Metallic Fuels for Actinide Transmutation

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Actinide and Fission Product Partitioning and Transmutation
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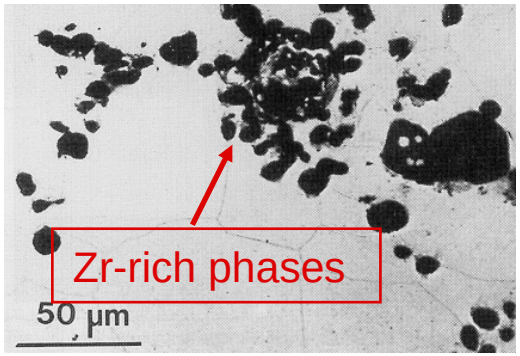
INL

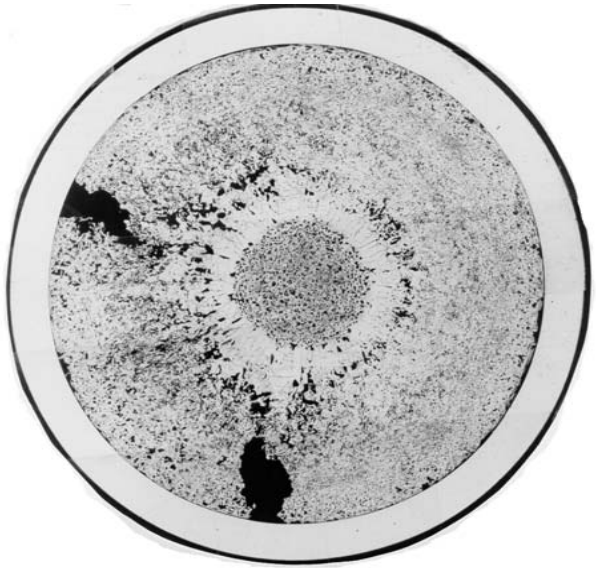
Outline of Presentation

- **Benefits of Metallic Fuels for Transmutation**
- **Overview of Current US Metallic Fuels Program**
  - Historic vs. Current Fabrication Methods
  - Characterization Activities
  - Irradiation Testing in the Advanced Test Reactor
    - > Fuel Test Matrix and Irradiations in Progress
    - > Postirradiation Examination Results
  - Metallic Fuels in the FUTURIX-FTA Experiment in Phénix
- **Conclusions and Future Work**

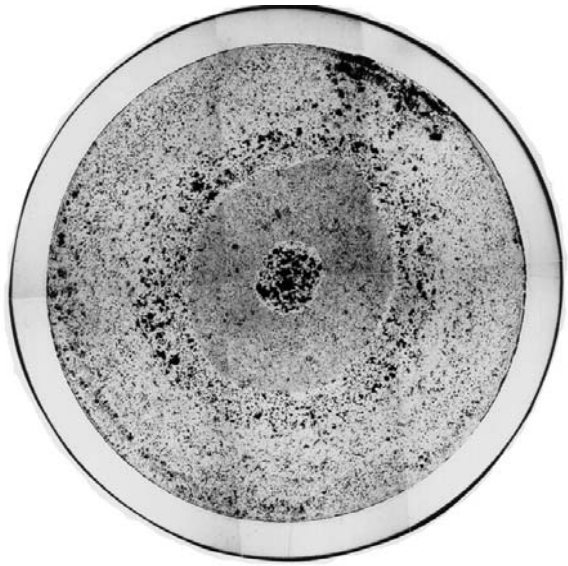
Overview of U-Pu-Zr Metallic Fuel Behavior



