The South African Pebble Bed Modular Reactor (PBMR) and its Fuel

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AFRICA

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South Africa

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South Africa

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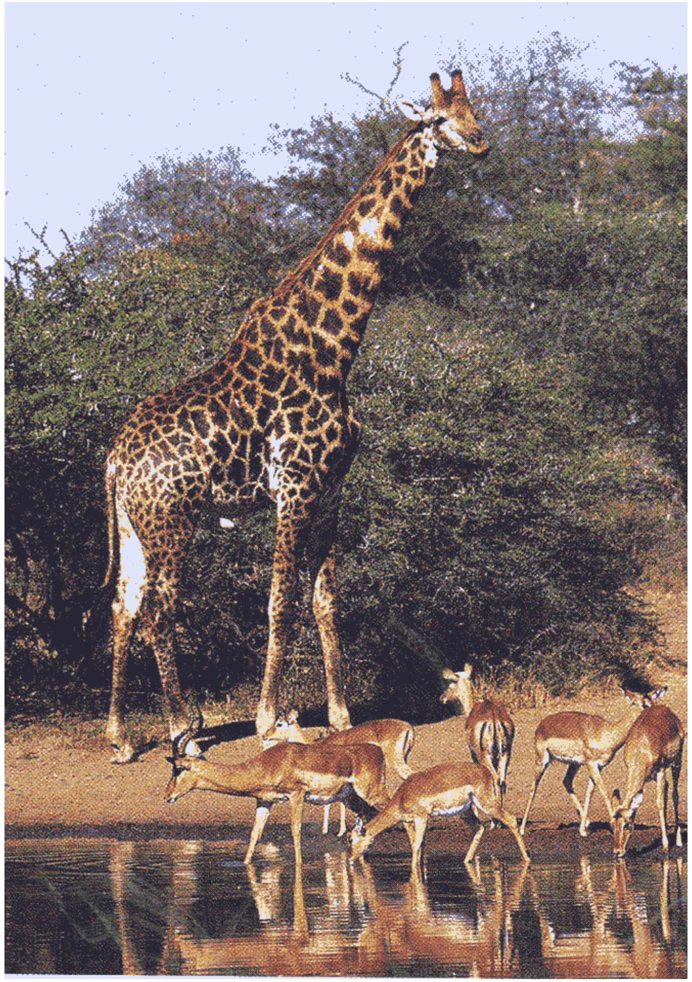
About 50 M inhabitants

11 official languages

Republic: Executive President

9 Provinces



PRETORIA
(Metropolitain City of Tswane)

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Capital of South Africa

1.2 M citizens (Pretoria)

Jacaranda city

University city

- University of Pretoria
- University of South Africa
- Technical University of Tswane
- Medical University of South Africa

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Main campus

UNIVERSITY of PRETORIA

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48k full-time students (71k)

All types of faculties

Highest research output

INTRODUCTION

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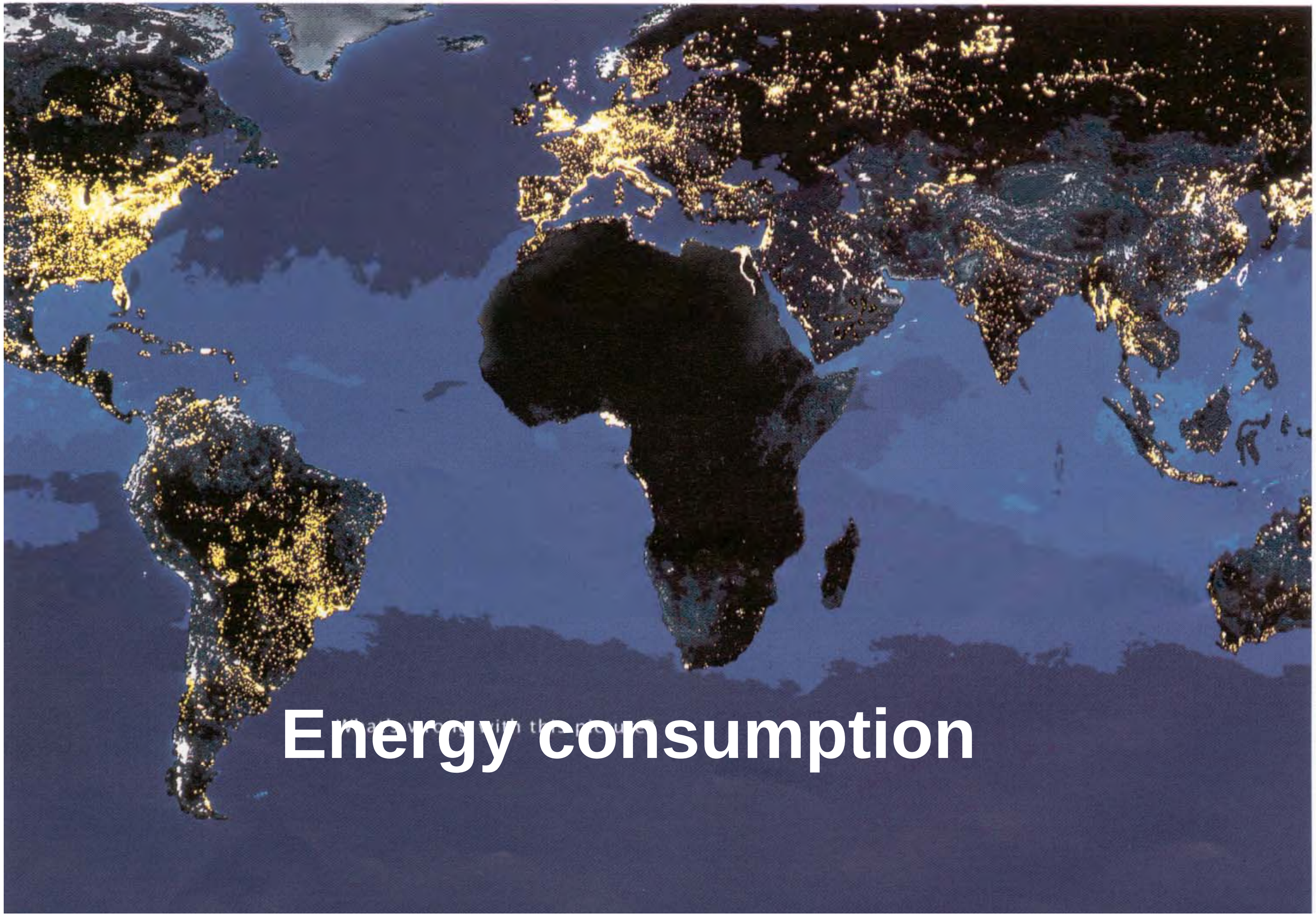

INTRODUCTION

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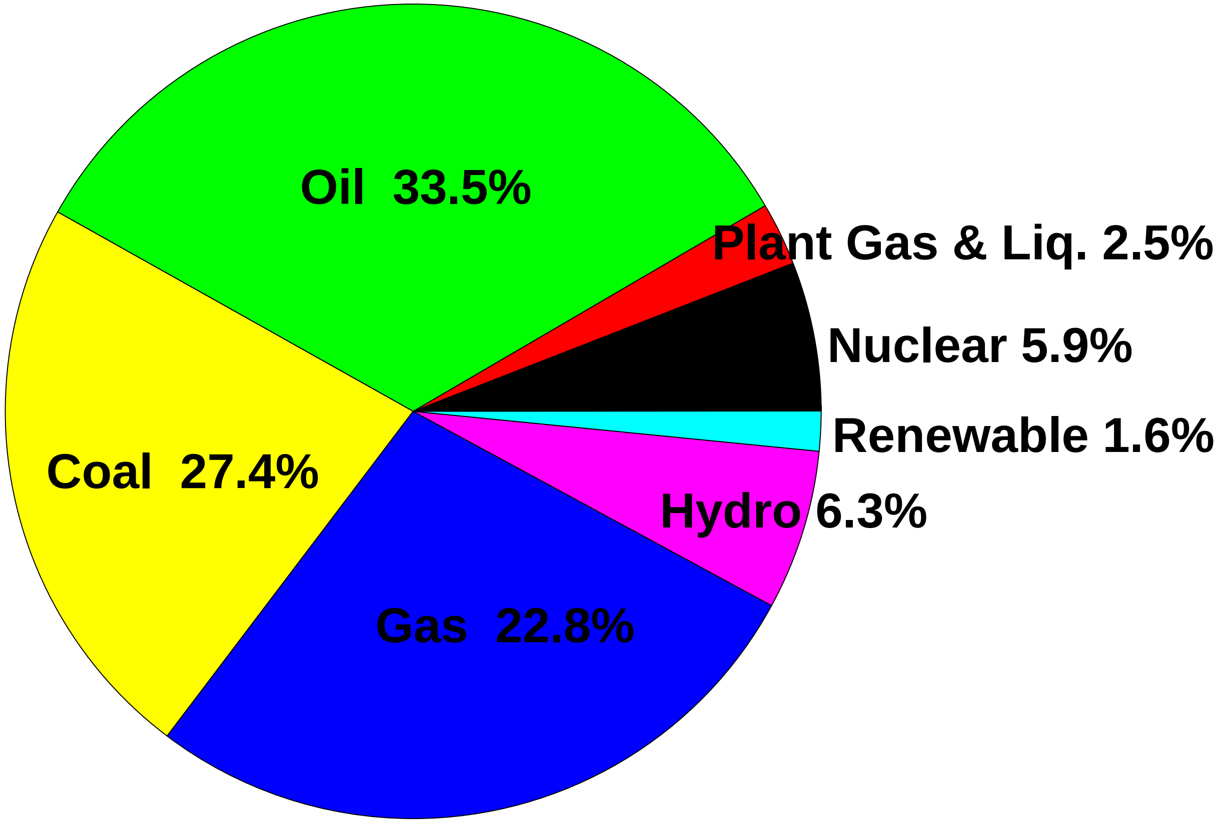
Energy Types

World Energy Production in 2006



Note: fossil fuels represent about 84% of the total.

