ATF Fuel – Enhanced UO_2

USA – University of Florida/Areva

Korea - Korea Atomic Energy Research Institute

China – Nuclear Fuel R&D, China General Nuclear Power Corp.

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Attributes of Additives to Enhance UO_2

- **High Thermal Conductivity**
- **High Melting Point**
- **Low Neutron Absorption Cross-section**
- **Minimal Chemical Reaction with UO_2 as a Function of Temperature**
- **Moderating Cross-section**

Potential Dopant Candidates for Higher Thermal Conductivity in UO2			
Dopant	Thermal Capture Cross Section (b)	Thermal Conductivity (W/m-K)	Melting Temperature (°C)
$_{42}$Mo	2.5	198	2896
$_{24}$Cr	2.9	939	2180
$_{4}$Be	0.01	330	2507
$_{6}$C	0.03	2200	700 (Oxd.)
			1700
$_{14}$Si	0.13	360	2730
			1370(Rx UO2)

Enhanced UO_2 Thermal Conductivity

Benefits

- **Lower Fuel Centerline (Max.) and Average Temperature**
  Lower Thermal Expansion
  Lower Swelling
  Lower Thermal Stresses
  Lower Pellet Cracking
  Lower Fission Gas Release
  Higher UO_2 Thermal conductivity (UO_2 Thermal Conductivity a Function of Temperature)
  Lower Clad Inner Surface Oxidation (Lower Clad Inner Diameter Temperature)
  Reactivity a Function of Temperature (Doppler Effect-Increased Reactivity)
  Increased Moderation (with SiC and Diamond Dopants – Increased Reactivity)

Disadvantages

- **Reduced UO_2 Loading**
  Challenges Fabricating UO_2 Composite Fuels

Additives to Improve Thermal Conductivity

1. **Silicon Carbide Powder**
1. **Silicon Carbide Whiskers**
2. **Nano Diamond**
3. **Beryllium Oxide**
4. **Carbon Nano Tubes**
5. **Molybdenum**
6. **Other**

Silicon Carbide Attributes

Positive

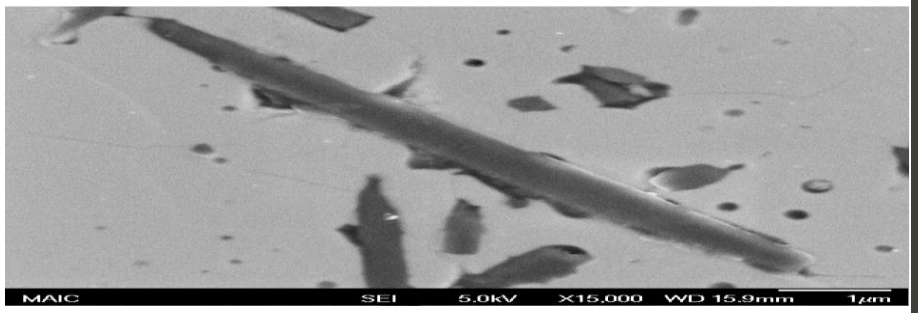
- **High Thermal Conductivity**
- **Proven Radiation Resistant – Major Gas Cooled Reactor Fuel Use**
- **Inexpensive**

