tm}(n,\gamma)^{170}\text{Tm}$ 80 barns</td>
<td>$\gamma$ 84 keV, 2.48% $\alpha_f$ 6.37</td>
</tr>
</tbody>
</table>

**Gamma Spectrum Tm-170**

**Bremsstrahlung Spectrum**
USNC’s Regulatory Approach to Sending Isotopes to Space

- The following slides are based on conversations with Tennessee, NRC, FAA, NASA, CCSFS
  - Agreement in concept as to the regulatory approach
- Certain details are still ambiguous
  - NSPM-20
    - FAA is still working on implementing guidance
    - NASA and Space Force both have sub-Tier-I reviews. NSPM-20 does not.
  - Multiple jurisdiction authority
    - Both KSC and CCSFS are considered as areas of exclusive federal jurisdiction
    - There may be overlapping regulatory authority
    - There will be a handoff in authority at some point from NRC to FAA
NSPM-20 - Presidential Memorandum on the Launch of Space Nuclear Systems

• Trump administration determined it was advantageous to launch radioactive material into space
• NSPM-20 was written to ensure that radioactive material can be launched into space safely
• NSPM-20 designated the FAA to be the agency to oversee commercial launches
• Main Take-aways:
  • Quantify of Material
    • Determines review level (Tier)
  • Doses and exceedance probabilities
    • Determines both acceptability and review level
• Lacking implementation instructions (FAA) for NSPM-20 and 14 CFR 450 for launch of radioactive material.
  • “Within 1 year of the date of this memorandum, the Secretary of Transportation shall issue public guidance for applicants seeking a license for a launch or reentry involving a space nuclear system. This guidance shall describe the process used to evaluate any such license application, including relevant safety standards, as appropriate and consistent with applicable law”
## NSPM-20 Safety Guidelines

<table>
<thead>
<tr>
<th>Total Effective Dose to Public</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 25 mrem - &lt; 5 rem</td>
<td>&lt; 1 in 100</td>
</tr>
<tr>
<td>5-25 rem</td>
<td>&lt; 1 in 10,000</td>
</tr>
<tr>
<td>&gt; 25 rem</td>
<td>&lt; 1 in 100,000</td>
</tr>
</tbody>
</table>

### Tier II and III probability thresholds

<table>
<thead>
<tr>
<th>Launch Tier</th>
<th>Total Effective Dose to Public</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier II</td>
<td>5-25 rem</td>
<td>&gt; 1 in a million</td>
</tr>
<tr>
<td>Tier III</td>
<td>&gt; 25 rem</td>
<td>&gt; 1 in a million</td>
</tr>
</tbody>
</table>

### Tier II and III activity thresholds

<table>
<thead>
<tr>
<th>Launch Tier</th>
<th>Activity</th>
<th>Reactor Fuel Enrichment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier II</td>
<td>&gt; 100,000 x A2</td>
<td>&lt; 20%</td>
</tr>
<tr>
<td>Tier III</td>
<td>any</td>
<td>&gt; 20%</td>
</tr>
</tbody>
</table>
## Exceedance Probability

### NSPM-20 Safety Guidelines

<table>
<thead>
<tr>
<th>Total Effective Dose to Public</th>
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### Tier II and III probability thresholds

<table>
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<tr>
<th>Launch Tier</th>
<th>Dose to Public</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier II</td>
<td>5-25 rem</td>
<td>&gt; 1 in 1E6</td>
</tr>
<tr>
<td>Tier III</td>
<td>&gt; 25 rem</td>
<td>&gt; 1 in 1E6</td>
</tr>
</tbody>
</table>

![NSPM-20 Safety Guideline /Tier Dose Limits](image-url)
Licensing Activities to Date

- USNC was granted a Radioactive Material (RAM) License for TRISO/FCM fuel manufacturing at the PFM Facility on April 22, 2022.
- USNC was granted a second RAM License for EmberCore activities on July 18, 2023.
From Tennessee RAM License to the Launch Site

• Material would be initially licensed in the jurisdiction of the home facility (Tennessee)
• Sealed source and device registered with home facility
• License reciprocity with NRC Region 1 for activities at KSC or CCSFS.
• Multiple sites of integration at KSC/CCSFS.
• If required, 10CFR37 security program is implemented at integration and launch site
NRC/FAA Regulatory Authority

