High Density Fuels

OECD-NEA EGATFL 3:rd meeting

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Materials & product performance

Outline

- Requirements
- Metallic Uranium
- Uranium Nitrides
- Uranium Carbides
- Uranium Silicides
- Comparison of HDF:s

Requirements

- Higher uranium density
- Behaviour during normal operation similar or better than UO_2
- Behavoiur in water/steam similar or better than UO_2
- High melting point
- If Accident Tolerant Fuel concepts are not required or affected by
  - Law
  - Local codes
  - Cost penalties for non-ATF fuels

- → Any ATF concept will have to benefit the plant owner with a lower **Fuel Cycle Cost** than any alternative

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Metallic Uranium

- Pros
  - Uranium loading
  - Thermal conductivity
  - Easy reprocessing

- Cons
  - Reaction with water
  - Melting point

- Conclusion
  - Too volatile in water to be considered as ATF

Uranium Nitrides

- Pros
  - High density, and thereby Uranium loading
  - High thermal conductivity
  - Low Neutron cross section for ^{15}N
  - Known fabrication routes
  - Existing performance data
- Cons
  - Somewhat difficult fabrication
  - Sensitive to water and steam
  - Very High Neutron cross section for ^{14}N
  - ^{15}N enrichment adds complexity and cost
- Other
  - Need/opportunity for ^{15}N recovery during reprocessing

Nitrides –Impact on Fuel Cycle Cost

	UN
Front end	
U mining	Same as UO_2
Conversion	Same as UO_2
U-Enrichment	Same as UO_2
Other isotope enrichment	For the $U^{15}N$: Difficult and possibly high cost ^{15}N enrichment
Fabrication	Several possible routes, Sensitivity to Oxygen, SPS has demonstrated good pellets. Traditional pressing and sintering possible?
Fabrication Waste	More or less same as UO_2
Operation	Good behaviour likely to enhance economy
Back end	
Reprocessing	Pure UN is farily easy to convert into U_3O_8 + NH_3+H_2 by treatment in hot steam. Reprocessing of enriched ^{15}N. When mixed with fission products -TBA
Disposal	TBA

UN manufacturing and reprocessing

- Manufacturing
  - U-metal –hydriding –Nitriding – Spark Plasma Sintering (SPS)
  - Wet sol-gel route to achieve UN +sintering
  - UN:s sensitivity to oxygen and carbon requires protective atmosphere in most process steps
  - Grinding with hydrocarbon cooling (kerosene or white oil)
  - Washing before loading into cladding tubes (e.g. with $SCCO_2$, or chlorinated HC:s)
- Reprocessing farily straight forward
  - Hot steam has proven good results for pure UN
  - Recovery of ^{15}N as enriched ammonia

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Uranium Carbide

- Pros
  - High Uranium loading
  - Very high thermal conductivity
  - Low release of volatile fission products

- Cons
  - Highly reactive with water and steam, forming mainly methane and hydrygen.
  - Dissociates, forming $UC_{1.1}$ at temperatures above 2250 °C

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Carbides –Impact on Fuel Cycle Cost

	UC
Front end	
U mining	Same as UO_2
Conversion	Same as UO_2
U-Enrichment	Same as UO_2
Other isotope enrichment	No
Fabrication	UO_2 + C carbothermic reduction. Sensitivity to moisture, Self ignition has been reported.Traditional pressing and sintering possible?
Fabrication Waste	Difficulties due to the volatile nature of the UC
Operation	++ for density, -- for water sensitivity
Back end	
Reprocessing	Pure UC- Direct dissolution in HNO_3 or Oxidizing + dissolution. When mixed with fission products -TBA
Disposal	TBA

UC -Manufacturing

Shaker mixing of UO_2-C

Mill to reduce UO_2-C powder size

Form UO_2-C granules

Press UO_2-C green pellets

Argon

Carbothermic reduction of pellet to UC in furnace at 1850°C

O_2-CO-CO_2 off gas

Crush to coarse UC powder

Mill to fine UC-powder

Mix with pressing agent/lubricant

Press UC green pellets

Sinter UC pellets in furnace at 1600°C

UC Pellets

Uranium Silicide

- Pros
  - Good thermal conductivity
  - Relatively stable in water and steam

- Cons
  - Higher thermal neutron cross section than $U^{15}N$, UC and UO_2, but significantly lower than $U^{14}N$

Silicides –Impact on Fuel Cycle Cost

	U_3Si_2
Front end	
U mining	Same as UO_2
Conversion	Same as UO_2
U-Enrichment	Same as UO_2
Other isotope enrichment	No
Fabrication	Severeral possible routes, direct conversion may be an option
Fabrication Waste	More or less same as UO_2
Operation	+
Back end	
Reprocessing	TBA
Disposal	TBA

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U_3Si_2 –Manufacturing and reprocessing

- Manufacturing
  - U-metal –hydride/dehydride mixing with Si, arc-melting-pressing-sintering[2)]
  - Fairly complicated manufacturing process.
  - Grinding in water possible?

