Overview of Fuel Compact Fabrication at ORNL

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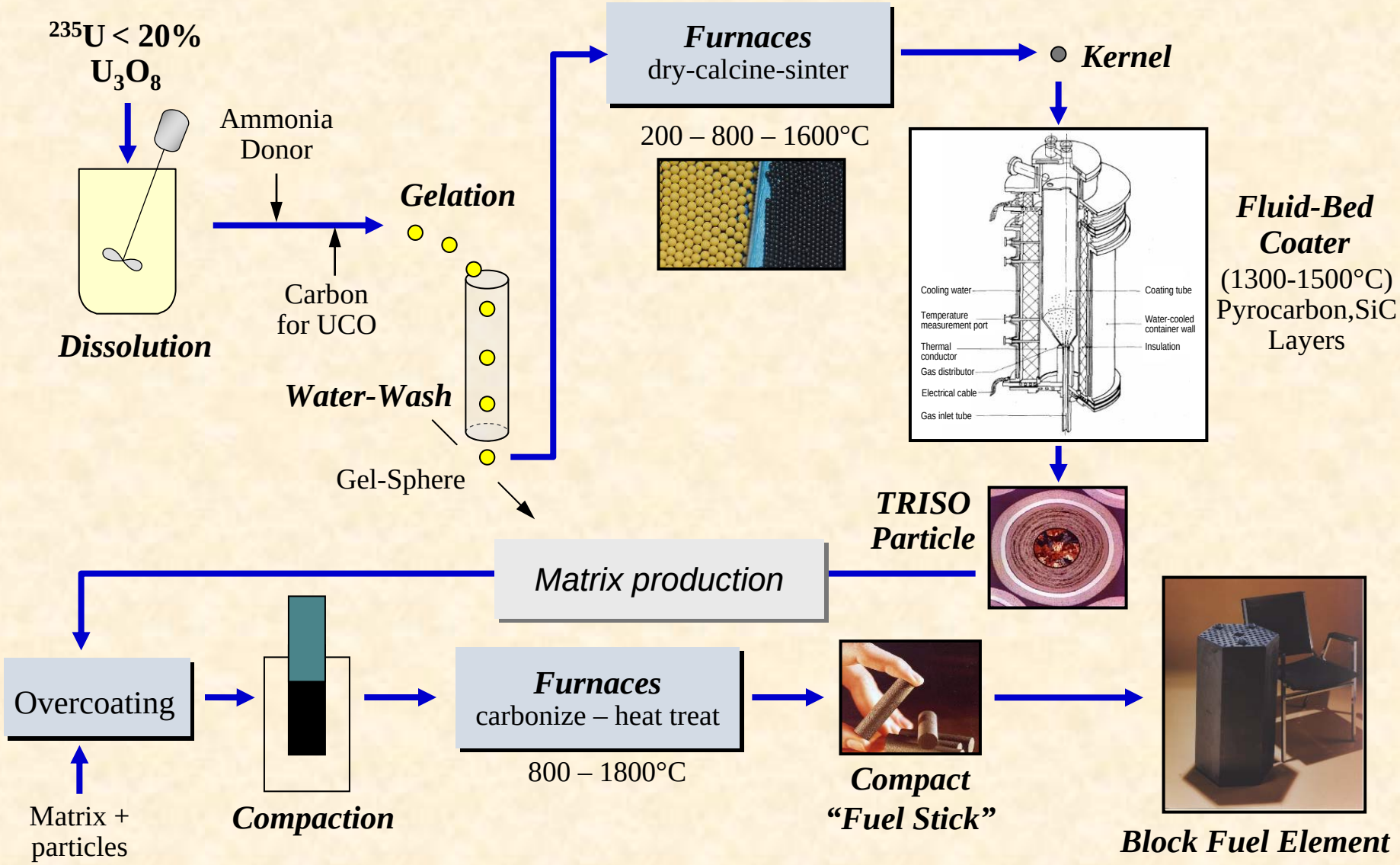
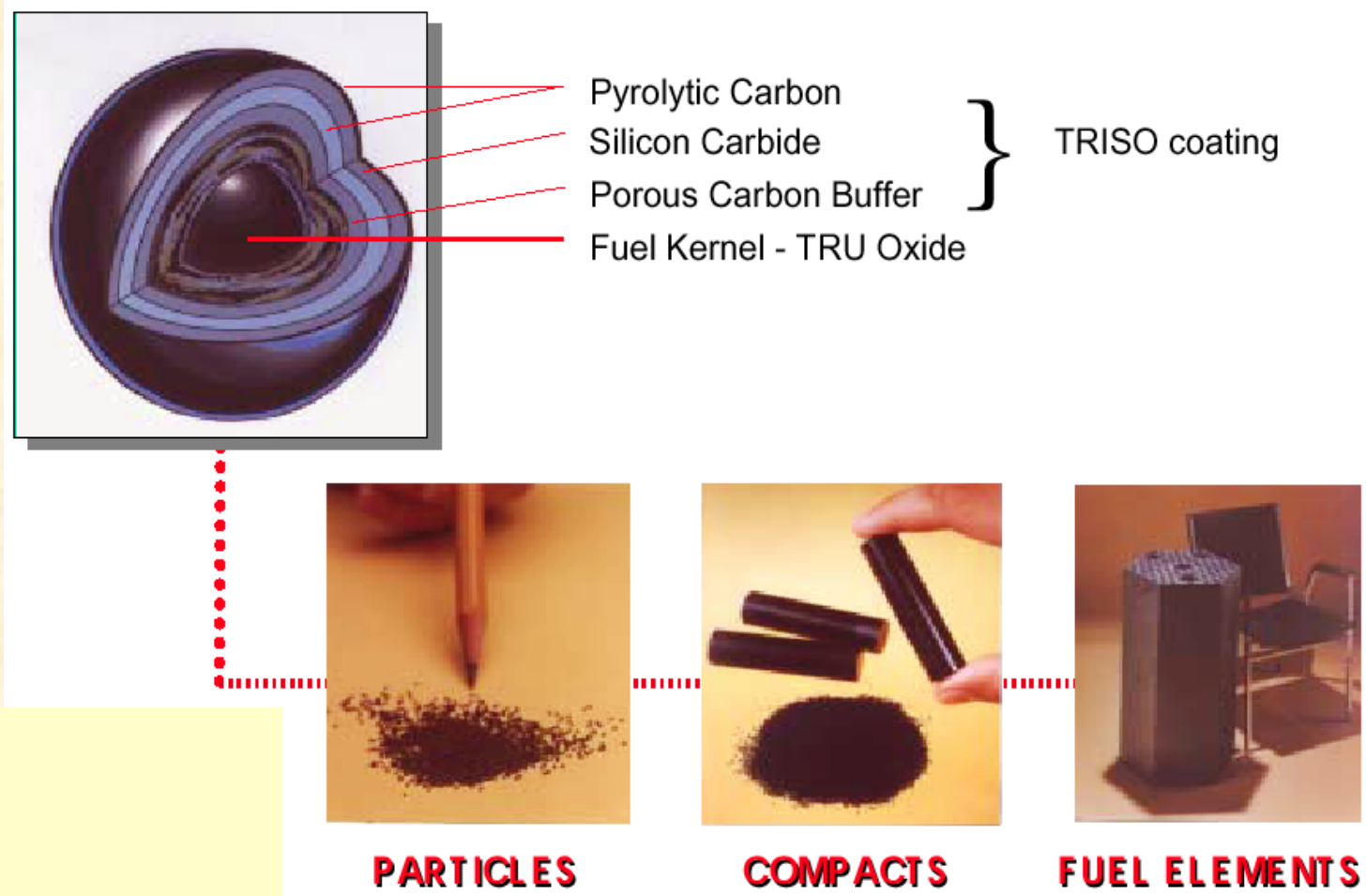
VHTR Overview