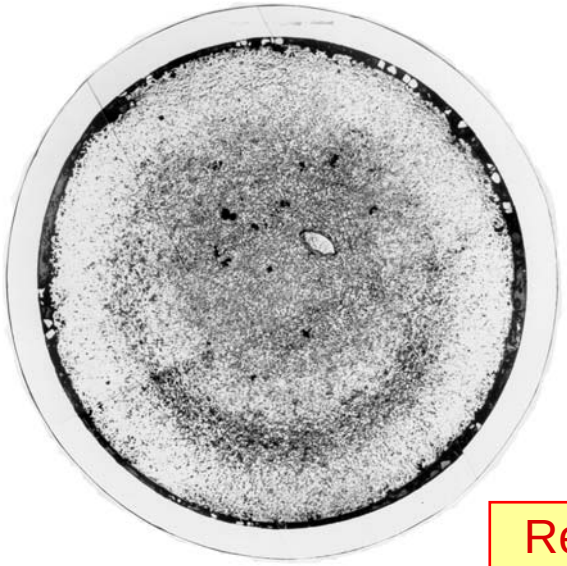
{ As-fabricated U-20Pu-10Zr



X419 at 3% BU

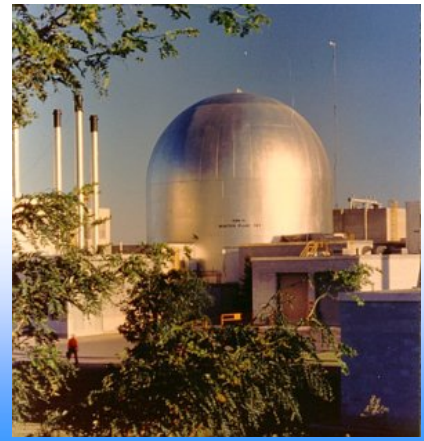


X420B at 17% BU



X423A at 1% BU

Redistribution of U and Zr occurs early; inhomogeneity does not affect fuel life.



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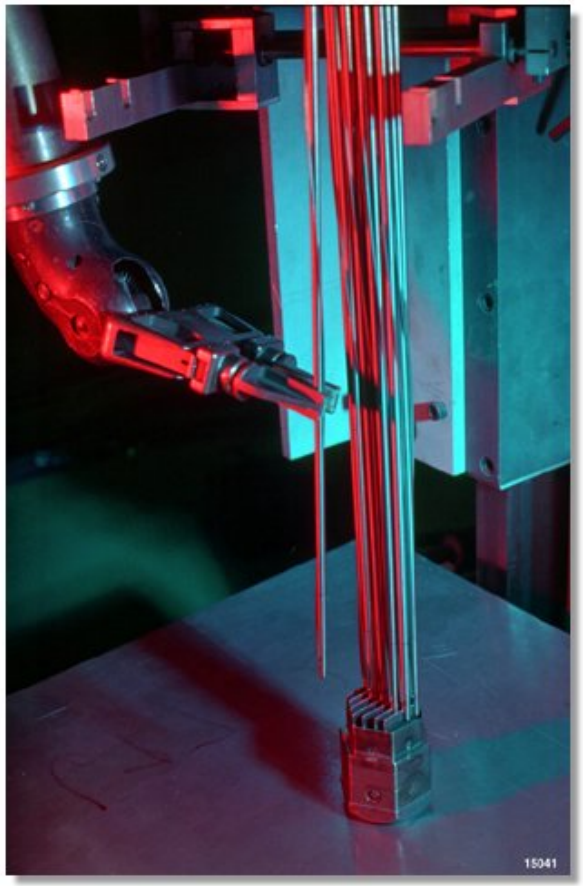
Benefits of Metallic Fuels for Transmutation



- **Fabrication**
  - Historic ease of fabrication on large scales, remote environments
  - Process not sensitive to fuel composition (exception: Am)
  - Na-bonding allows for:
    - > Loose tolerances on fuel diameters
    - > Large fuel pin thermal margins
- **Irradiation Performance**
  - Consistent over wide range of compositions
  - Large fuel swelling/high gas release accommodated by design
  - Compatible with sodium coolant
  - Demonstrated high-burnup reliability; lower-density alloys for transmutation offer even higher burnup potential