NUCLEAR REACTORS

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U.S. Department of Energy's Office of Nuclear Energy, Science and Technology:

Generation IV Nuclear Reactors

- Sustainability
- Economical
- Reliability
- Proliferation-resistance
- Safety – Self-regulating – no Chernobyl

SA PBMR Reactor

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- Improvement of German design (21 years running)
- Outlet working temperature – 950^{o}C
  TD efficiency higher than conventional nuclear reactors. Self-annealing of irradiation damage.
- Moderator and neutron reflector are from graphite
- Inherent safety self regulation mechanism
  Reason: Doppler broadening of neutron fission reaction cross-section peak

SA PBMR Reactor

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- Direct cycle reactor (Brayton cycle)
  No heat transfer system
- Coolant is He gas
- Small reactor: 250 or 400 MWth

  Suitable for urban development

  Reactor design: Seldom stoppages (Normal

  LWR - 18 to 24 months fuel replacement)

SA PBMR Reactor

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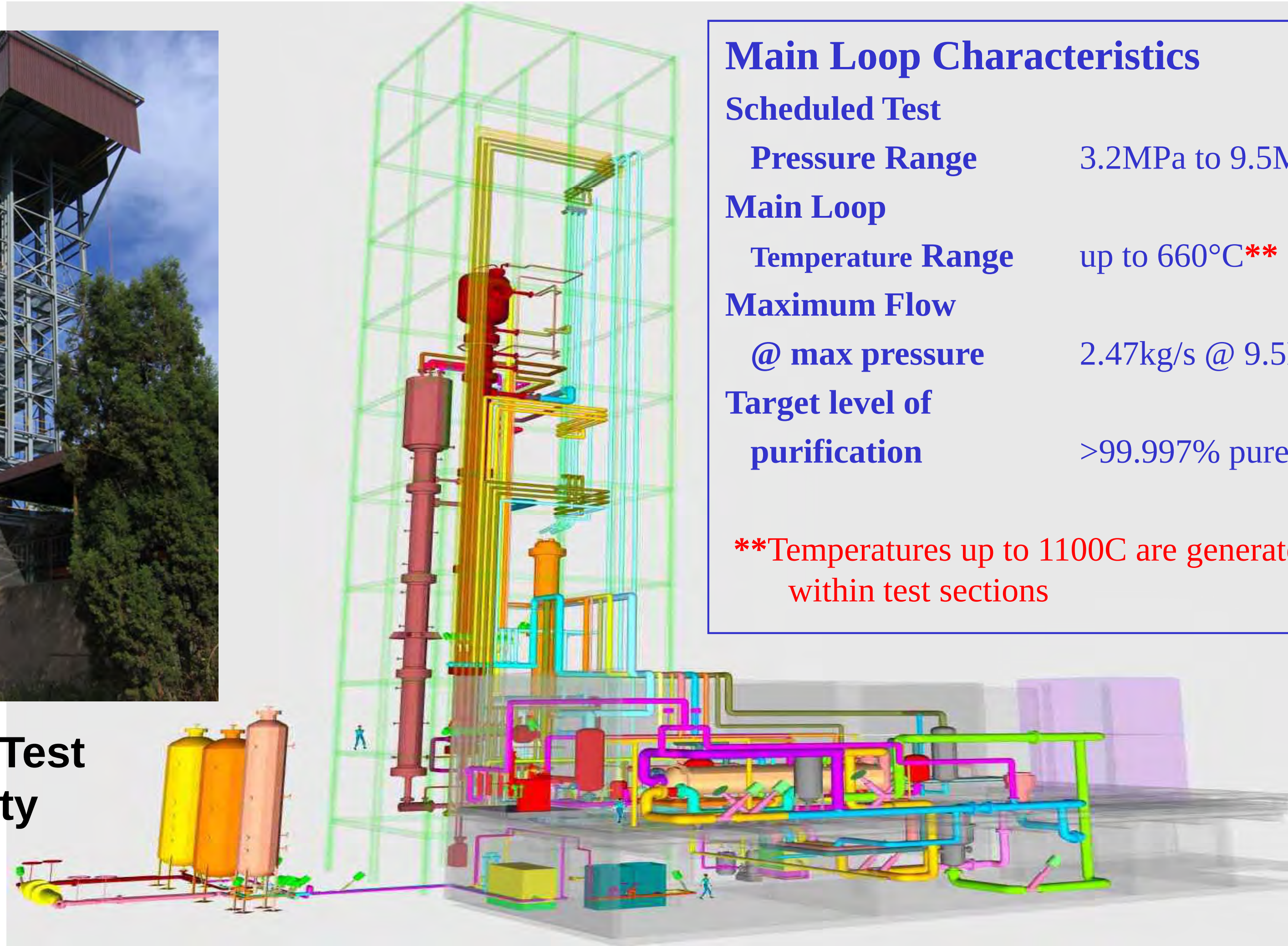
Helium Test Facility



Main Loop Characteristics

Scheduled Test Pressure Range	3.2MPa to 9.5MPa
Main Loop Temperature Range	up to 660°C**
Maximum Flow @ max pressure	2.47kg/s @ 9.5MPa
Target level of purification	>99.997% pure He

**Temperatures up to 1100C are generated within test sections

SA PBMR Reactor

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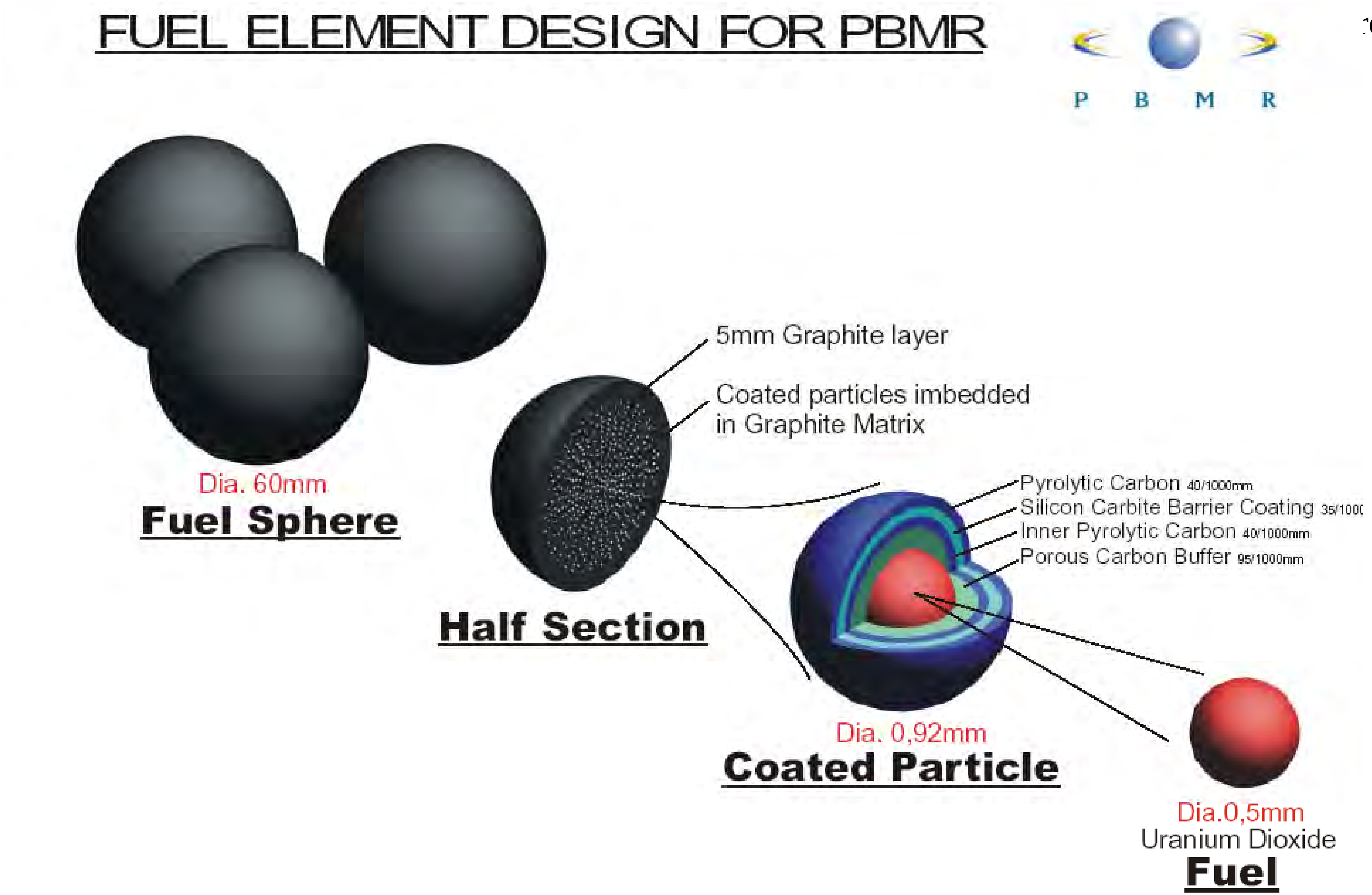
Unique feature of PBMR