- **Of the DOE GenIV reactor concepts, only the Very High Temperature reactor (VHTR) is receiving scale up considerations (to be built by 2017)**
- **The first step, however, is to develop and qualify a coating, characterization and compacting process for the VHTR fuel (but reactor design not yet chosen)**
- **A LEUCO kernel has been chosen (350µm diam.) and German fuel particles are used as a reference fuel**
- **An overcoating and compacting process has been chosen for fabricating 35% loaded compacts (Note, fuel compacts never before made using this process)**
- **Compacts are cylindrical and nominally 12.4 mm x 25.4 mm**
- **Compacts currently being irradiated in INL ATR reactor**

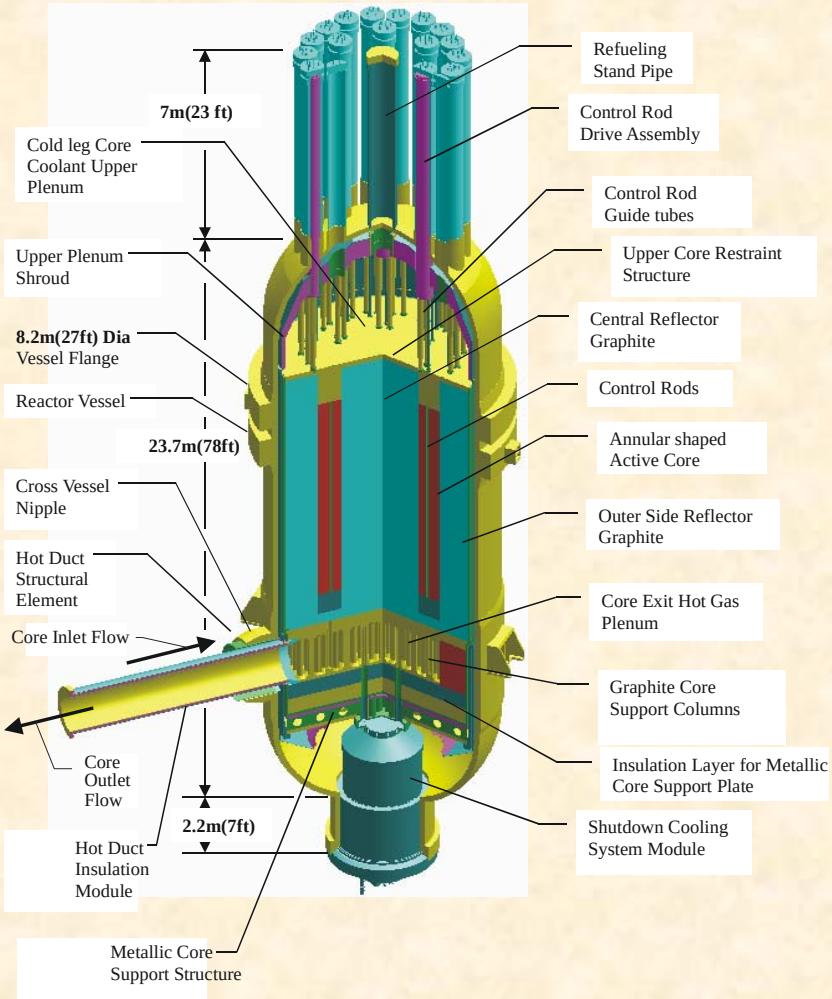