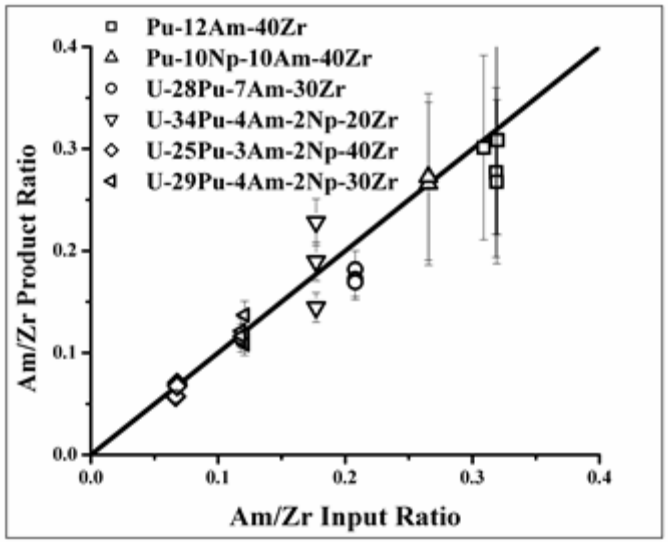
Historic Metallic Fuel Fabrication

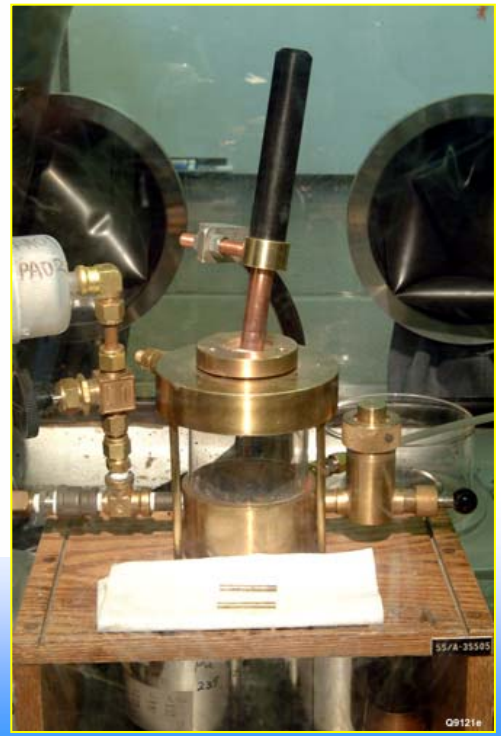
- **Fabrication by Injection Casting**
  - Graphite crucible inductively heated to melt and homogenize fuel alloy
  - Furnace evacuated and molds inserted into melt
  - Rapid pressurization of furnace forces melt into molds
- **Limitations for Transmutation Alloys**
  - Long time-at-temperature
  - Substantial loss of volatile Am from melt

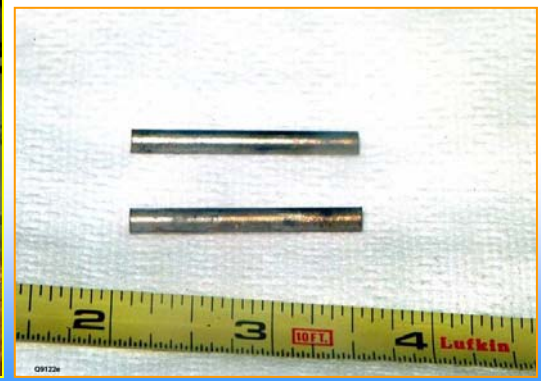
Current Fabrication with Minor Actinides

- **Rapid Melting, Homogenization, Casting**
  - Use of arc-melter with either gravity or vacuum casting
  - Time-at-temperature reduced from hours to minutes
  - Am volatile loss virtually eliminated
  - Research-scale only, not considered scalable

(See J.R. Kennedy poster on Fabrication & Characterization)