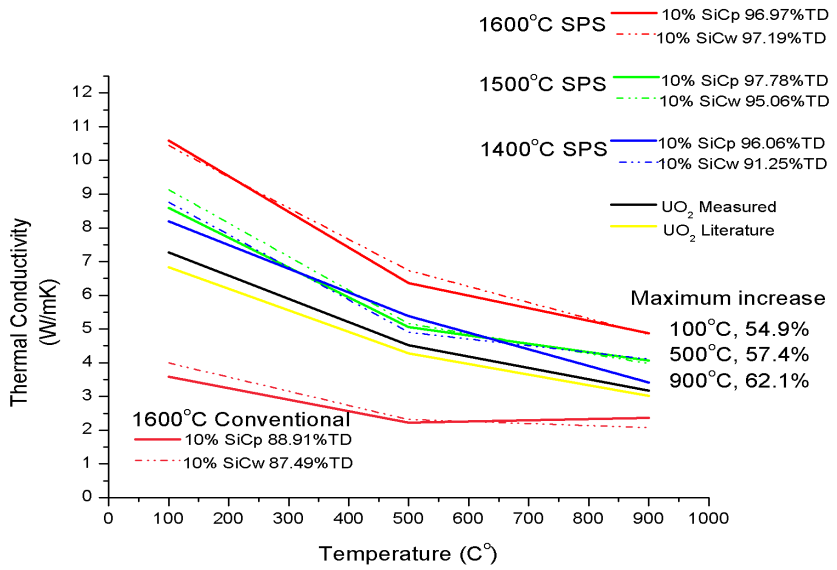
Negative

Potential Chemical Reaction with UO_2 above 1370°C

Enhanced Thermal Conductivity Silicon Carbide Composite Nuclear fuel

- 10% by Volume Silicon Carbide (SiC) Whiskers embedded in UO2 Matrix (Fig 1)
- Composite Fuel Produced by Spark Plasma Sintering - 15X15 and 17X17 - 10% SiC /UO2 pellets
- 10% SiC Whiskers/4.95% UO2 Pellets are undergoing irradiation in ATR (Feb 2014 insertion) in high power location
- First Capsule removal planned for





China UO_2 Normal Performance versus UO_2/10 w/o SiC Whiskers

Preliminary Analysis of ATF concept design by NPIC

Wenjie Li, Ping Chen, Yongjun Jiao
National Power Institute of China, China

Normal Operation – ATF1-1 - UO2/SiC Whiskers 10 w/o

Design name	Max. Pellet Temp., ° C	Margin from melting, ° C	Max.fuel average T, ° C
REF	1893	697	1112
ATF1-1	1521	1069	942

China Analysis Of 10 w/o SiC Wiskers

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Accident conditions – ATF1-1 - UO_2 SiC Whiskers 10 w/o

Design name	Pellet Center Temp., ° C	Pellet Aver. Temp., ° C	Cladding Inner Temp., ° C	Cladding Outside Temp., ° C
REF	2350.5	1704.9	982.9	954.0
ATF1-1	1575.0	1300.2	1010.4	980.0

Enhanced Thermal Conductivity Diamond Composite Nuclear Fuel-UF-USA

- 10% by Volume Diamond Particles embedded in UO2 Matrix (Fig 1)
- Composite Fuel Produced by Spark Plasma Sintering - 15X15 and 17X17 - 10% Diamond/UO2 pellets
- Major Enhanced Thermal Conductivity for Diamond embedded Fuel
- 10% Diamond/4.95% UO2 Pellets are undergoing irradiation in ATR (Feb 2014 insertion) in high power location
- First Capsule removal planned for PIE –Fall 2015