VHTR Fuel Manufacturing Steps

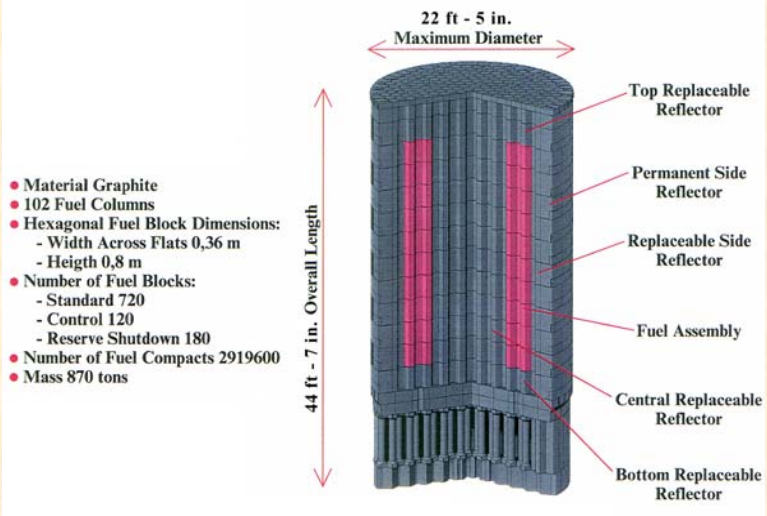


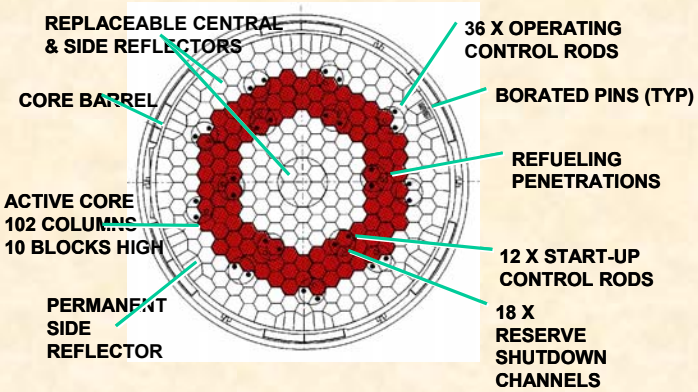
TRISO Fuel for the VHTR



VHTR Graphite Core and Fuel Block Loading Schematic



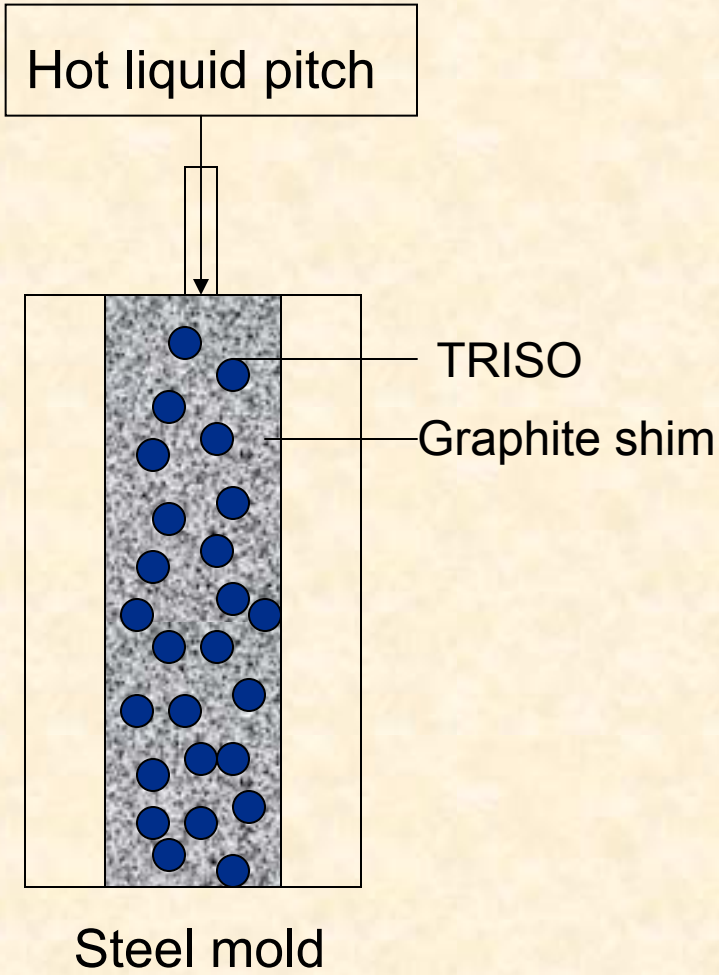


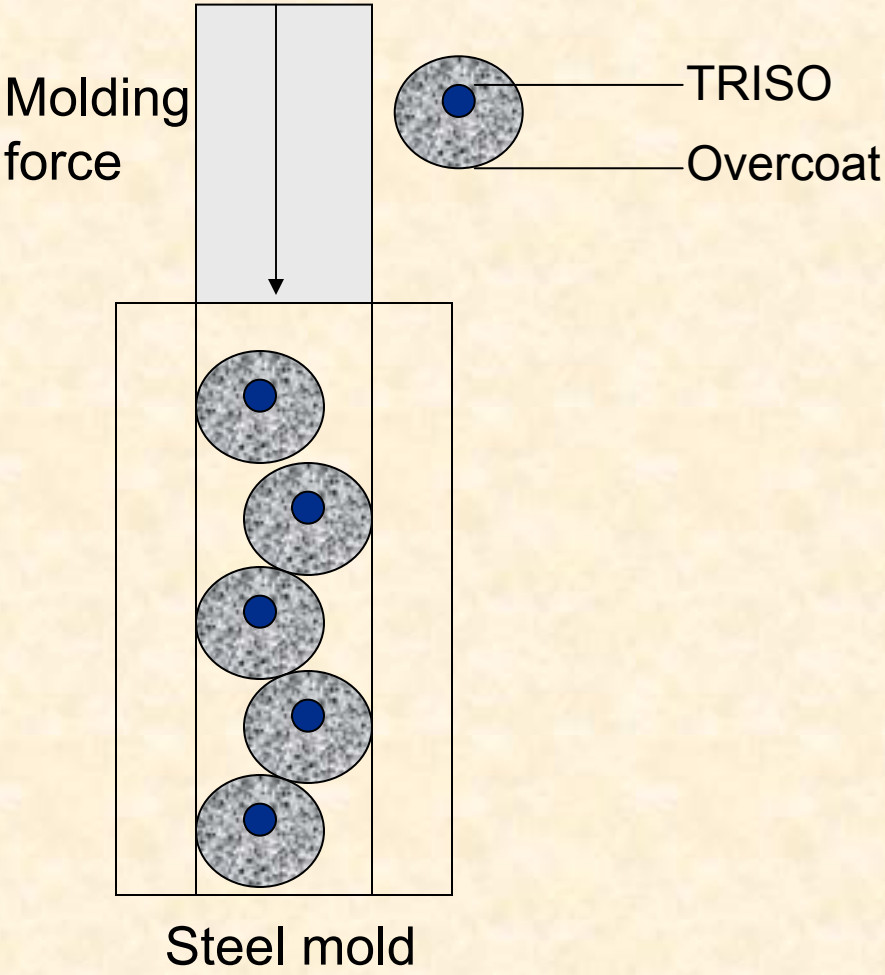


Selection of Overcoating and Compacting

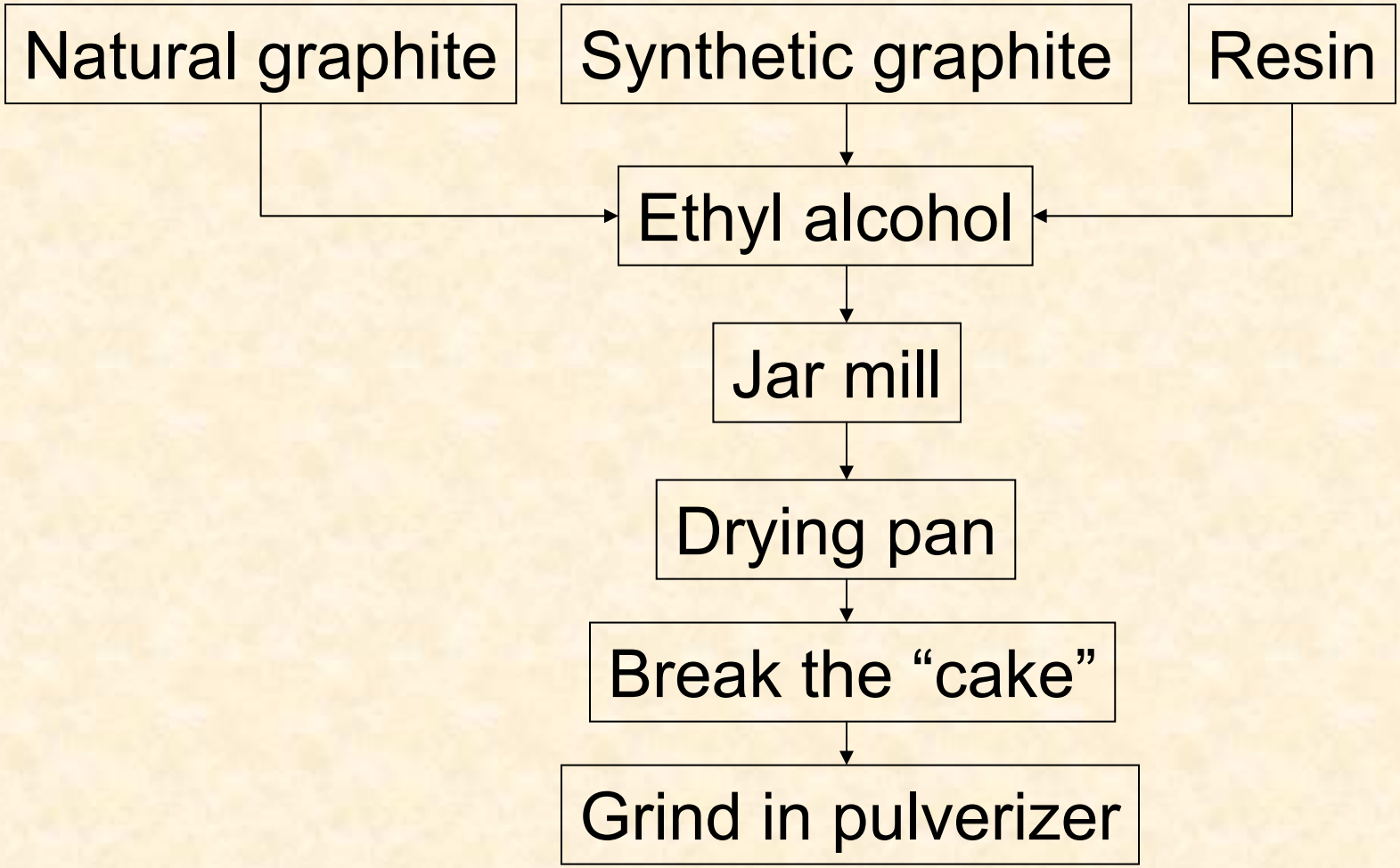
- **Two methods for producing compacts**
  1. **Slug injection**
  2. **Overcoating and compacting**
- **Want to avoid cracking SiC layer**
- **Overcoating gentler on particles**
- **Five major steps in overcoating and compacting process: (1) matrix production, (2) overcoating, (3) compacting, (4) carbonization, (5) heat treatment**