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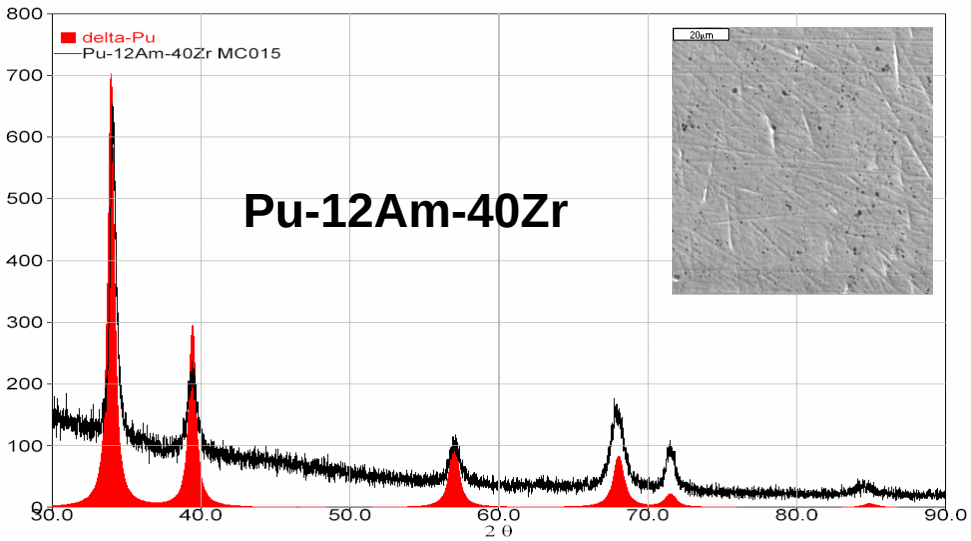
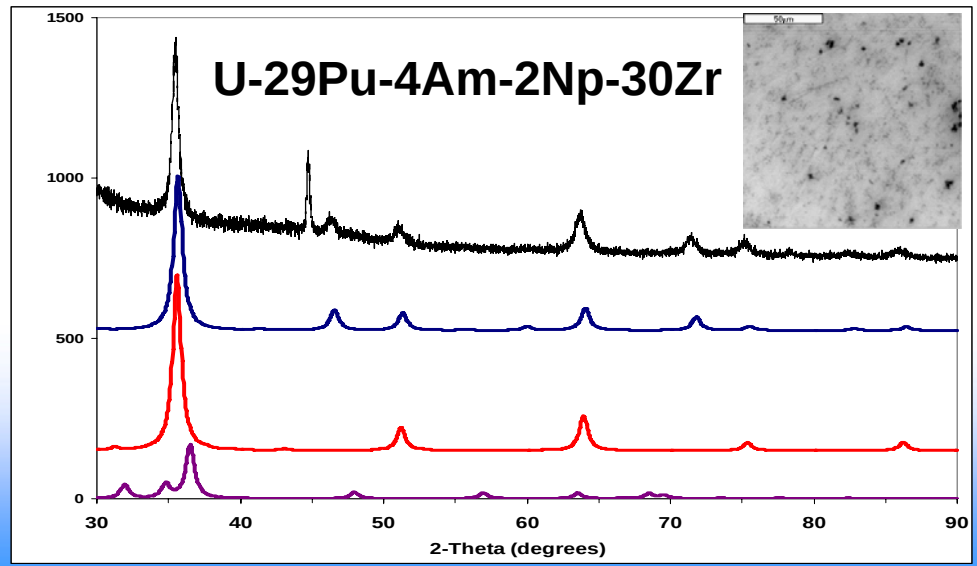
Characterization of Metallic Alloys

- **Phase Equilibria**
  - Crystal structures and phase transitions identified up to 1450°C
- **Properties**
  - Density, specific heat, thermal expansion, thermal diffusivity measured up to 1200°C
- **Compatibility**
  - Diffusion couple testing with Fe and stainless steels underway