- Reprocessing
  - Dissolution in Hg catalyzed HNO_3, of both Irradiated and unirradiated fuels was demonstrated in the -80:s.

[2)] Manufacturing route developed at INL, work is ongoing

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Comparison of different High density Fuel materials

Material	Melting point, °C	Density, g/cm³	^{235}U concentration @ 5% enrichment, g/cm³	Thermal conductivity, W/mK	Calculated cross section $m^{-1} \times 10^{-6}$ Thermal, 2200 m/s
UO_2	2878	10,96	0,48	See next slide	0,093
$U^{15}N$	2600	14,31	0,67		0,0082
$U^{14}N$	2600	14,31	0,68		654
UC	2400	13,6	0,64		1,15
U_3Si_2	1665	12,2	0,56		32,6

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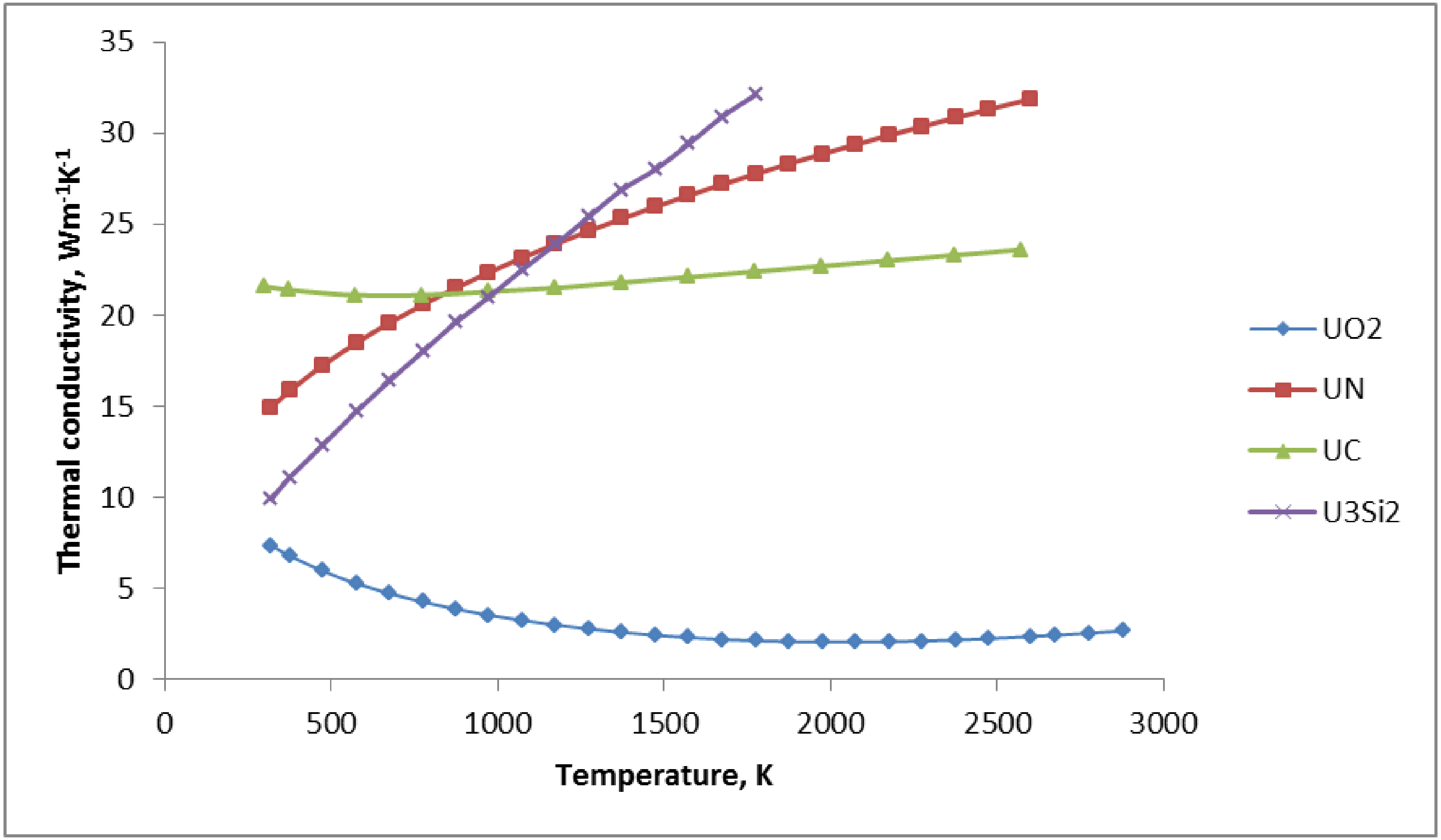
Comparison of thermal conductivity