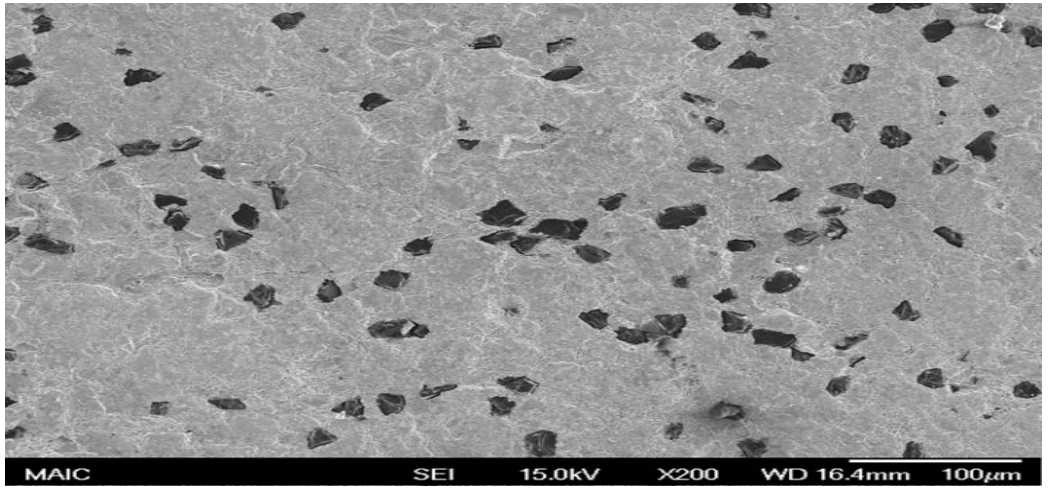


Figure 1: SEM of Sintered Diamond Pellets magnified 200x

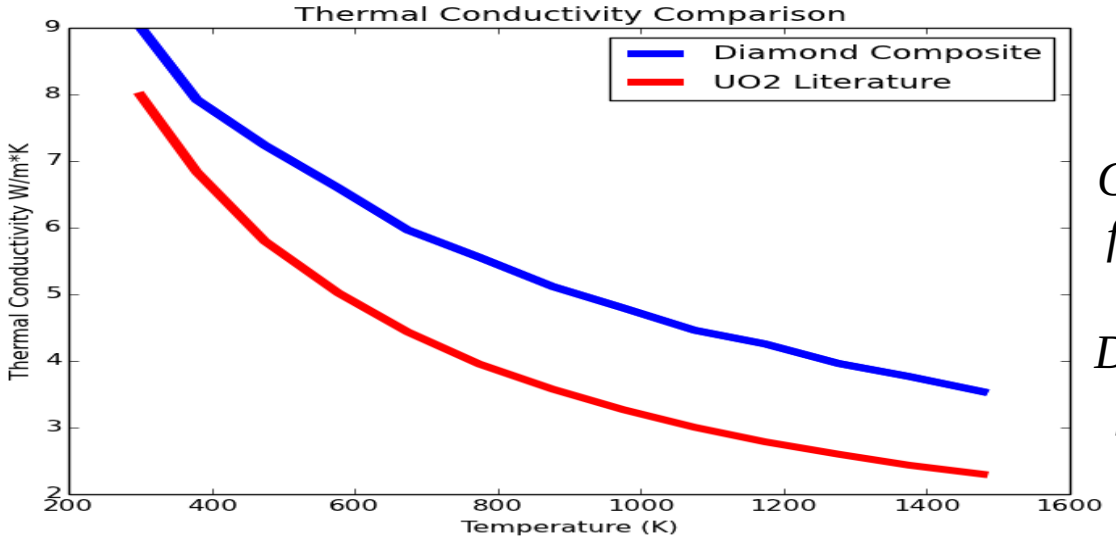
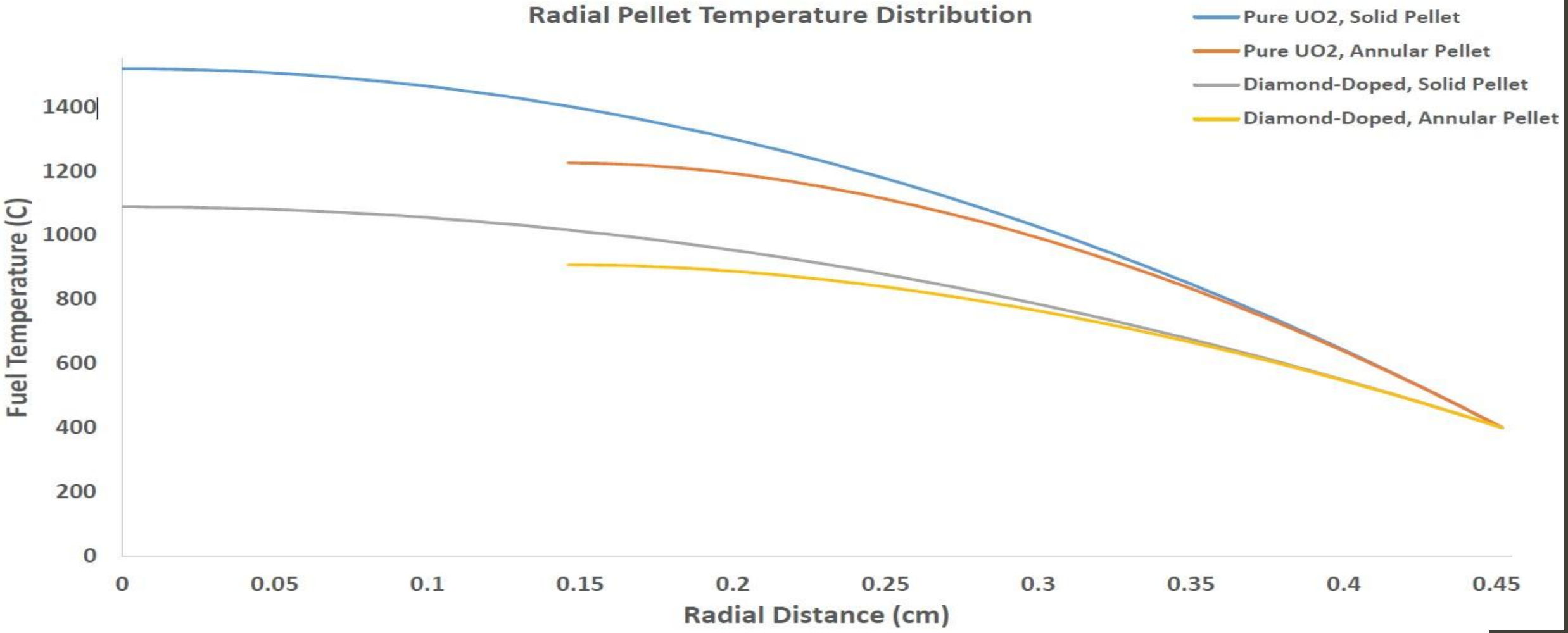