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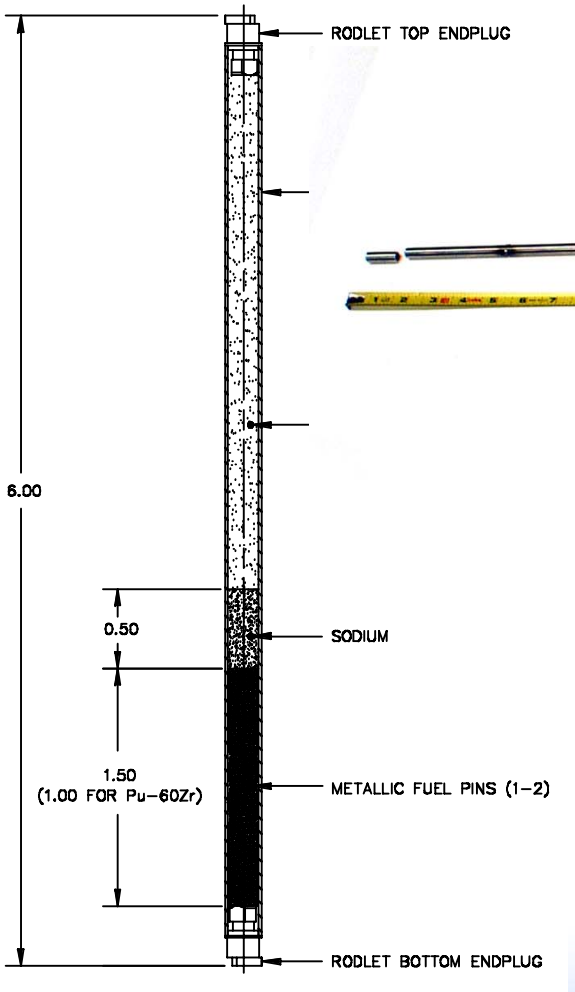
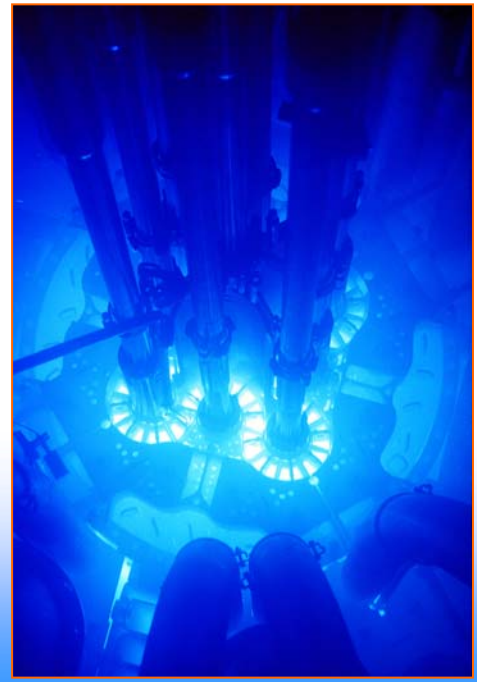
Irradiation Testing of Metallic Fuels in the ATR



Capsule Assembly Mock-Up

Q9123e



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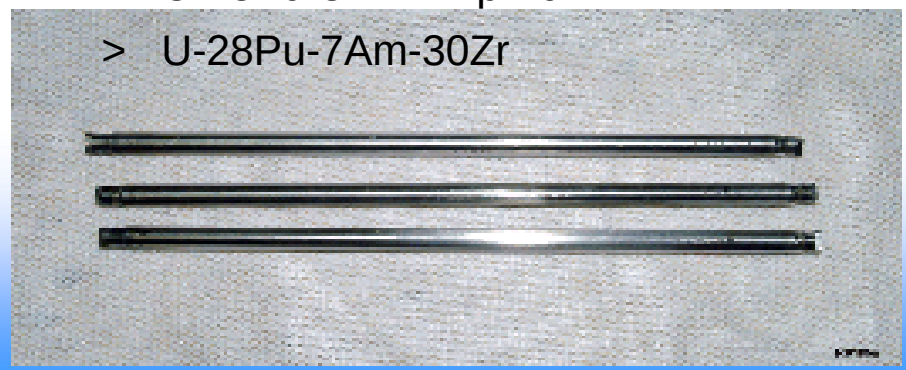
Metallic Fuel Test Matrix in ATR

Tests Completed

- **AFC-1B (8% BU)**
  - > Pu-40Zr & Pu-60Zr
  - > Pu-12Am-40Zr
  - > Pu-10Am-10Np-40Zr
- **AFC-1F (8% BU)**
  - > U-29Pu-4Am-2Np-30Zr
  - > U-34Pu-4Am-2Np-20Zr
  - > U-25Pu-3Am-2Np-40Zr
  - > U-28Pu-7Am-30Zr