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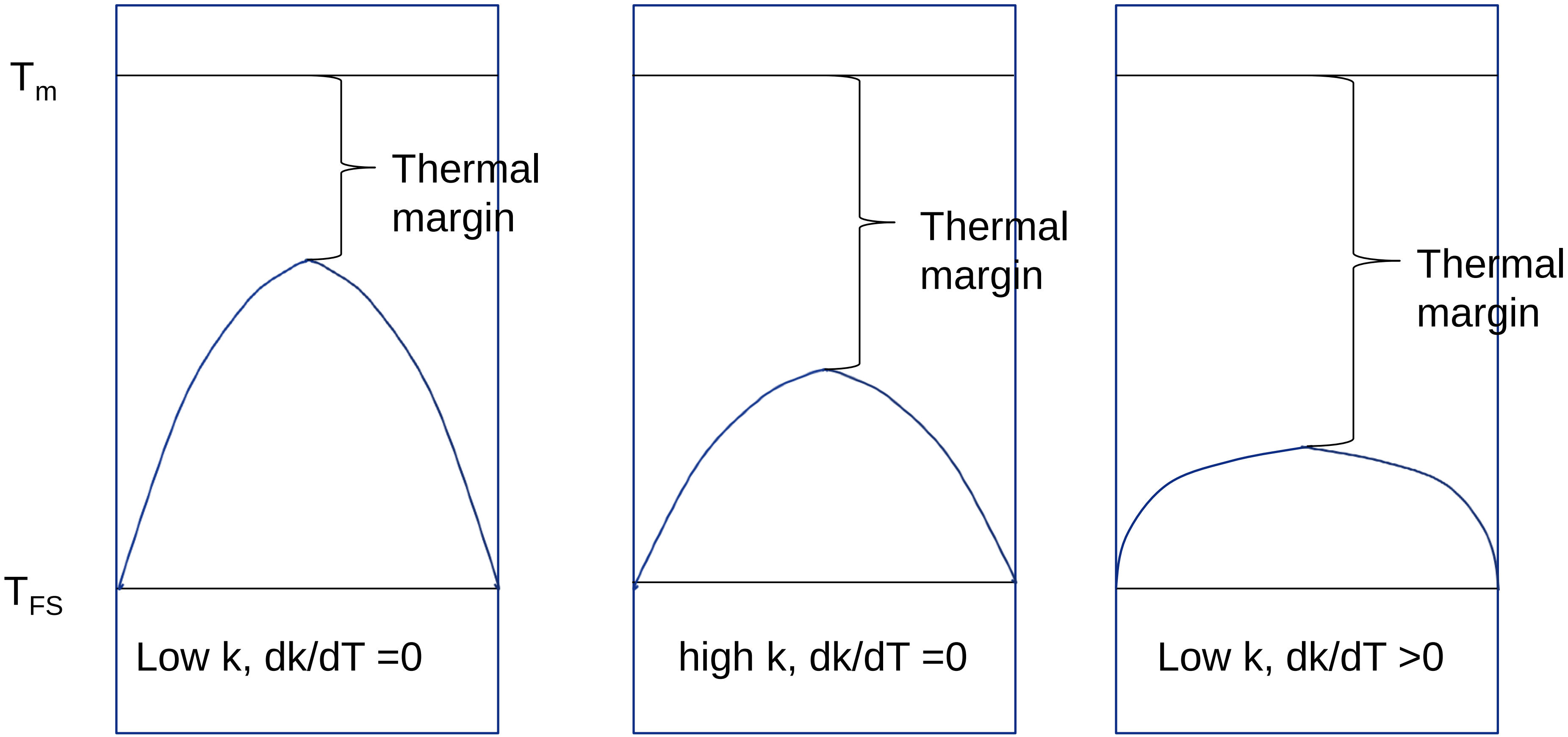
Thermal margin to melt, principle



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Conclusions

- Two leading candidates: $U^{15}N$ and U_3Si_2

- Need for common set of material data/calculations for comparison of different fuel concepts