Fuel elements – TRISO particle & pebble

Containment of radioactive nuclides

SA PBMR Reactor



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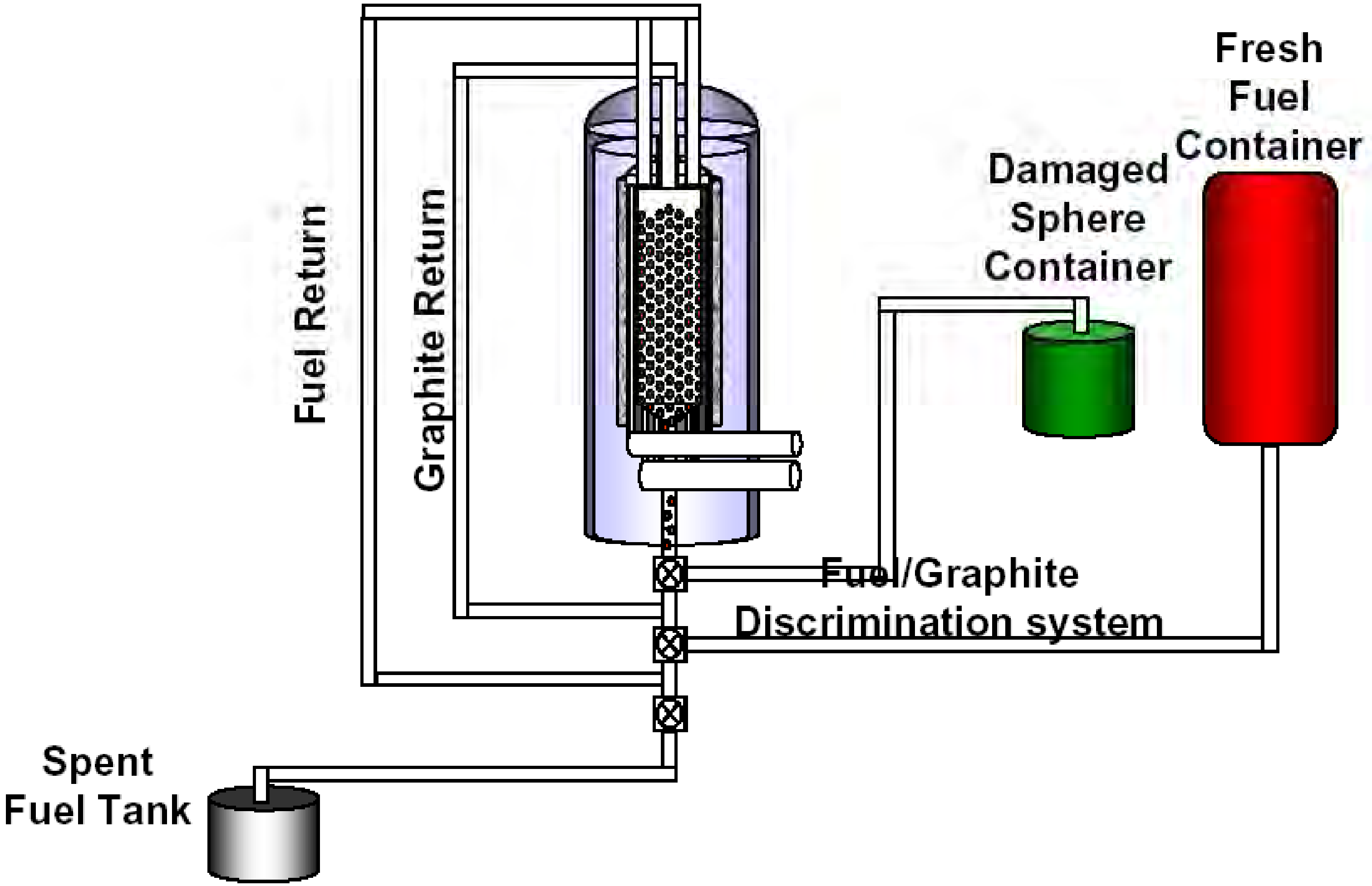
Movement of pebbles through the reactor



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Containment of radioactive nuclides

Some statistics for 110 MWe reactor

- 360,000 pebbles in core
- About 3,000 pebbles handled by FHS each day
- About 350 pebbles are discarded daily
- One pebble discharged every 30 seconds
- Average pebble cycles through core 10 times

Fuel handling is most maintenance-intensive part of plant but is handled automatically

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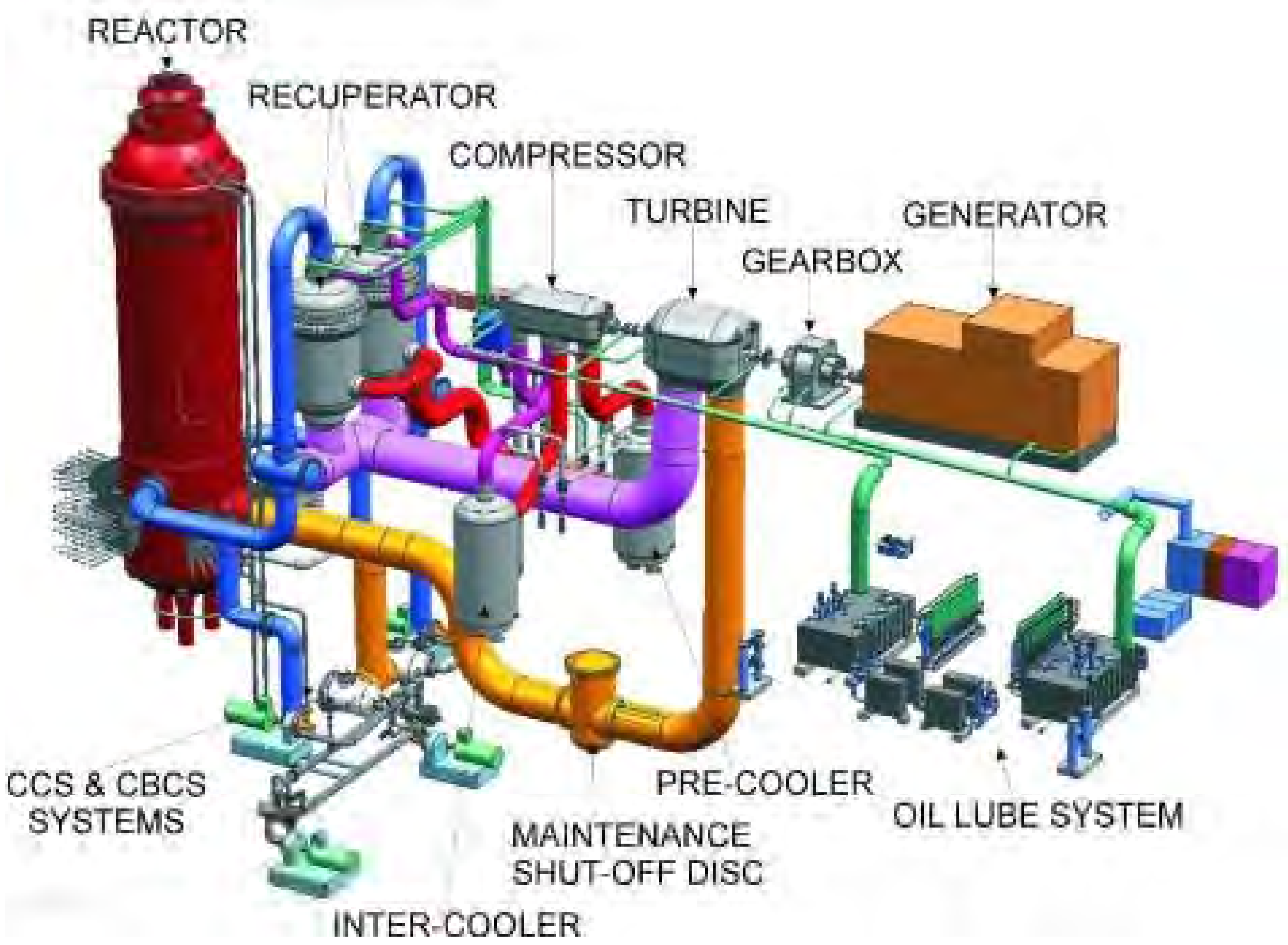
Schematic outlay



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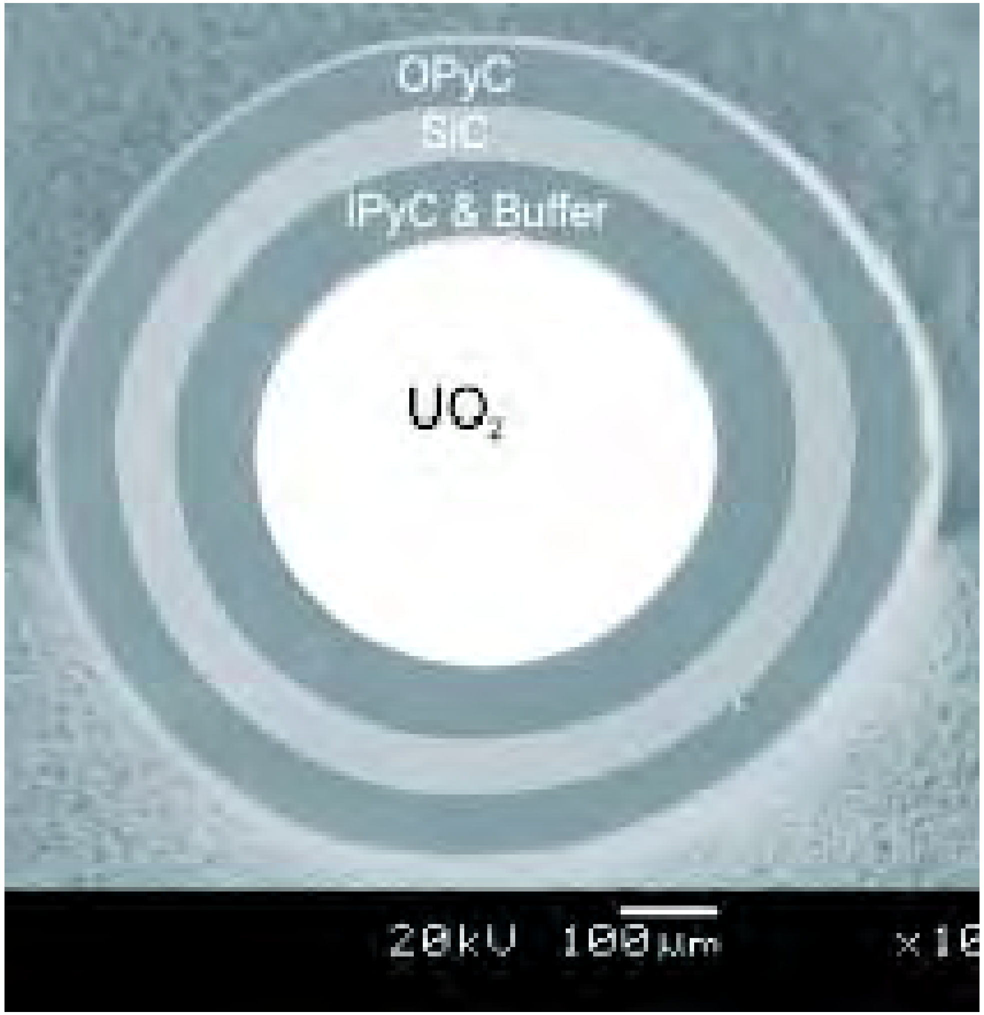
Coated fuel particle (TRISO)