Figure 2: Thermal Conductivity for 10% VF 12 µm Diamond NP fuel pellets

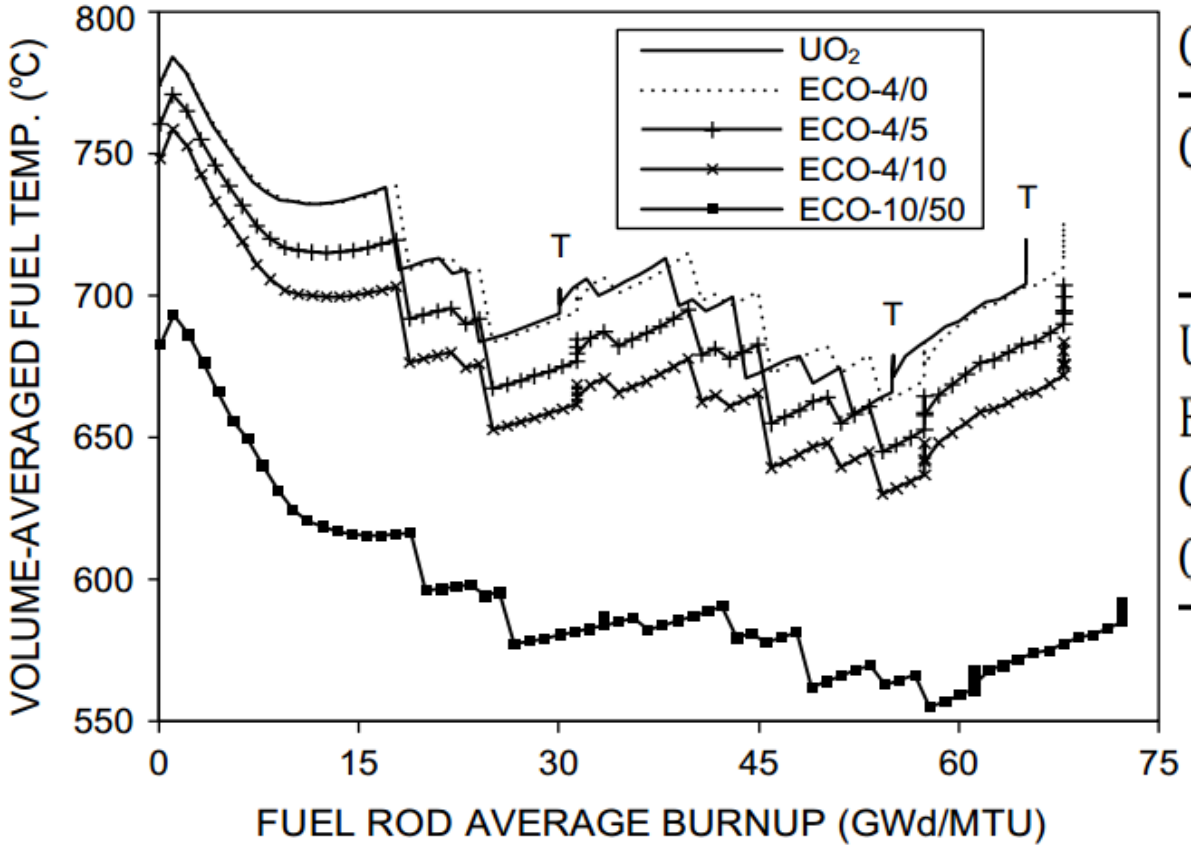
Radial Pellet Temperature Distribution for Conventional and Annular Pellet for UO_2 and diamond/ UO_2 composite



Average and Peak Temperatures for Various Fuel Designs - UF

	Solid UO_2	Annular UO_2	Solid UO_2-Diamond	Annular UO_2-Diamond
Average Temperature, °C	**959**	**864**	**744**	**685**
Peak Temperature, °C	**1519**	**1226**	**1089**	**908**