Overcoating and Compacting vs. Slug Injection Process





Matrix Production



Overcoating

- Overcoating of particles in the past was achieved by slow rolling action
- Slow rolling of these smaller particles was found to be inefficient, better results were observed with “centrifugal overcoating”
- Centrifugal overcoating consists of pre-mixing matrix and particles and spinning them at speeds high enough to force the mixture to the walls of a circular container
- An agitator is then used to “spray” the particle/matrix mixture off the wall of the container and through a mist of methanol
- The mist of methanol is achieved with an ultrasonic atomizer coupled to a syringe pump
- Matrix is added and this process is repeated until the appropriate overcoat thickness, that will lead to a compact with 35% packing fraction, is achieved
- Calculations showed that ~160μm overcoat thickness is required

Overcoating and Fuel Particle Packing Fraction (FPPF)

- **Fuel particle packing fraction agreed upon with the programs (Reactor and Fuels)**

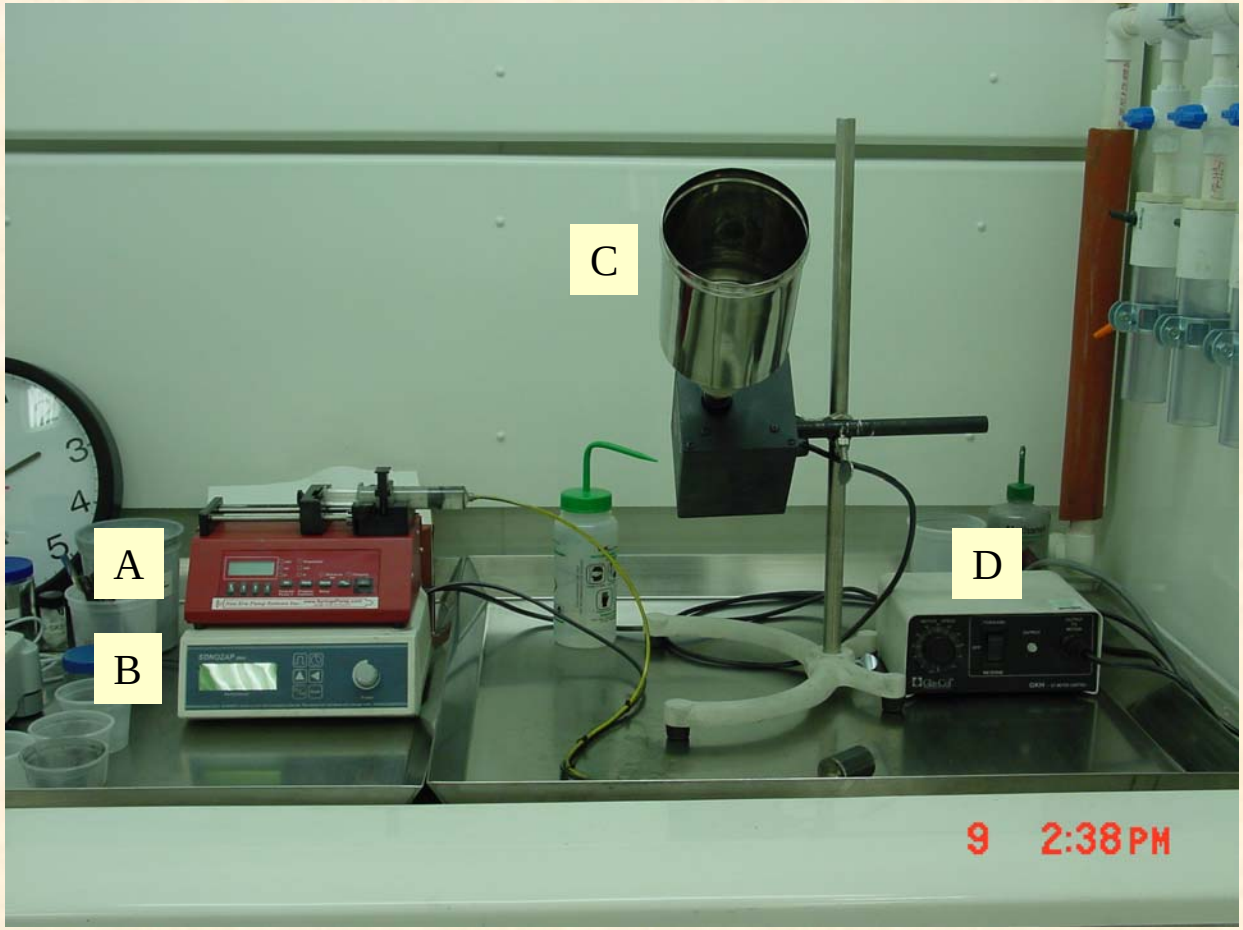
$$\frac{0.35(\text{vol. of compact})}{\text{vol. of TRISO}} = \text{\# of particles in a compact with 35\% packing fraction}$$