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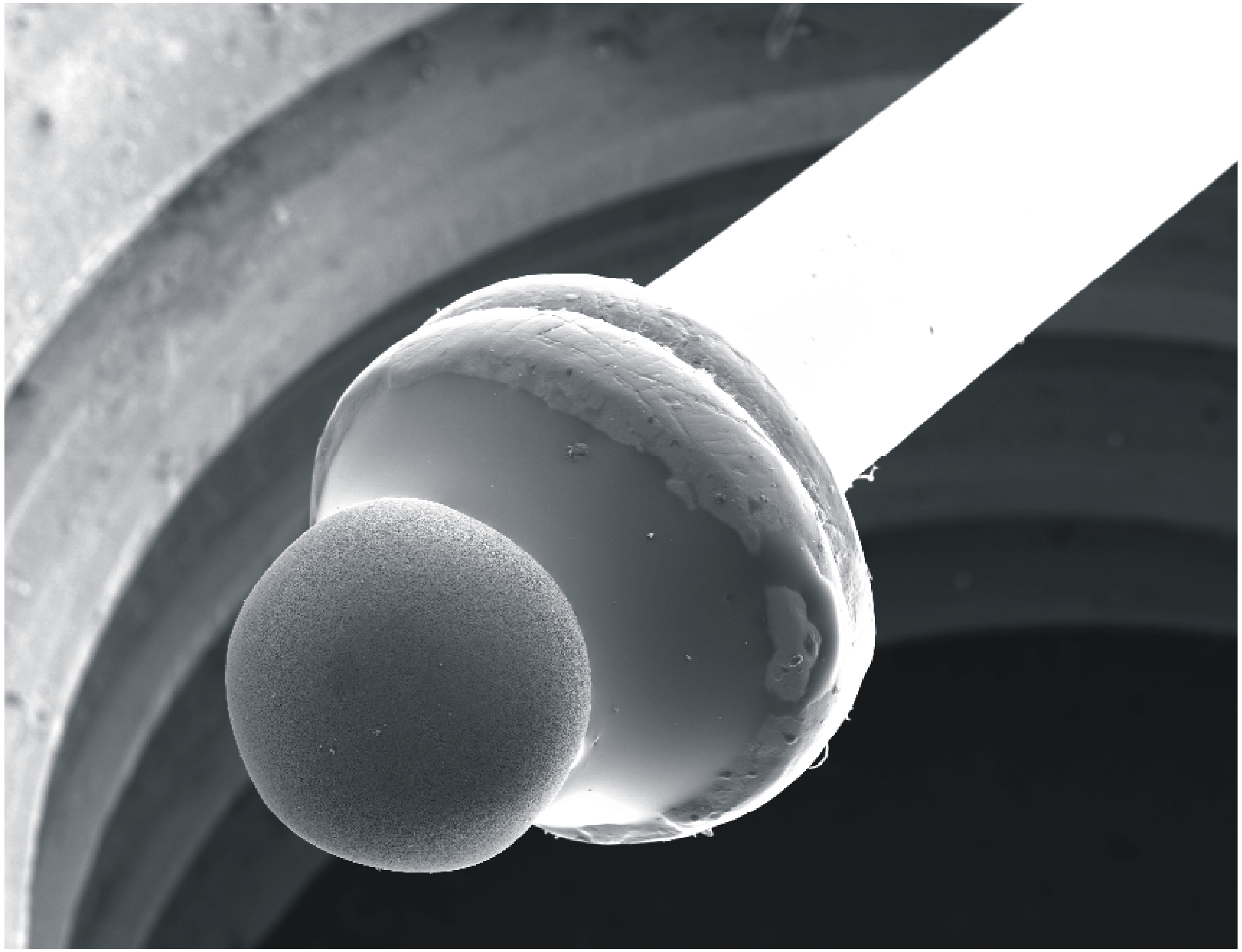
Size of the TRISO particle



SEM image of TRISO on the head of a pin

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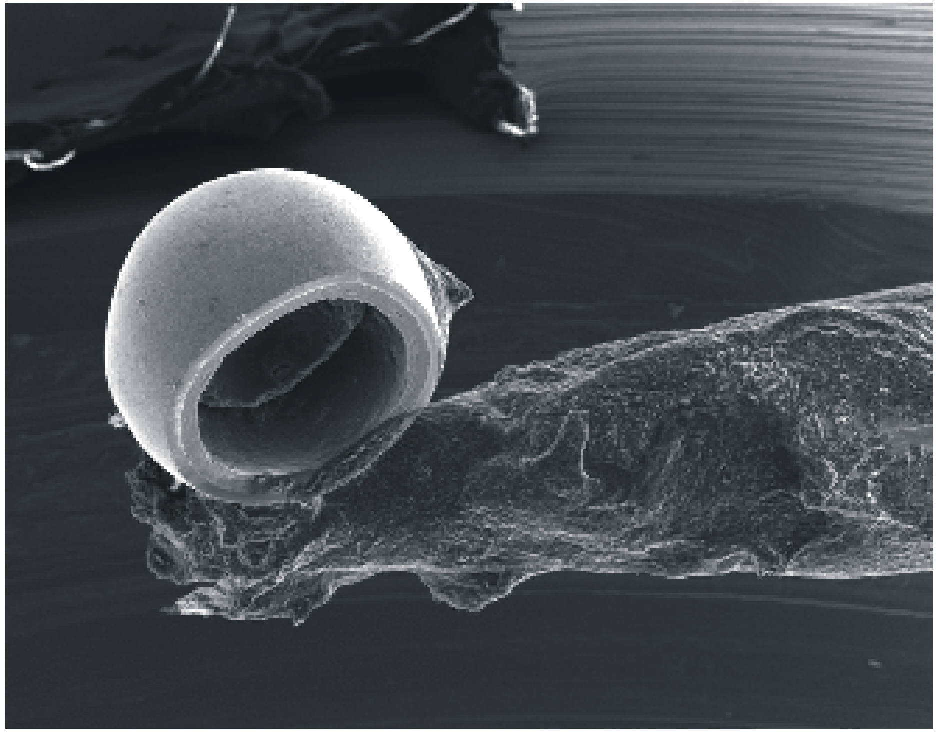
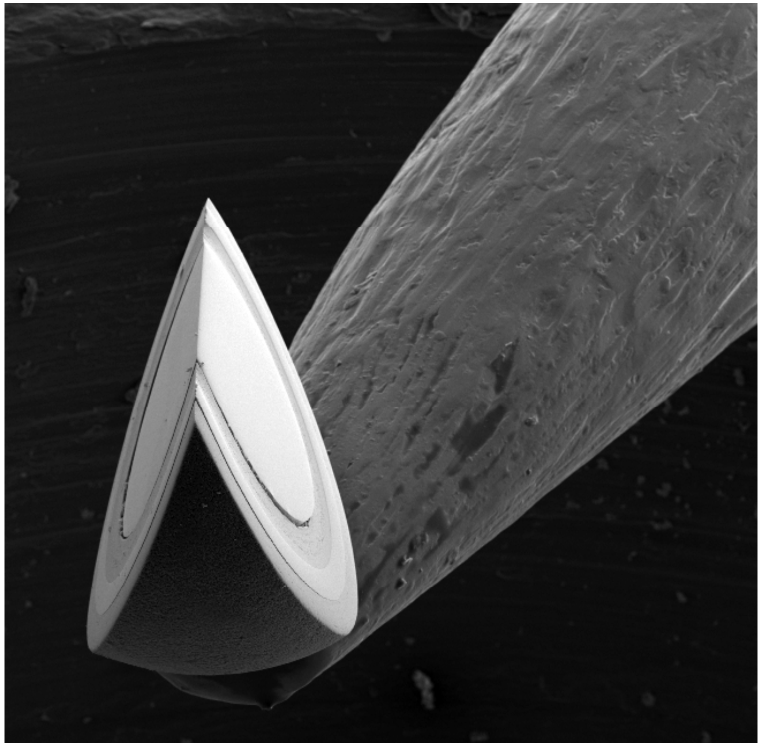
Size of the TRISO particle





Dissected particle on point of a pin. Piece of cake?

Buffer & IPyC layers

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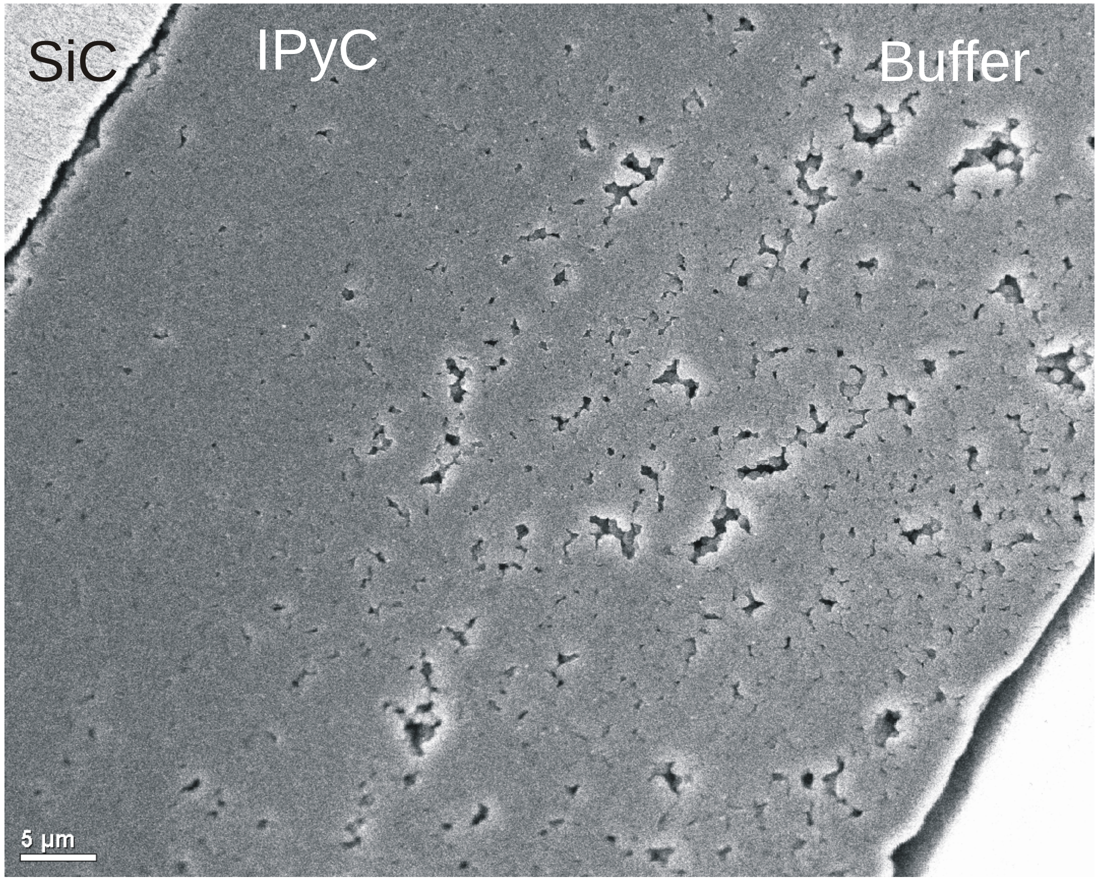
Buffer layer