Tests in Progress

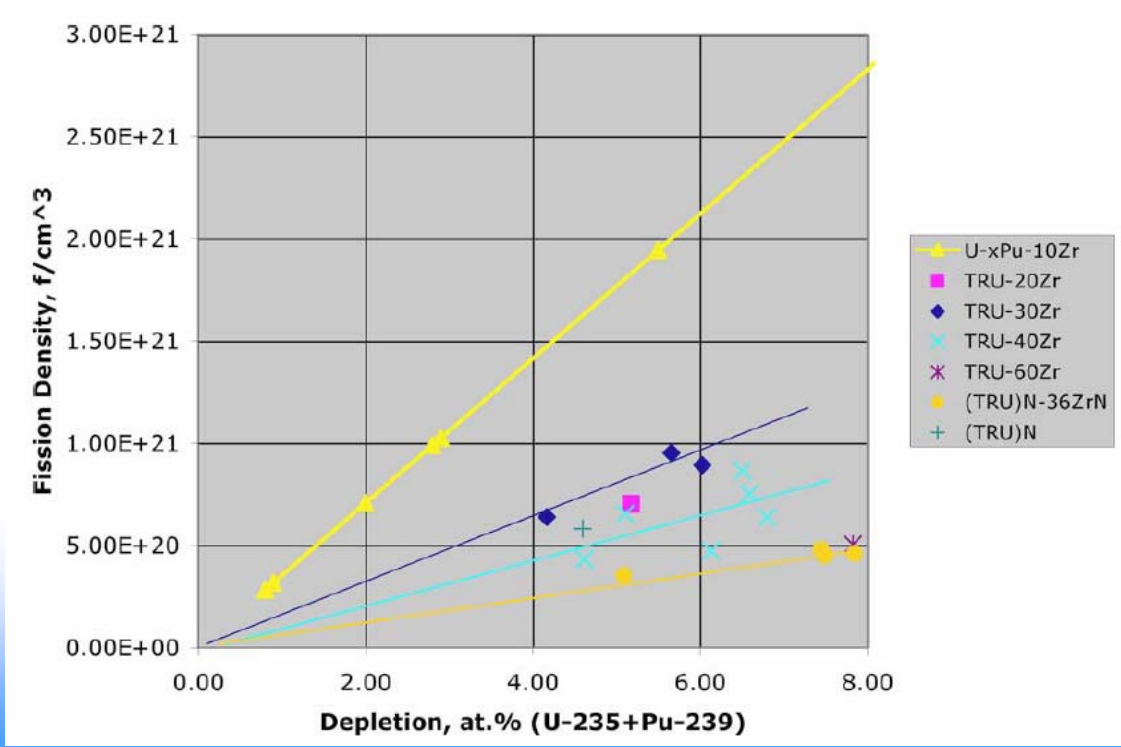
- **AFC-1D (currently at 28% BU)**
  - > Pu-40Zr & Pu-60Zr
  - > Pu-12Am-40Zr
  - > Pu-10Am-10Np-40Zr
- **AFC-1G (currently at 13% BU)**
  - > Pu-10Np-40Zr
- **AFC-1H (currently at 15% BU)**
  - > U-29Pu-4Am-2Np-30Zr
  - > U-34Pu-4Am-2Np-20Zr
  - > U-25Pu-3Am-2Np-40Zr
  - > U-28Pu-7Am-30Zr



Representative PIE Results from ATR Tests

- **Importance of Burnup Metric**
  - Metallic fuels for transmutation use increased Zr content
  - Results in less-dense fuels than traditional U-20Pu-10Zr alloy
  - Comparable fission density results in much higher at.% burnup in transmutation alloys

Lower density transmutation alloys may be capable of much higher burnups.



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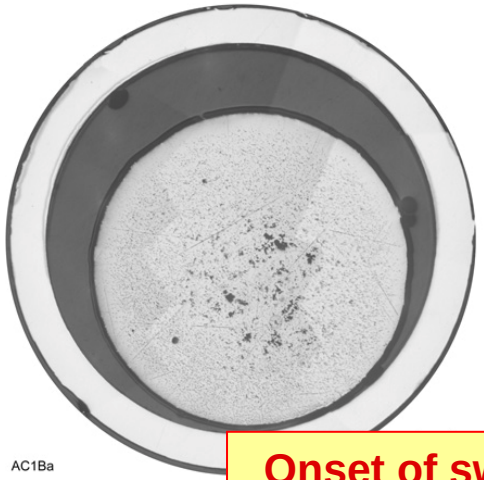
PIE—Swelling Behavior of Transmutation Alloys