$$(\text{\# of particles}) \times 4/3\pi(r + x)^3 = \text{vol. of compact}$$

Where "r" is the radius of the TRISO particle and "x" is the overcoat thickness

**The number of particles is ~4400 per compact and "x" is ~160μm

Picture of Overcoater



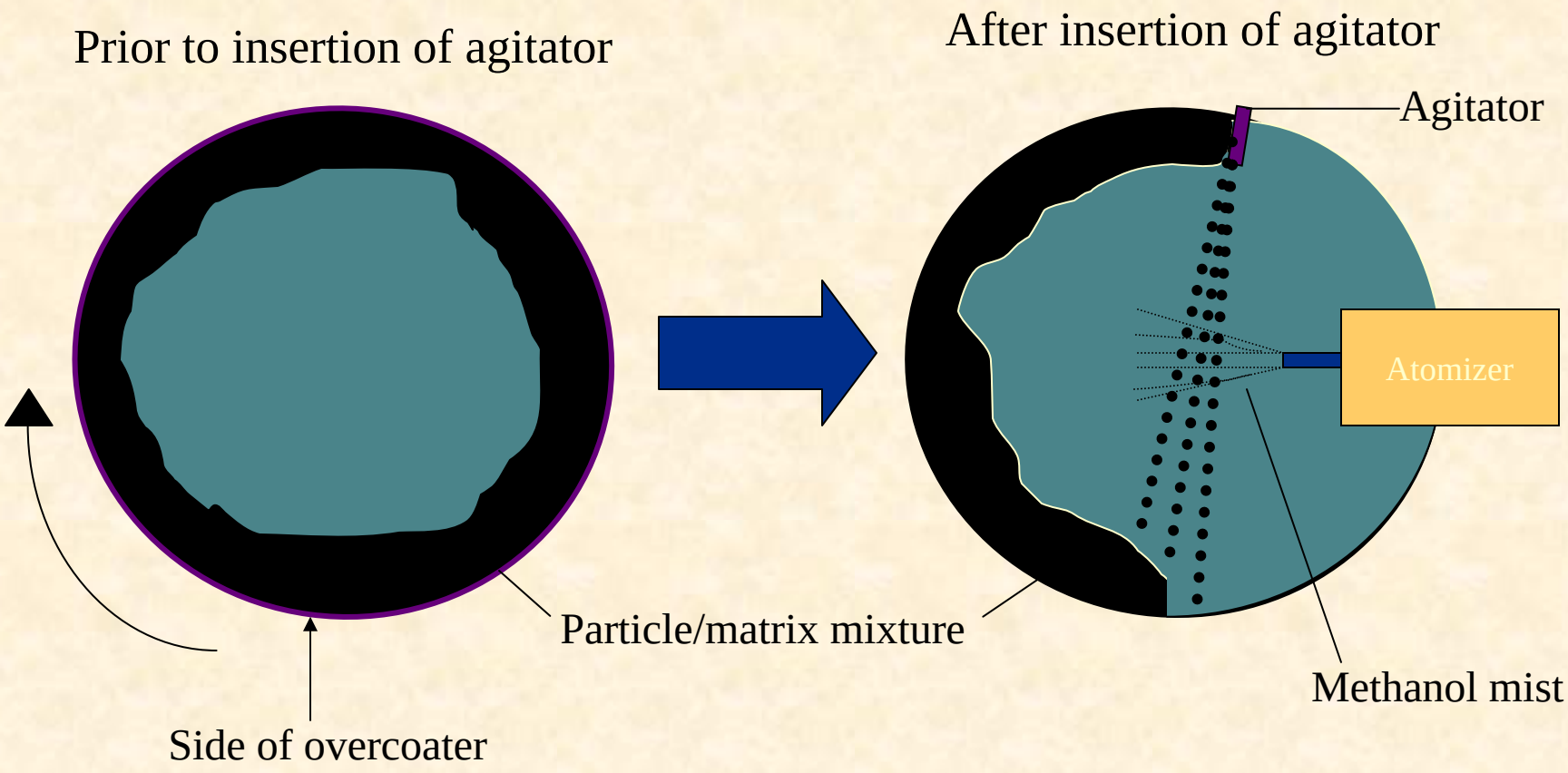
A. Syringe pump

B. Ultrasonic atomizer

C. Overcoater

D. Overcoater speed controller

Schematic Representation of Centrifugal Overcoating Process—Top View

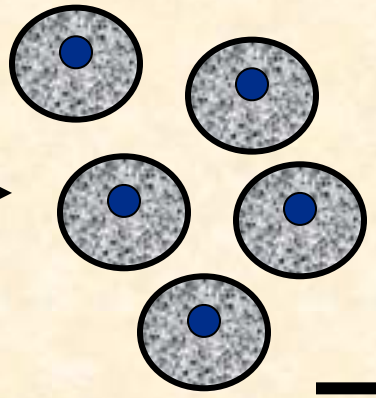


Sizing Overcoated Particles

- The overcoated particles are taken from the overcoater and sized using sieves and an electronic sieve shaker
- Three sieves are used, nos. 14, 16, 18
- Through testing, the overcoated particles that come to rest on a no. 18 screen (1mm screen openings) have the correct overcoat thickness
- The particles that are too big (i.e. +14, 16) can be washed with methanol to remove the overcoat
- Particles that are too small (i.e. -18, +20, -20) can be re-overcoated
- The yield per overcoating run is ~70%
- The yield per batch of particles is ~98%