- Absorber of recoil fission products
- Traps fission gases
- Absorbs thermal stresses

IPyC

- Similar to buffer layer
- Growth layer for SiC layer
- Diffusion barrier for some elements



IPyC layer

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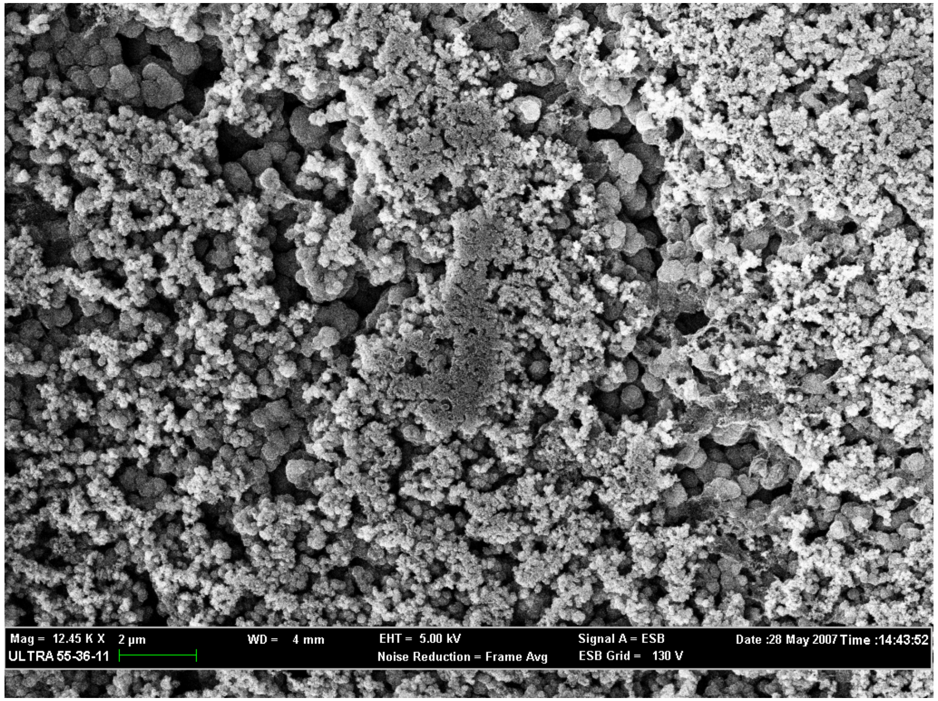

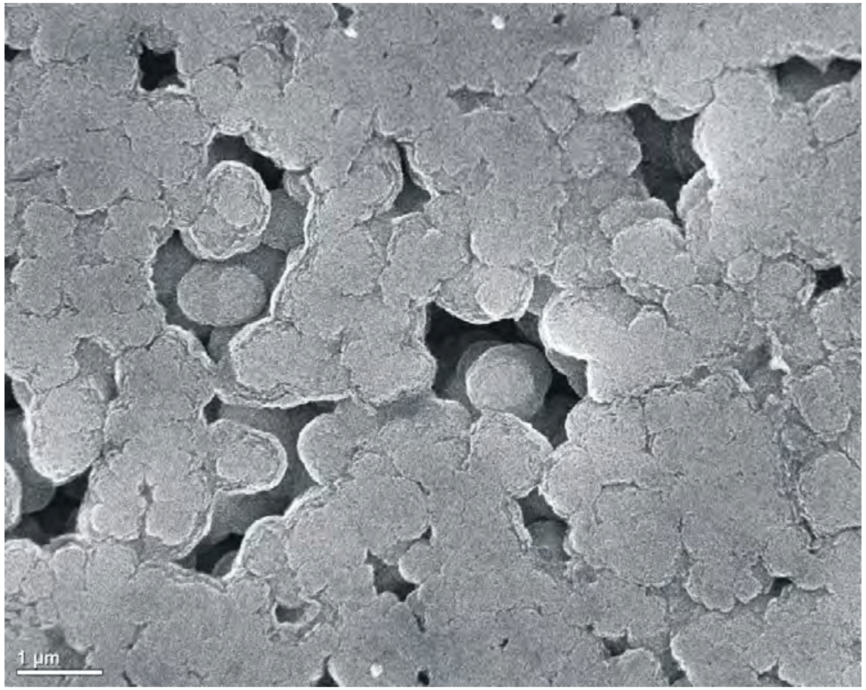

Chemically etched IPyC

Microstructure: Spheres with openings in between

Traps fission gases & Absorbs thermal stresses

IPyC layer

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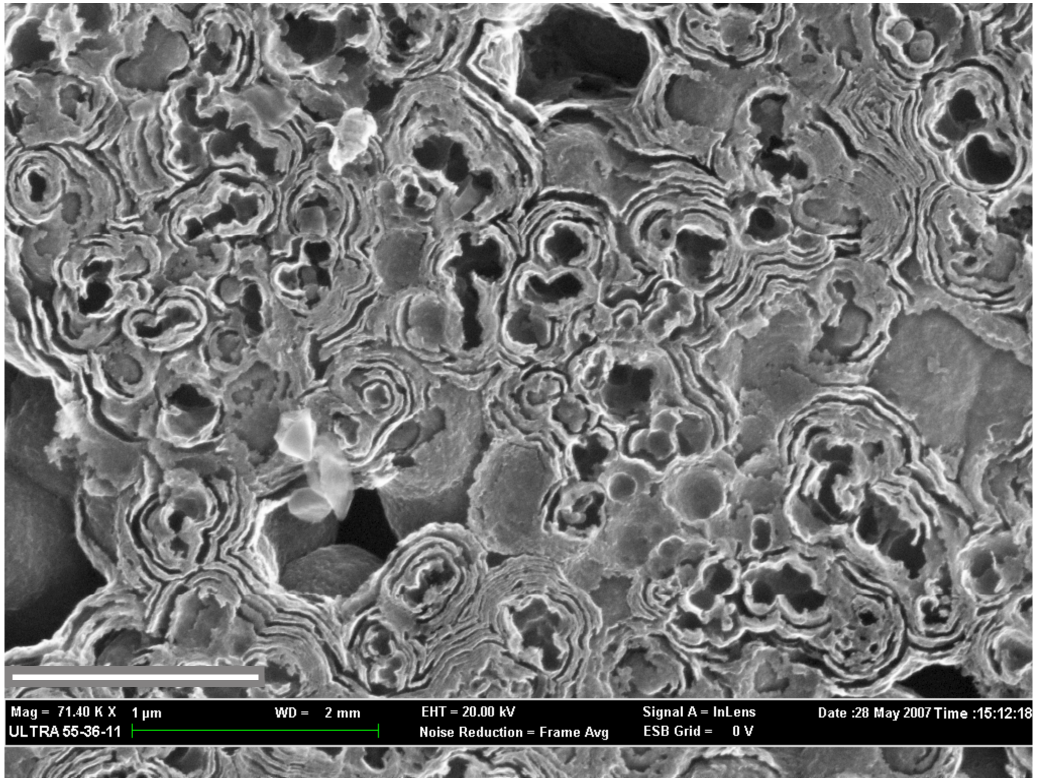

Inner microstructure: Concentric hollow “spheres”

Functions: Gas absorption & accommodation of termal expansions and contractions.

SiC layer

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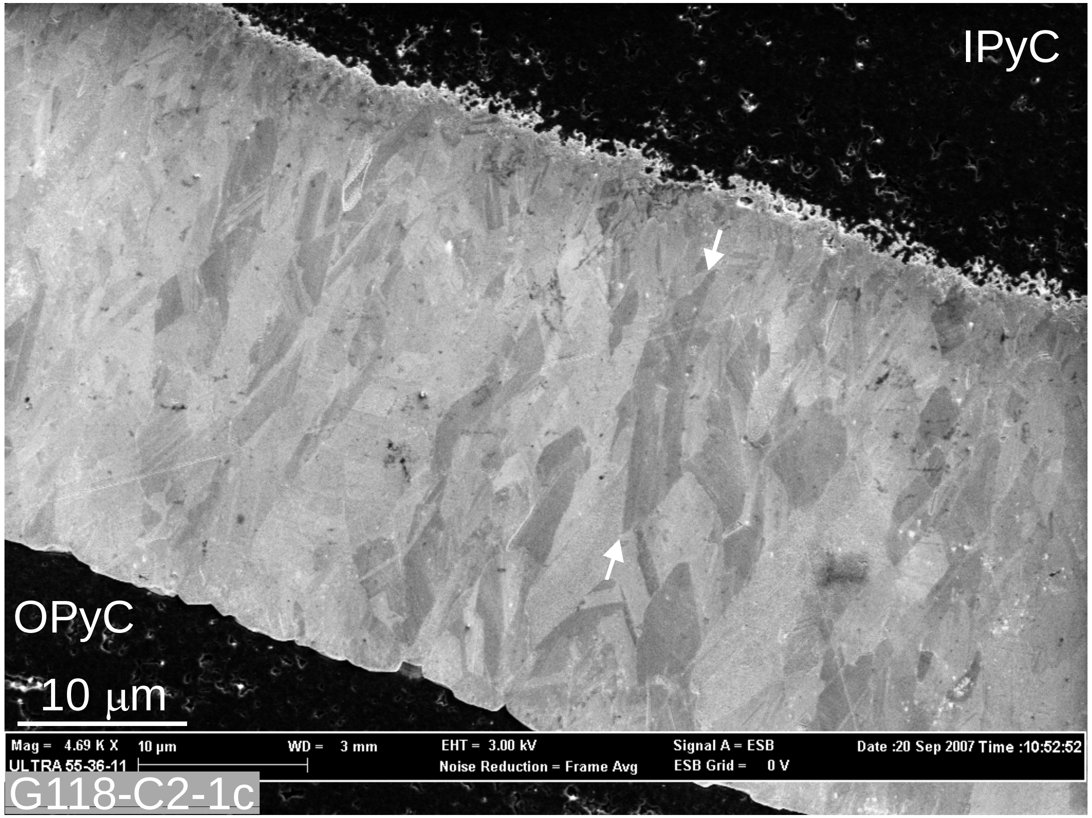

- Main diffusion barrier for fission products.
- Mechanical stren-gth and rigidty to particle

Stronger bonding between IPyC and SiC than with OPyC. SiC: facetted crystals - columnar growth (arrows).