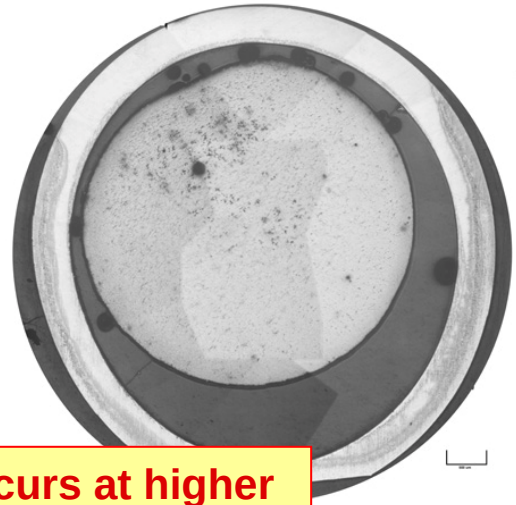
Pu-12Am-40Zr

U-29Pu-4Am-2Np-30Zr

4.6 at.%
3.5x10^{20} f/cm^3

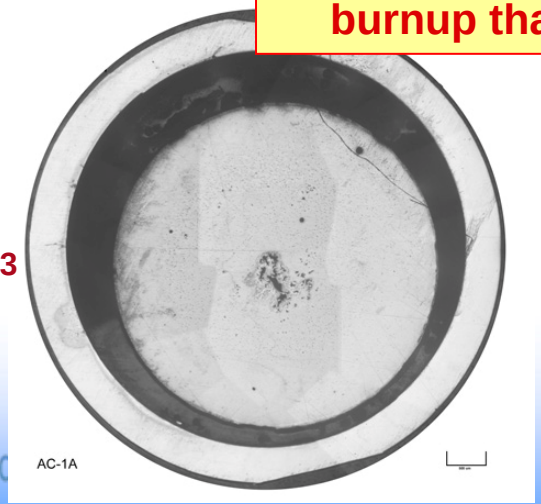


4.2 at.%
5.0x10^{20} f/cm^3

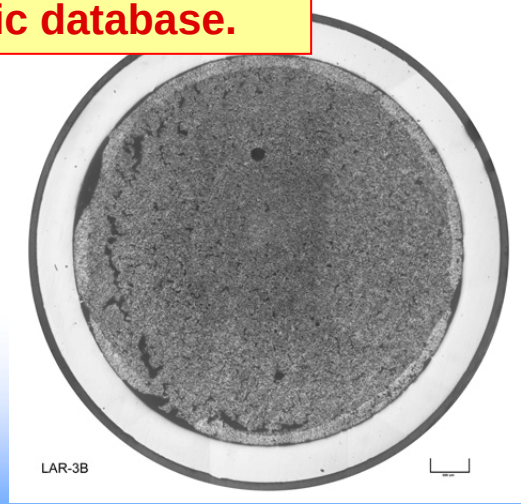


Onset of swelling occurs at higher burnup than historic database.