- FAA jurisdiction begins when activities hazardous to the public begin at the launch site.
  - While “hazardous activities” is not defined and is decided by the FAA on a case-by-case basis, it generally means when the rocket is energized, pressurized, or fueled with the intention of going to space.
- An accident at this point could affect members of the public who are not located at the launch site.
- The launch vehicle provider is responsible for launch approval from the FAA per 14CFR450
- Payload operator can apply for Payload Review request per 14 CFR 450.43
- Additional requirements from NASA/KSC and Space Force/CCSFS
  - NASA NPR 8715.26
  - DoD DAFMAN 91-110
USNC’s Approach

- RAM License from Tennessee
- Register sealed source/device with Tennessee
- Reciprocity from Region 1 NRC for use at KSC/CCSFS
- Payload Review with FAA
- FAA consults with NRC HQ, NASA, CCSFS
- Material shipped to integration site, in accordance with DOT regulations
- Material received under reciprocal RAM license
- Jurisdiction change from NRC to FAA when rocket begins fueling
- FAA/NSPM-20 operates under a stochastic risk model
Discussion

• Does this strategy make sense, as explained?
• What are the potential pitfalls?
• What other aspects should be considered?
• Any other questions about EmberCore or Ultra Safe Nuclear?
  • Interest in hearing more about Tm-170?
Questions?
Let’s talk more about Thulium-170!
Key Technology - EmberCore – **AA Battery of the Future**

| Performance          | • 1 million x the energy density of Li-ion  
|                      | • Compact volume/surface area              |
| Safety               | • Multiple encapsulation                   
|                      | • Regulatory/launch approval focused       |
| Cost Effective       | • Charge and go (no radiochemistry)        
|                      | • Affordable raw materials, commercial radioisotopes |
| Modular              | • Compatible with different radioisotopes and power needs  
|                      | • Pack Designs for heat, electricity, or x-rays |

**Radioisotope Heater Unit (RHU)**

- Precursor
- Wall Encapsulation

**Ember Manufacturing Process**

- Manufacture (Non-Radioactive)
- Charging (Single Irradiation)
- Packaging (Hot Cell)

**Analogy**

- Battery with heated wall
- Battery with radioisotope heater
Tm-170 Simulated Beta Spectrum

![Graph showing energy spectra of 884 keV and 968 keV emissions along with the total spectrum.](image-url)
Tm-170 simulated Bremsstrahlung Spectrum
Tm-170 HPGe Spectrum 0 – 1 MeV
Tm-170 HPGe Spectrum 0 – 200 keV

- Foreground (113609464 counts)
  - Live Time: 3600 s
  - Real Time: 4823 s

- Yb-170
  - $E_{\text{X-ray}} = 52.39$ keV

- Yb-170
  - $E_{\text{X-ray}} = 51.35$ keV

- Tm
  - $E_{\text{X-ray}} = 57.52$ keV

- Tm
  - $E_{\gamma} = 78.7$ keV (not detected)

- Tm-170
  - $E_{\gamma} = 84.25$ keV
Shielding Thulium-170

- Generates its own Bremsstrahlung (Z=69)
- High energy Bremsstrahlung (up to 1 MeV), especially at high activities
- Significant spectrum hardening when shielded
- Must determine Bremsstrahlung spectrum before using Microshield

Microshield Library

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Activity (Curies)</th>
<th>Activity (Becquerels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tm-170</td>
<td>2.7027e-011</td>
<td>1.00000e+000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Energy (MeV)</th>
<th>Activity Photons/sec</th>
<th>%Energy Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0514</td>
<td>1.274e-002</td>
<td>12.767</td>
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<tr>
<td>3</td>
<td>0.0554</td>
<td>9.309e-003</td>
<td>10.775</td>
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<tr>
<td>4</td>
<td>0.0843</td>
<td>3.235e-002</td>
<td>53.487</td>
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</table>

20-Bin Bremsstrahlung Spectrum

<table>
<thead>
<tr>
<th>#</th>
<th>Energy (MeV)</th>
<th>Activity Photons/sec</th>
<th>Point Source Photons/sec</th>
<th>%Energy Activity</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>2.7900e-003</td>
<td>2.7900e-003</td>
<td>1.851</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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<td>4.7900e-003</td>
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<tr>
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<tr>
<td>5</td>
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<td>14.690</td>
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<tr>
<td>6</td>
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<td>1.5100e-003</td>
<td>11.021</td>
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<tr>
<td>20</td>
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<td>1.7000e-011</td>
<td>0.000</td>
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</table>