SiC layer

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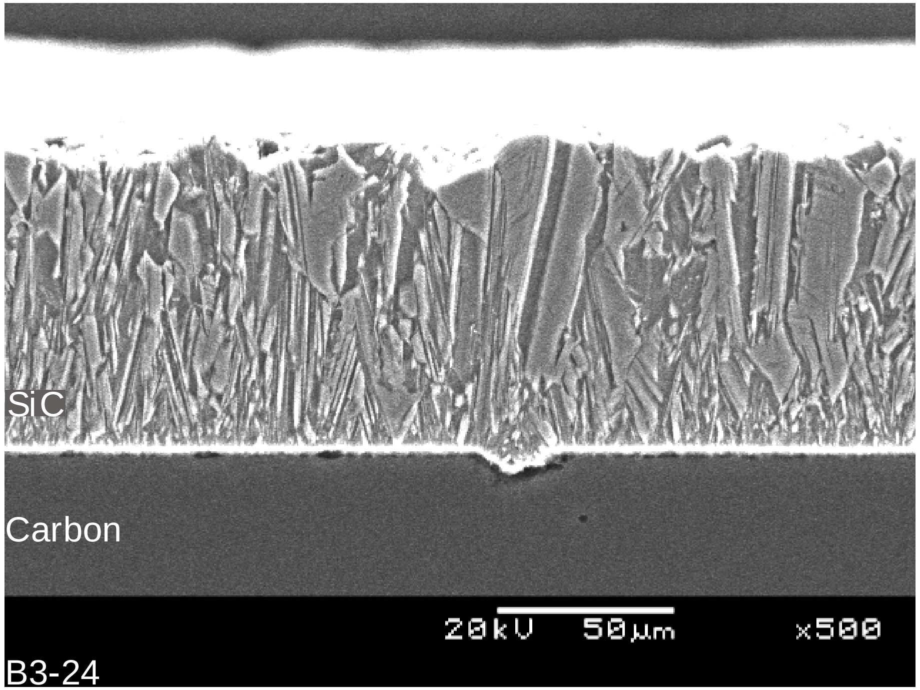

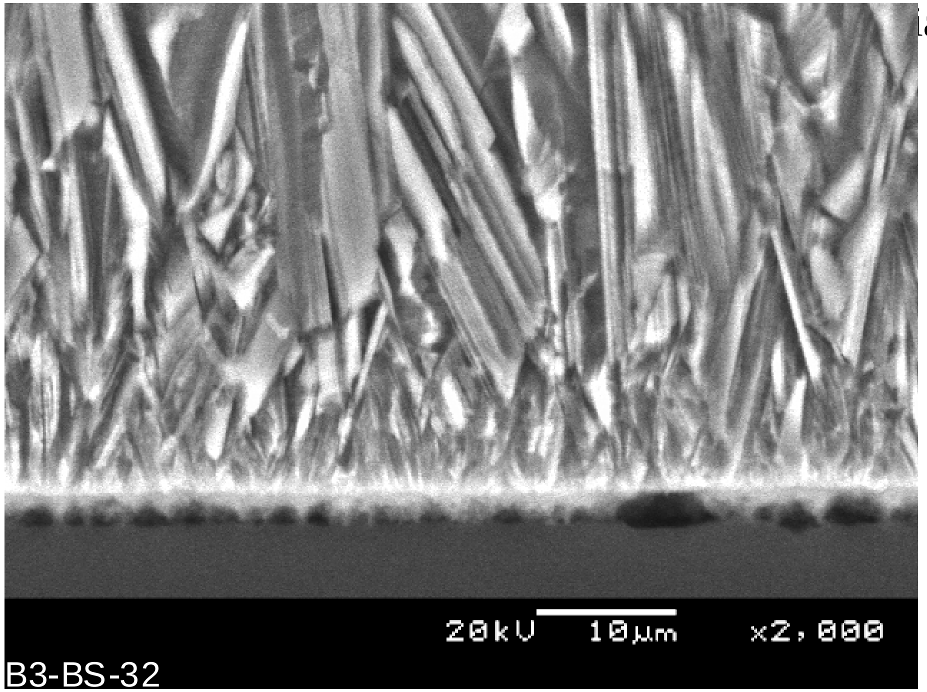

SiC layer on glassy carbon (Sigradur®) substrate. Contact layer - very small SiC crystals. Increasing thickness - larger SiC crystallites form columnar structure.

SiC layer

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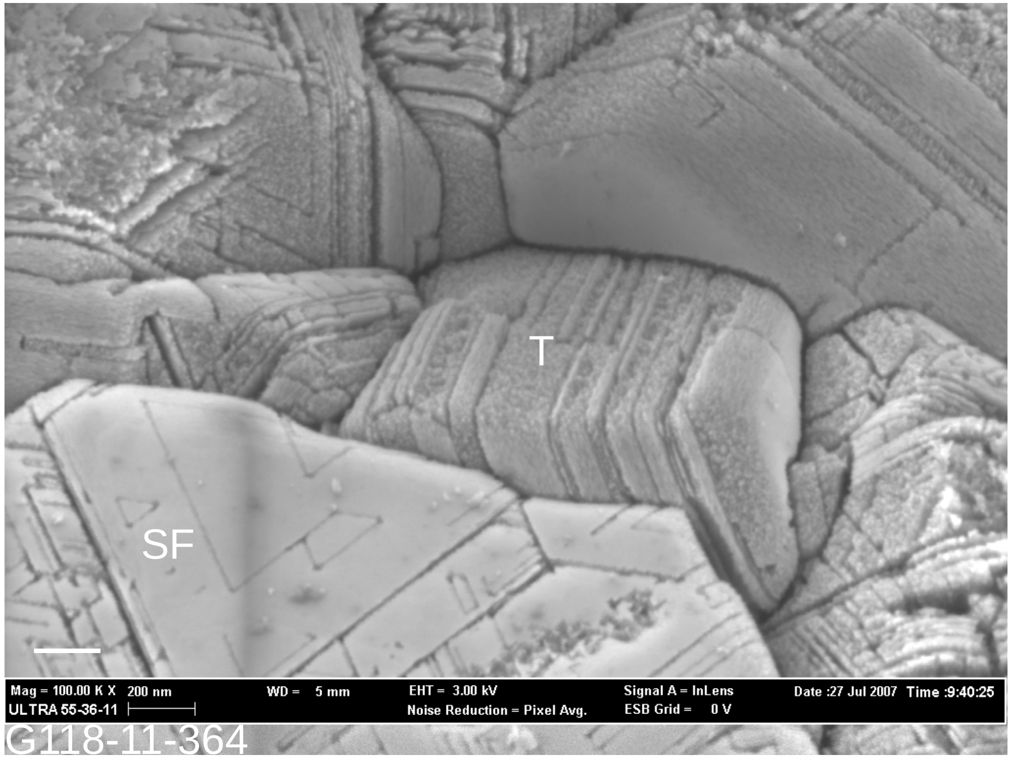

Twins T
Stacking faults SF

Defects necessary for mechanical strength.

Chemically etched SiC at SiC/OPyC interface showing substrate for epitaxial layer. Homo-epitaxy: crystal continues to grow. Epitaxy: a new poly-type. Magnification bar is 200 nm.

SiC layer

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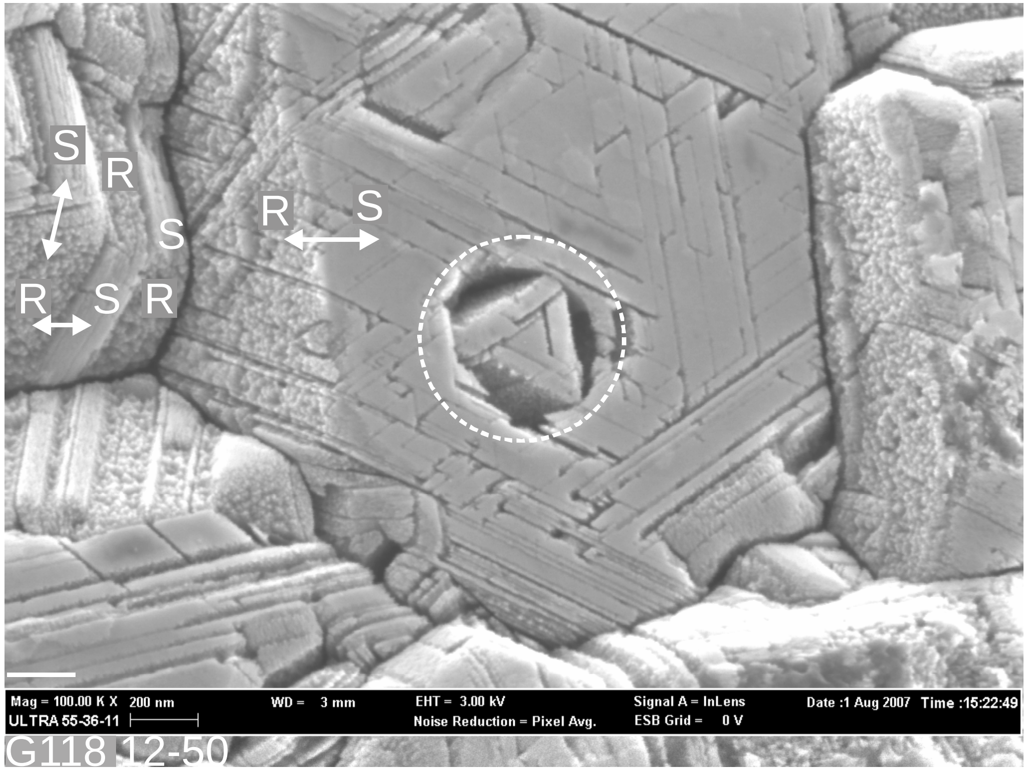

Chemically etched SiC at SiC/OPyC interface.

Circle: Uneven etching near stacking faults. Note different etching patterns: rough R and smooth S on different faces of twinned crystals - different chemical properties of the Si and C faces of SiC crystals.