Overcoating, Sizing and Tabling of Particles

Overcoating setup

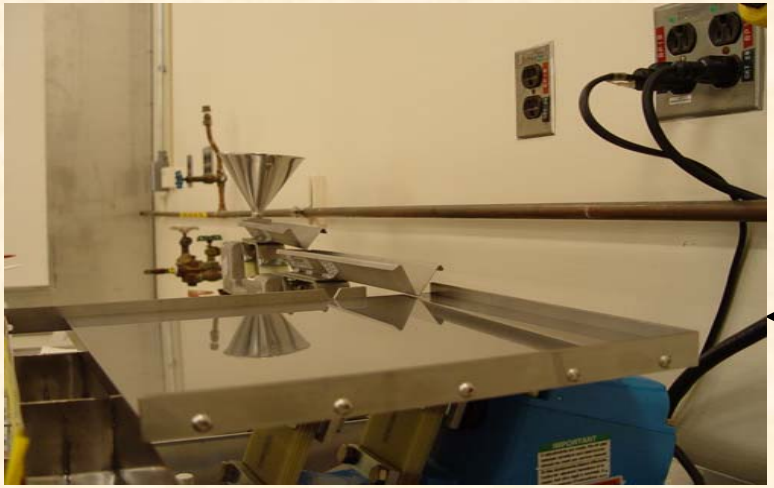


Sieve shaker

+14

+16

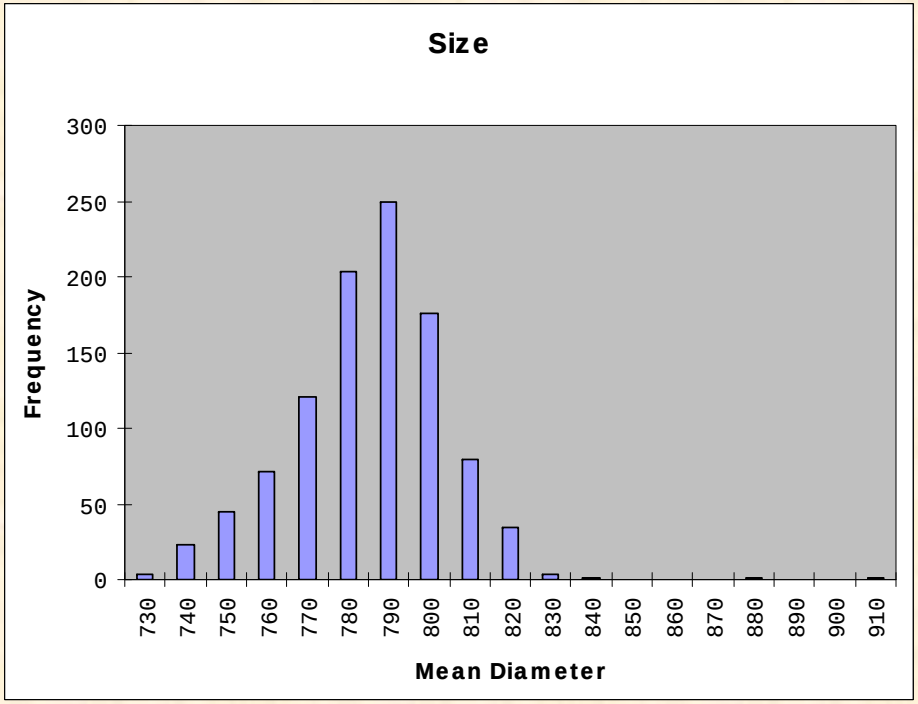
+18

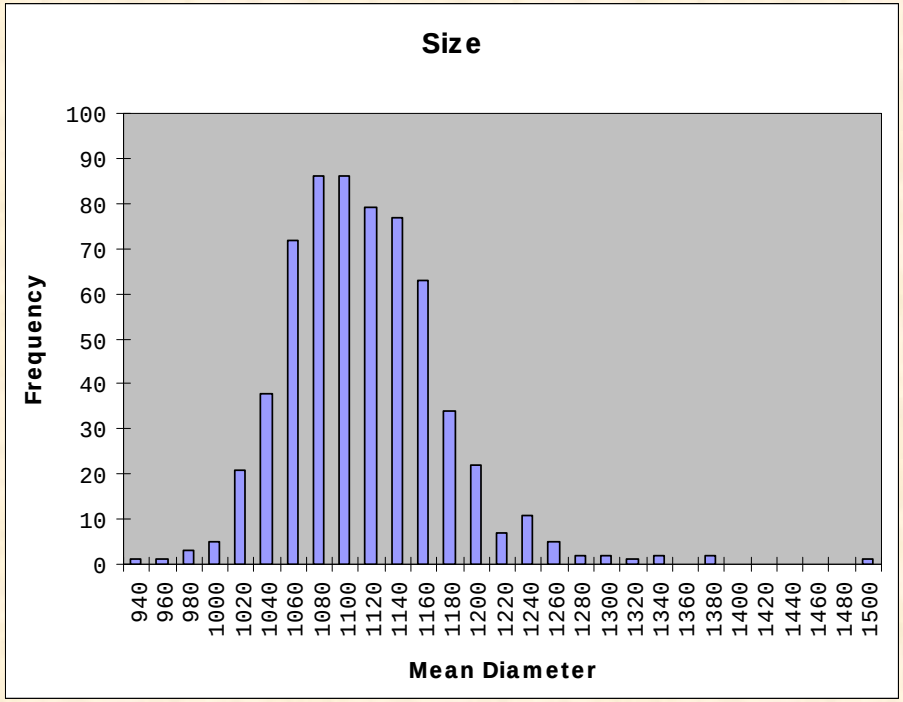


Tabler

UT-BATTELLE

Verification of +18 Sized Particles



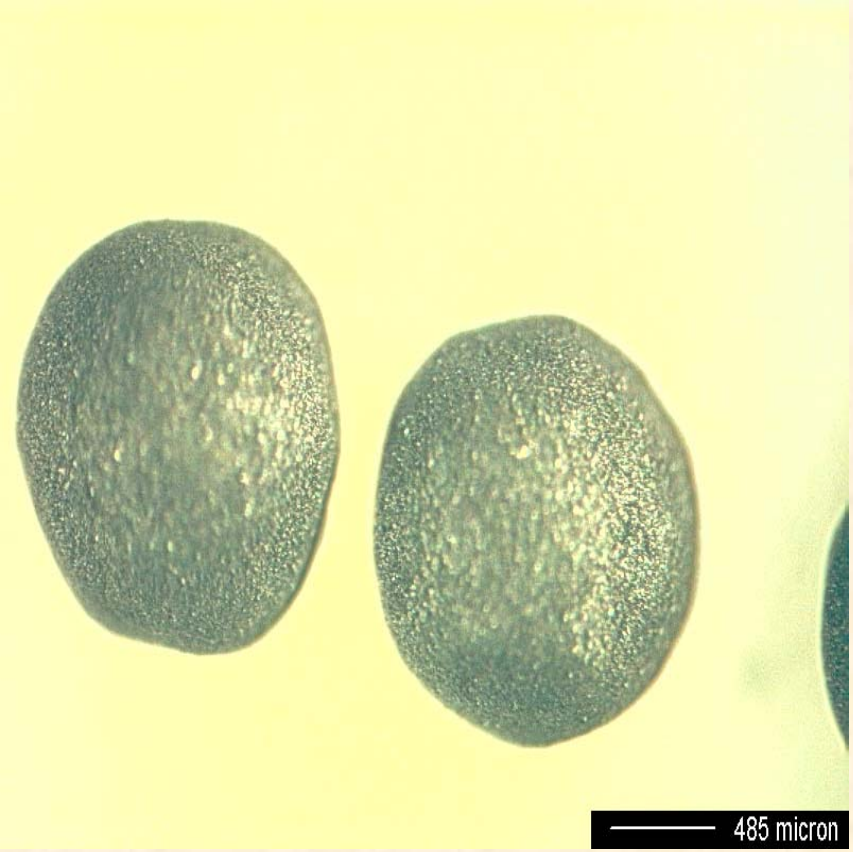


Mean diameter prior to overcoating =780µm

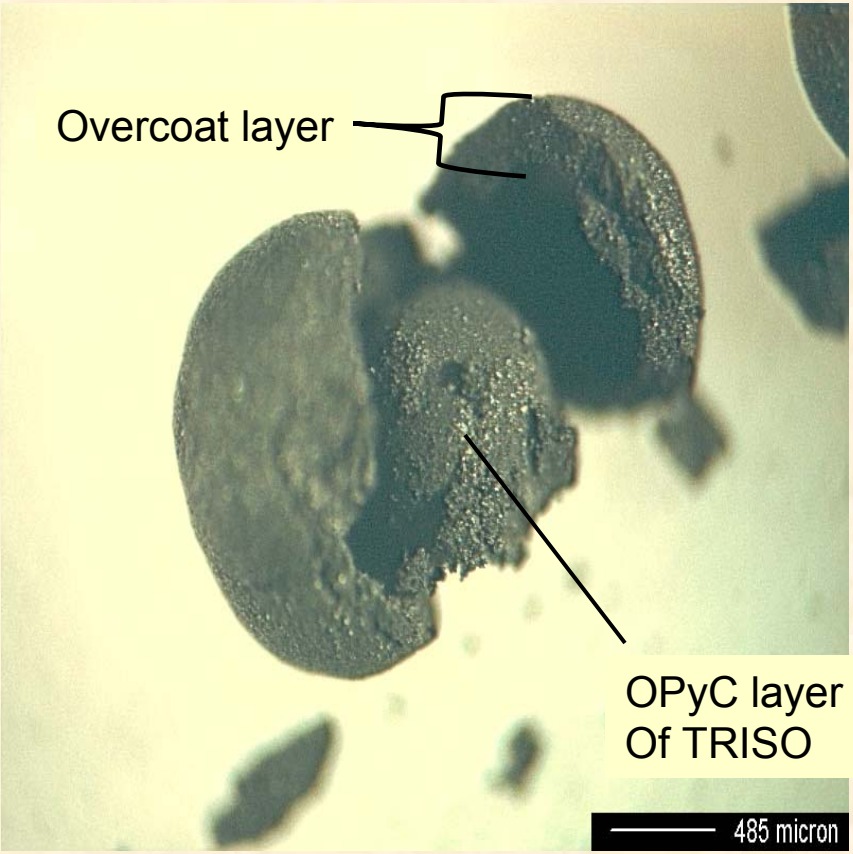
Mean diameter after overcoating =1105µm

Diameter increased by 325µm, an overcoat thickness of 162.5µm

Images of Overcoated Particles

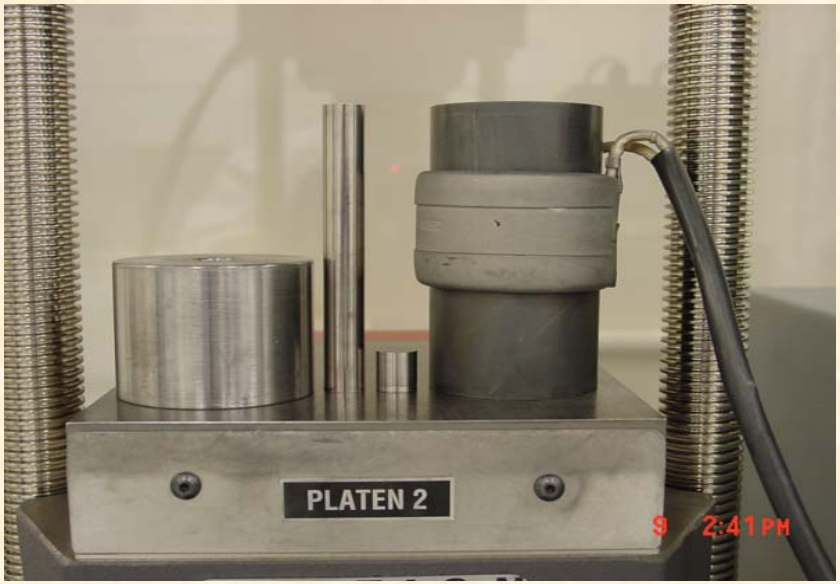


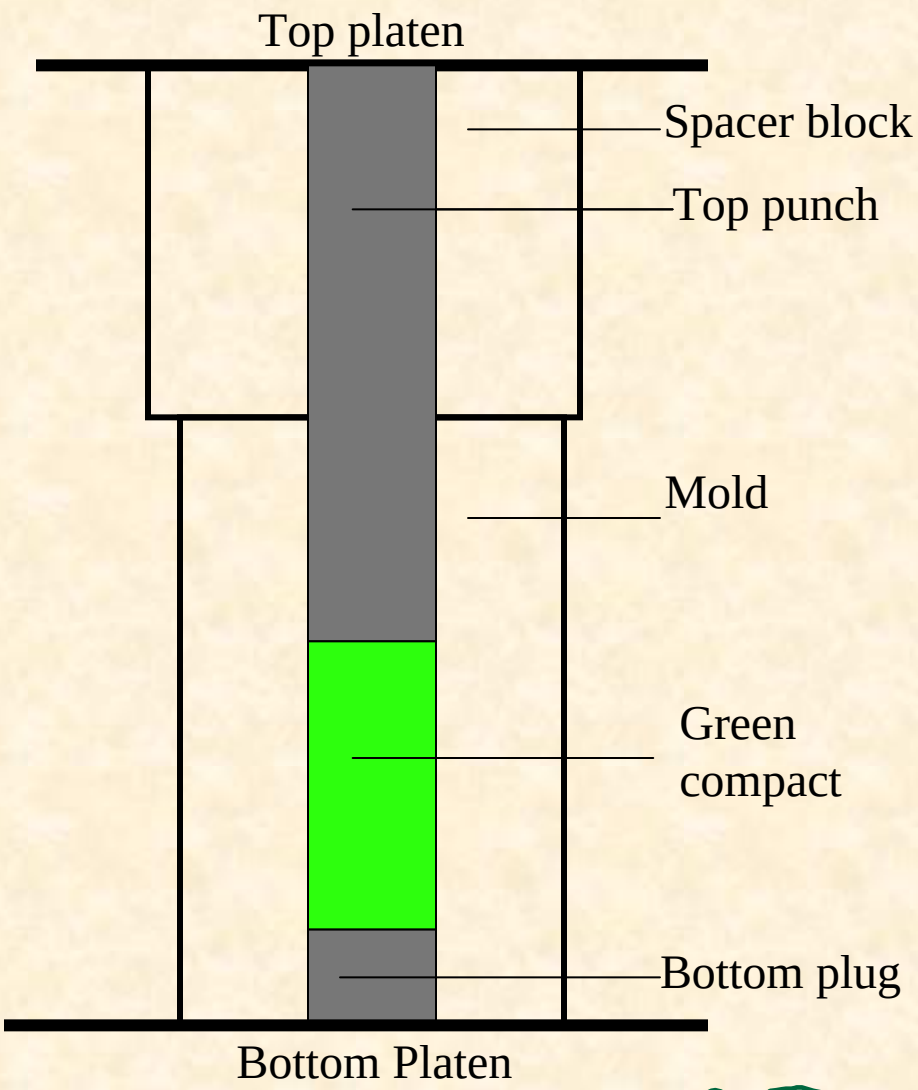
Overcoated particles



Same overcoated particle with overcoat broken off

Compaction Mold



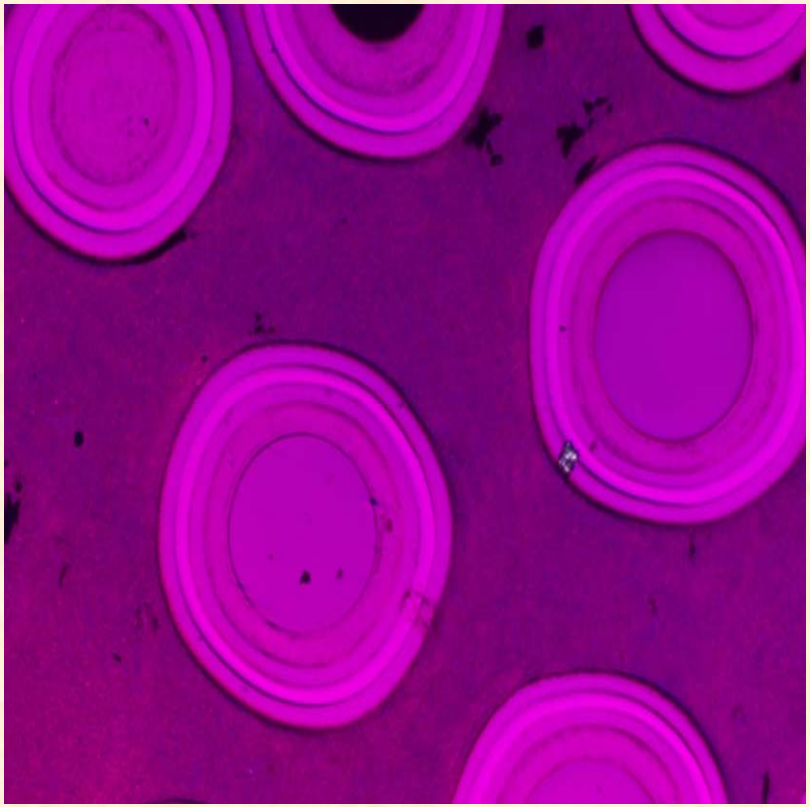


Carbonization and Heat-treatment

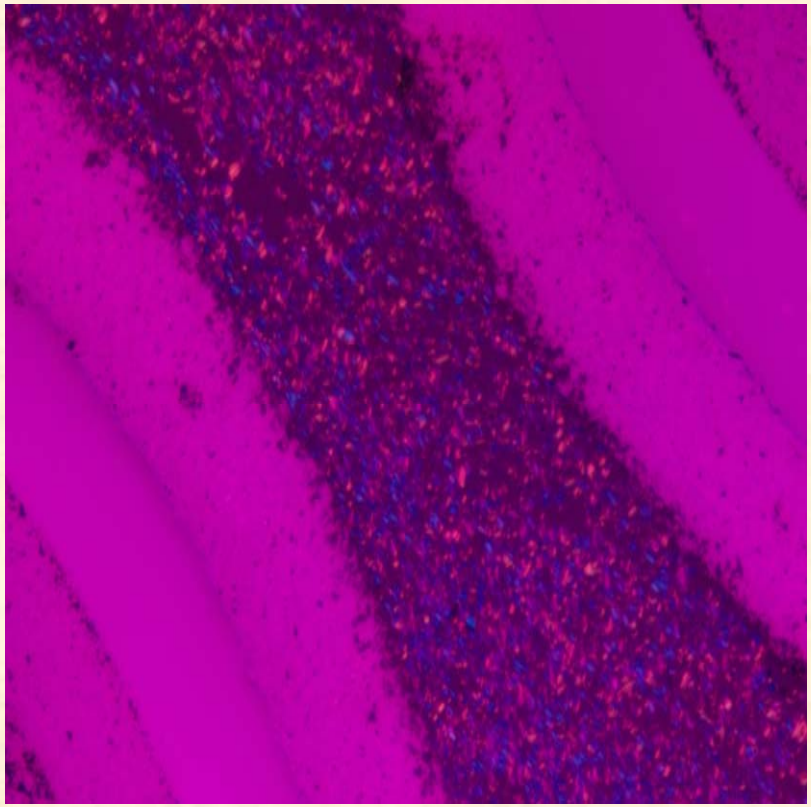
- A tube furnace with a quartz tube is used to carbonize the compacts to 950°C, under flowing helium