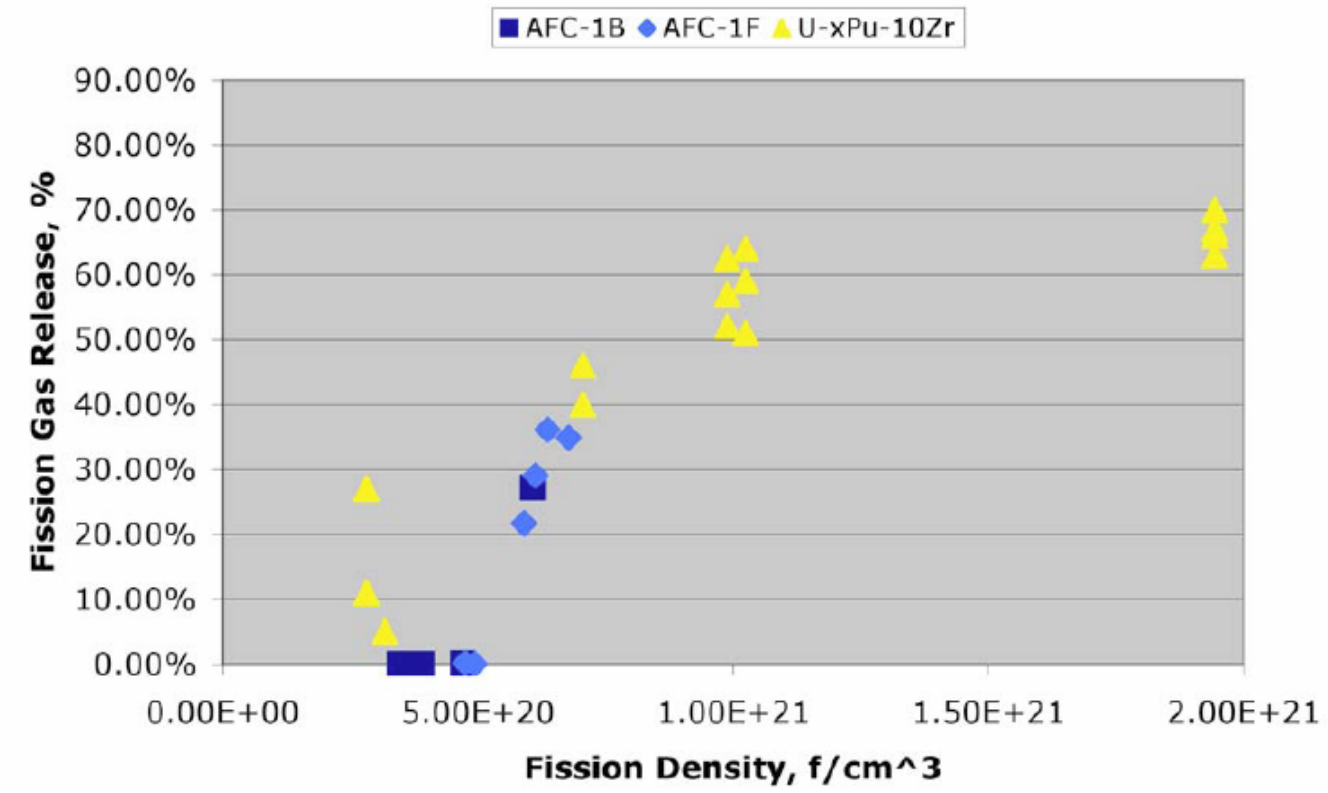
6.8 at.%
4.7x10^{20} f/cm^3



6.0 at.%
6.8x10^{20} f/cm^3



PIE—FGR Behavior of Transmutation Alloys

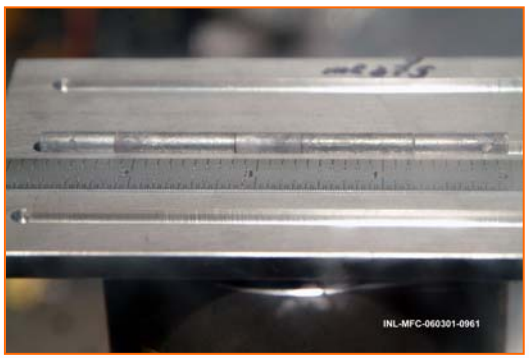


Incubation period may extend to slightly higher dose, but gas release quickly converges with historic database.

Metallic Fuels in FUTURIX-FTA

- **DOE 1: U-29Pu-4Am-2Np-30Zr**
- **DOE 2: Pu-12Am-40Zr**

Arrived at CEA-Marcoule on September 6, 2006



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Conclusions

- **Metallic Fuels an Attractive Option for Actinide Transmutation**
  - Simple, economic and remote fabrication appears viable
  - Irradiation performance over very wide range of alloy compositions consistent with historic database
  - Very high burnup potential advantageous for transmutation mission
- **Future Work**
  - Continued irradiation testing (e.g., RE additions in 2007, FUTURIX-FTA)

    (See W.J. Carmack poster on AFC-2 Test Design)
  - Design and demonstration of an engineering-scale injection casting furnace to mitigate Am loss
    - > Very rapid (conventional) induction heating
    - > Cold crucible/induction skull melter
  - Remote (hot cell) fabrication demonstration using recovered TRU