SiC / IPyC interface

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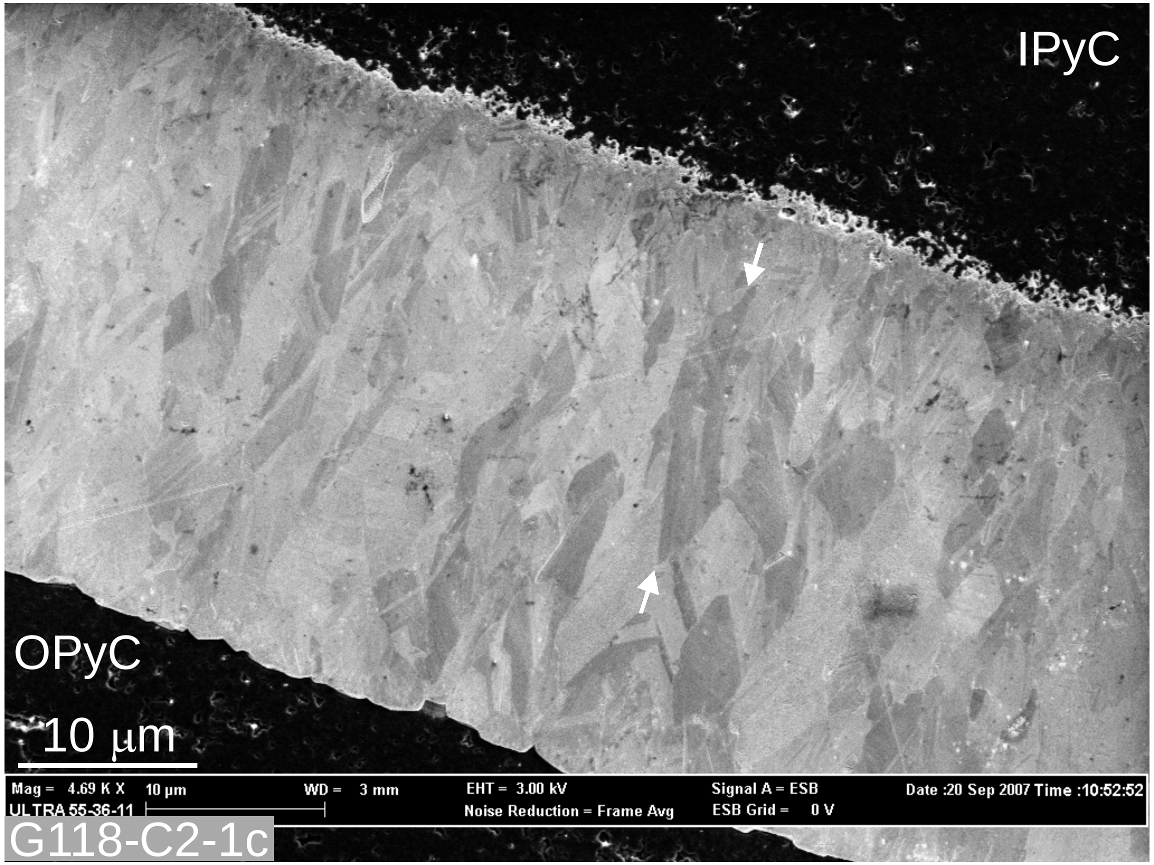

<u>Conclusion</u>

OPyC layer less strongly bonded to SiC layer

Mechanical shocks to TRISO: OPyC layer breaks loose keeping SiC layer (i.e. main diffusion barrier) intact thereby keeping radioactive fission products from escaping.

OPyC LAYER

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Main functions of OPyC layer

- Protect SiC from external gas reactions during manufacturing.
- Another barrier for gaseous fission product release.
- Provide compressive pre-stressing of SiC layer.
- Protect SiC layer during handling.

Microstructure of OPyC is similar to IPyC. Also cavities and spherical PyC.

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Functions of the layers

- Inner porous graphite

  Absorption of gaseous fission products

  Thermal expansion
- Inner pyrolytic graphite

  Absorption & growth basis for SiC layer
- SiC

  Fission product containment (diffusion barrier)

  Strength
- Outer pyrolytic graphite

  Protection

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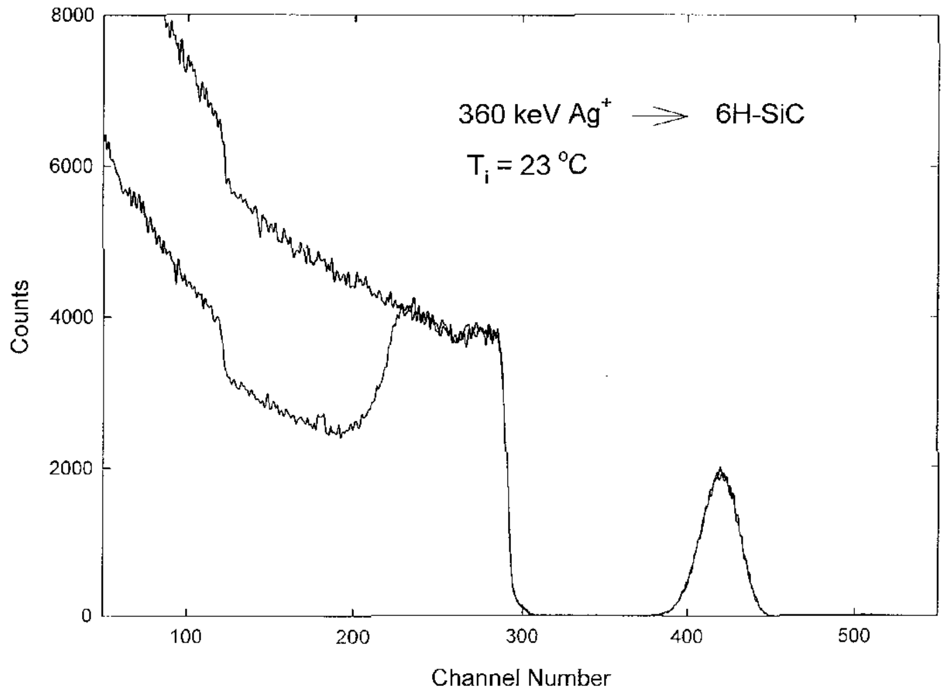
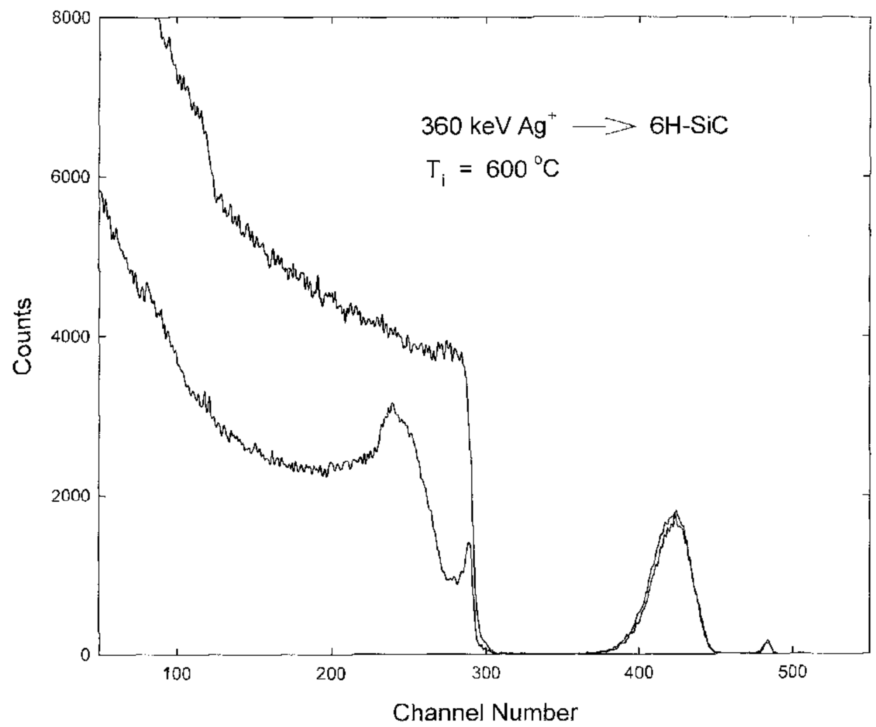
Radiation damage





Channeling: Room temperature bombardment – amorphization
600°C bombardment – no radiation damage

SUMMARY

Energy crisis

- Nuclear power plants are coming back into fashion.
- Generation IV nuclear power plants: PBMR

PBMR design

- Containment of radioactive nuclides - fuel
- Safe: self-regulating

Coated fuel particles

- Carbon layers – gas containment
- SiC layer diffusion barrier for metals

Africa’s Energy Consumption

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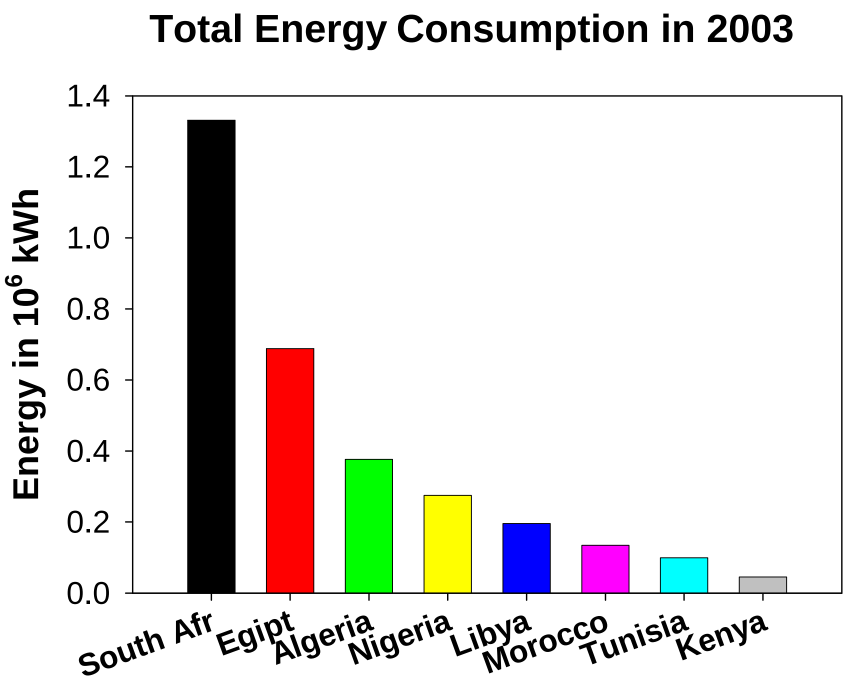