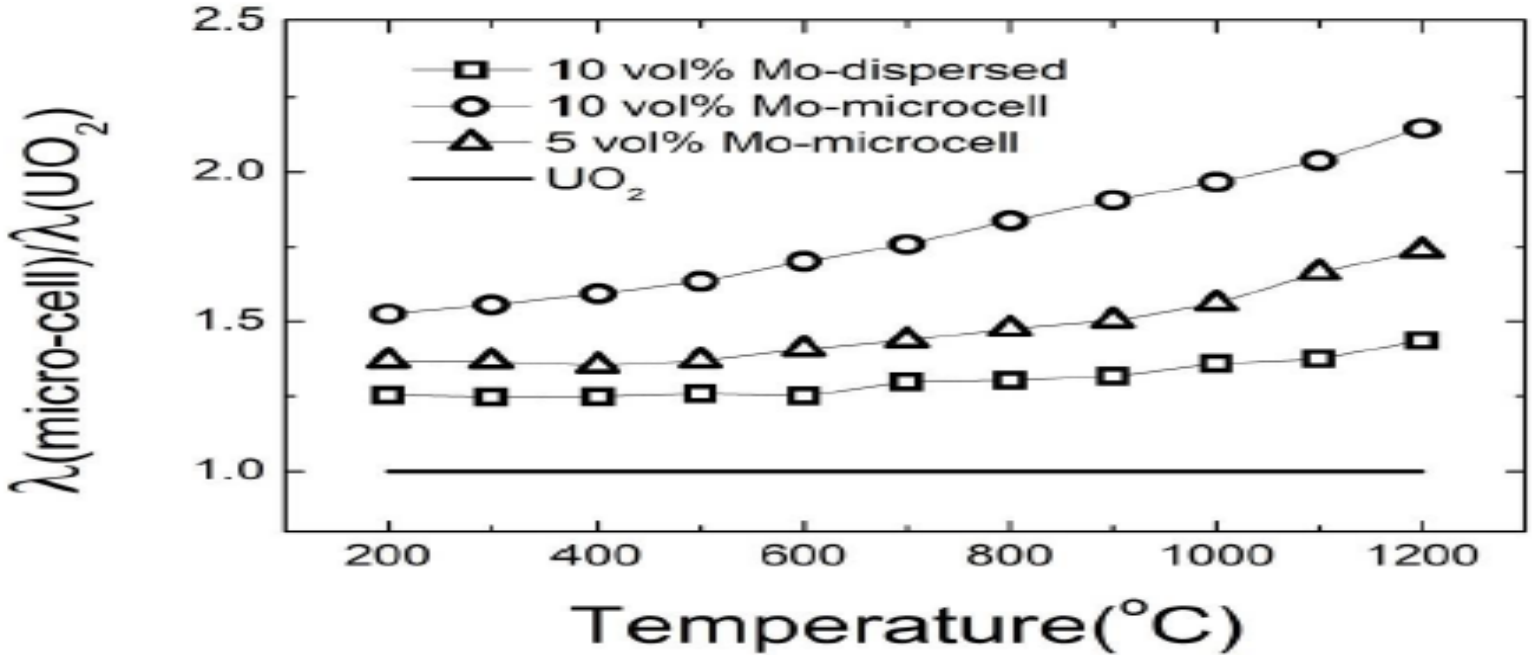
Enhanced Thermal Conductivity BeO Composite Nuclear Fuel



Compositions of fuel materials considered

Component	Fuel type		
	Standard UO_2 (%)	ECO-4/*x* (%)	ECO-10/50 (%)
UO_2	95.9	91.9	86.3
BeO	0.0	4.0	9.6
Closed porosity	4.0	4.0	4.0
Open porosity	0.1	0.1	0.1

Enhanced Thermal Conductivity Moly Powder Composite Nuclear Fuel



Thermo-physical Property of Micro-cell UO_2 Pellets and High Density Composite Pellets for Accident Tolerant Fuel

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Summary

- **There are currently major programs underway in the U.S.A., China, and Korea that are assessing the ability of UO2 enhancers to perform under hot, radioactive conditions in reactor.**
- **Preliminary results show that enhanced UO2 dopants have the potential to greatly improve nuclear safety.**
- **Hopefully, this NEA program will help to integrate the individual national programs.**

Thank you for your attention