- The compacts are carbonized in a quartz boat (little chance for iron contamination)
- An Astro furnace is used to heat-treat the compacts to 1800°C, both vacuum and flowing argon atmospheres have been tried
- The compacts are heat-treated in graphite crucibles (minimize contamination)

Side View of Fully Pressed Compact

Optical Images of Cross-sectioned Compacts



Cross-sectioned compact



TRISO layers separated by matrix

The Fuel Compacts Have Broken Records

- **The fuel fabricated at ORNL has achieved the highest burn-up of any fuel ever tested.**
- **In March of 2008 the fuel reached 9% burn-up and is still going strong. (Current LWR reactors achieve 3-4% burn-up)**
- **Achieving a higher burn-up allows for more efficient use of the uranium in the fuel and produces less waste.**

Conclusions

- A method for fabricating compacts has been developed at ORNL
- The fabrication method involves overcoating and compacting TRISO particles
- To date, the process has been very robust and no broken particles (as a result of the compacting process) have been found
- The worked performed at ORNL has produced the world's most successful, in terms of achievable burn-up, fuel particles and compacts

The Research Presented Here Has Been Published in Several Journals, Making the Cover of TWO

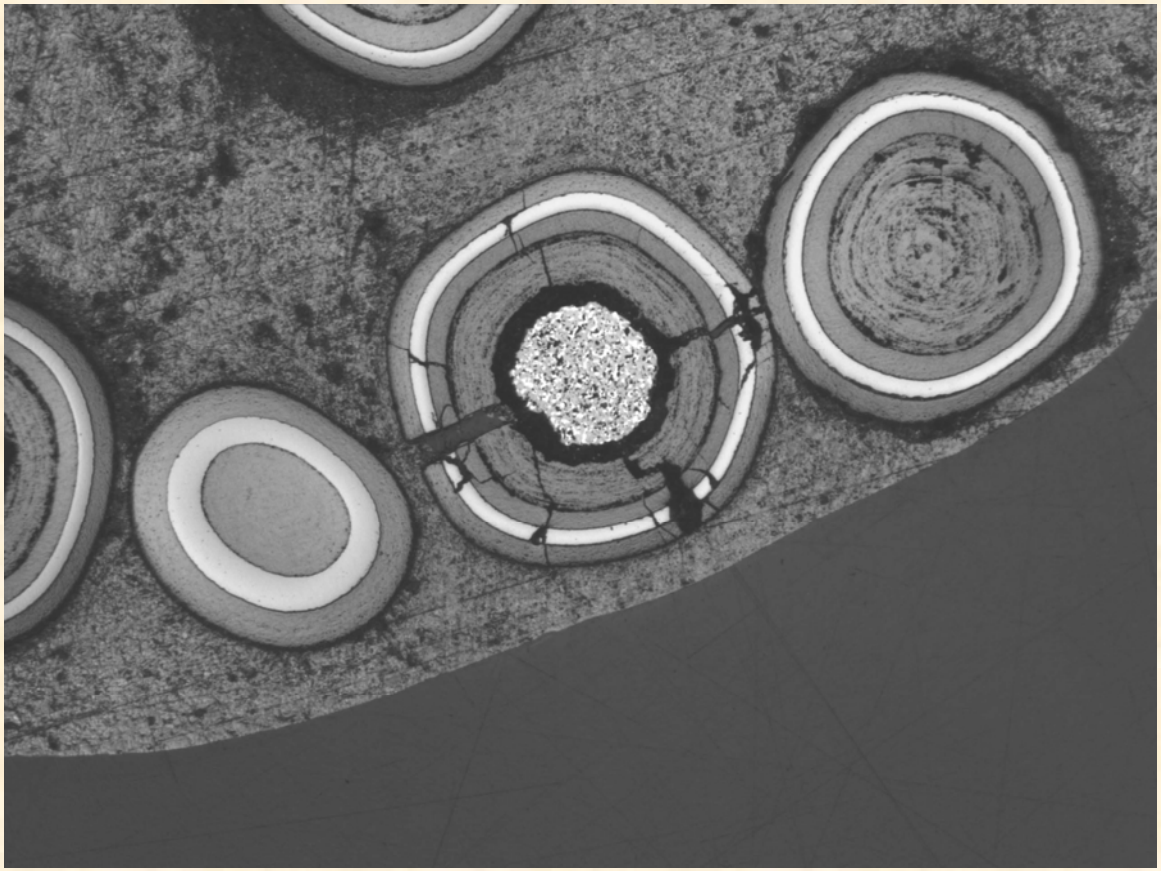
We Made the Cover of Mechanical Engineering Magazine!!

"The Seeds of Fission"

"A new old way to package fuel. The first nuclear Vessel turns 50"

Mech. E. vol. 126/No.1 Jan. 2004

Another Journal Cover! Journal of Nuclear Materials



Morris, R.N., and Pappano, P.J., “Estimation of maximum coated particle fuel compacting packing fraction,”

Journal of Nuclear Materials, vol. 361, issue 1, 31 March 2007, pgs. 18-29 (Selected for cover)