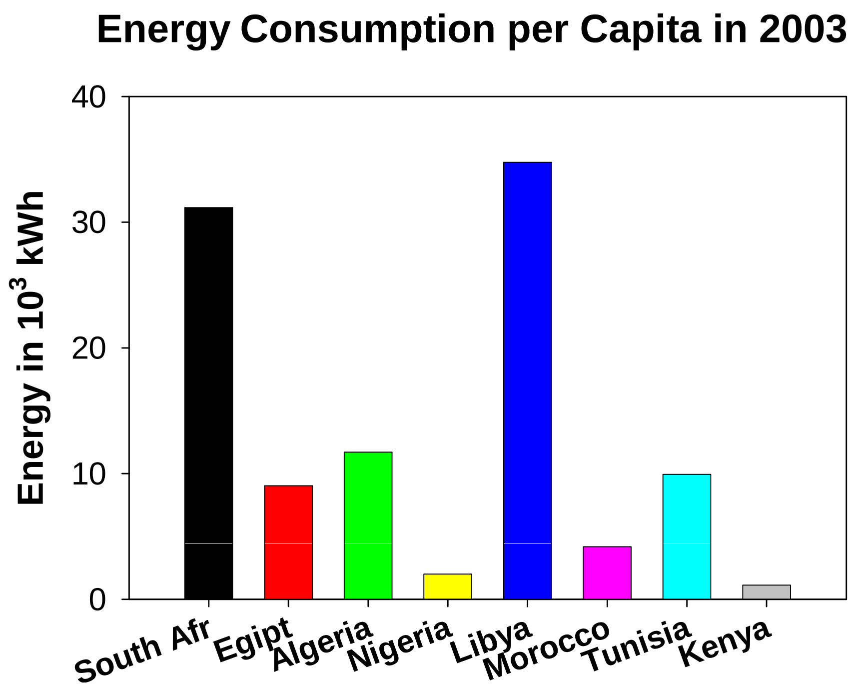

Energy crisis in fossil fuels

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Table1: *2003 World & USA proven fossil fuel reserves profitably recoverable with current technology.*

Resource	**World Reserves**	**USA Reserves**	**Lifetime***
	10^{15} kWh	**10^{15} kWh**	**Years**
Oil	2.050982	0.03516	10
Gas	1.582186	0.055669	9
Coal	7.910929	2.050982	250
Oil Sands	0.439496	0.03516	8

*Lifetime: USA reserves/USA 2003 production rate.

Energy crisis in fossil fuels

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Conclusions from Table

- ❖ Limited lifetime for world's fossil fuel. (Profitability)
- ❖ Enhanced by increasing affluency of countries.
- ❖ Coal not a medium term solution:
  - # Kyoto Protocol
  - # Radioactivity
  - # SO_2 – acid rain

Renewable energy option

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Table 2. *Renewable energies and applications*.

Type	**Application**
Solar energy	Thermal: Heating and cooling buildings, Domestic hot water, swimming pools, solar furnaces.
	Electricity: Photovoltaics
Wind energy	Electricity: Wind turbines
	Mechanical: Water pumping, grinding

Renewable energy option

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Table 2. (*Continued)*

Type	**Application**
Hydro energy	Electricity: Turbines
	Mechanical: Water wheels
Biomass	Heat: Direct combustion
	Electricity
	Fuels: gas, liquids
Geothermal energy	Electricity via turbines
	Heat: central heating.

Renewable energy option

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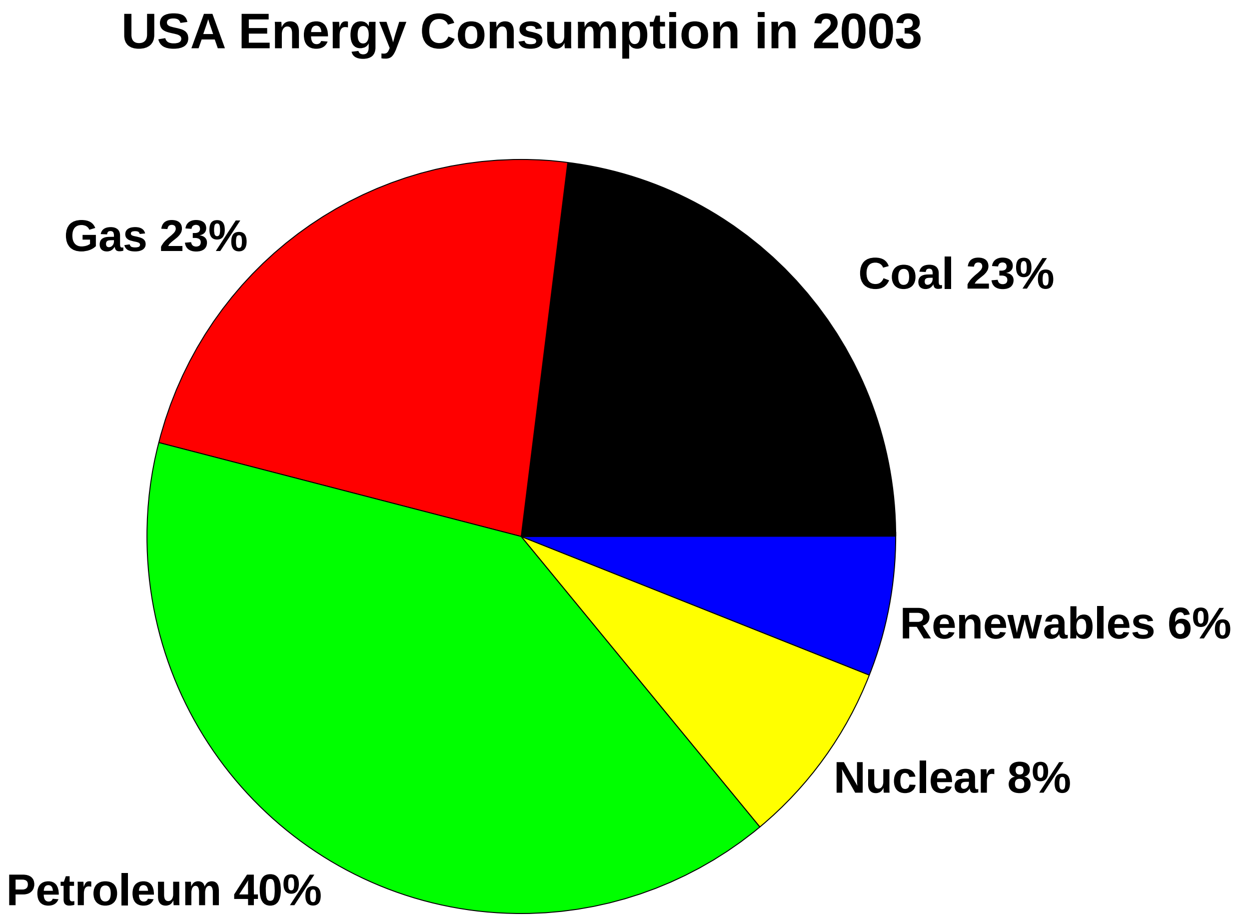

Renewable energy option

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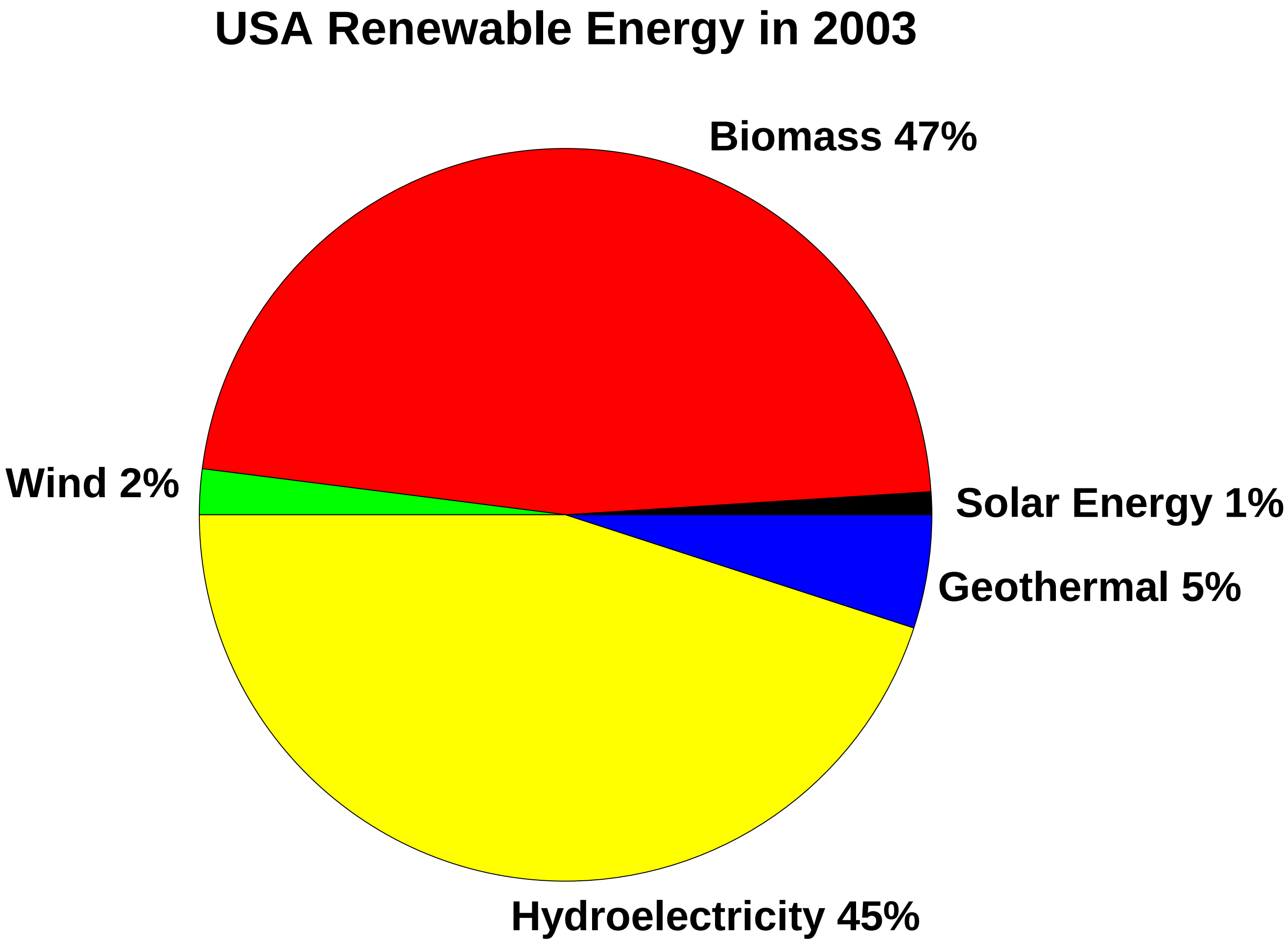

THE PBMR NUCLEAR POWER PLANT OPTION

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PBMR Solutions.