ACHIEVING HIGH BURNUP TARGETS WITH MOX FUELS: TECHNO ECONOMIC IMPLICATIONS

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SCOPE

- Indian FBR Program- Fuel & material development and irradiation experience
- High burnup issues
- Reference Design considered in the high burnup- FBR1
- Effect of high burnup on various design parameters & economy
- Summary
- R & D requirements for meeting high burnup targets

Indian FBR Program- Fuel & material development and irradiation experience

India's FBR Program: Fuels

<table>
<tr><th>Reactor</th><th>Mwe</th><th>Fuel</th><th>LHR, W/ cm</th><th>Target/ Achieved Burnup, GWd/ t</th></tr>
<tr><td>FBTR</td><td>13</td><td>UC- 70 % PuC</td><td>400</td><td>165</td></tr>
<tr><td>PFBR</td><td>500</td><td rowspan="2">UO_2- 28 % PuO_2 (Max)</td><td>450</td><td>112 (Test irradiation)</td></tr>
<tr><td>Future FBRs</td><td>500</td><td>450</td><td>100</td></tr>
<tr><td colspan="2">Metal fuel test irradiation</td><td rowspan="2">U-xPu- 6% (Max) Zr (or) U-xPu with a liner</td><td>450</td><td>150</td></tr>
<tr><td>MFBR</td><td>1000</td><td>500</td><td>200</td></tr>
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India's FBR Program- MATERIAL DEVELOPMENT

Parameter	Stage- 1	Stage- 2	Stage- 3	Stage- 4
Year	2010	2012	2016	2020
Target Burnup, GWd/t	125	150	200	200
Core	Oxide	Oxide	Oxide	Metal
Clad & Wrapper Material	20 % CW D9 & D9I	ODS alloy for clad & Ferritic steel for wrapper	ODS alloy for clad & Ferritic steel for wrapper	T91 alloy for clad & Ferritic steel for wrapper
Linear Power, W/ cm	450	450	500	> 500
R & D	Extension of ongoing R&D	New R & D	R & D for safety	R & D for safety

Status of irradiation

- FBTR Mixed carbide has achieved 165 GWd/ t burnup
- A fuel pin failure is noticed recently at a burnup of 148 GWd/ t
- PFBR 37- pin test SA containing 29% PuO_2 has been discharged at 112 GWd/ t burnup

HIGH BURN UP ISSUES

- Advantages
  - Better economy
  - Lesser fuel SA to fabricate
  - Lesser load on Reprocessing & waste management

- Design and fuel performance
  - Pin & Core design requirements
  - Influence of various parameters like melting point, thermal conductivity of fuel, gas release, etc., on fuel performance

- Material development to meet the target burnup
  - Adequacy of present material upto 150 GWd/ t burnup
  - Materials required for higher burnup

- Requirement from spent fuel
  - Specific Activity
  - Decay heat

- Economy
  - Fuel cycle cost & unit energy cost

Indian FBR Program- Fuel & material development and irradiation experience

Reference Design Considered- FBR1

Pin rating	-	450 W/ cm
Target Burnup	-	150 GWd/ t (112 dpa)
Structural material for clad & wrapper	-	Less swelling material upto 150 GWd/ t burnup is considered
Pin Dia	-	6.6/ 5.7 mm
Core Length	-	1000 mm
Wrapper	-	131.3 mm / 3.2 mm thick
Inlet temperature	-	397 °C (670 K)

Reference core & fuel SA

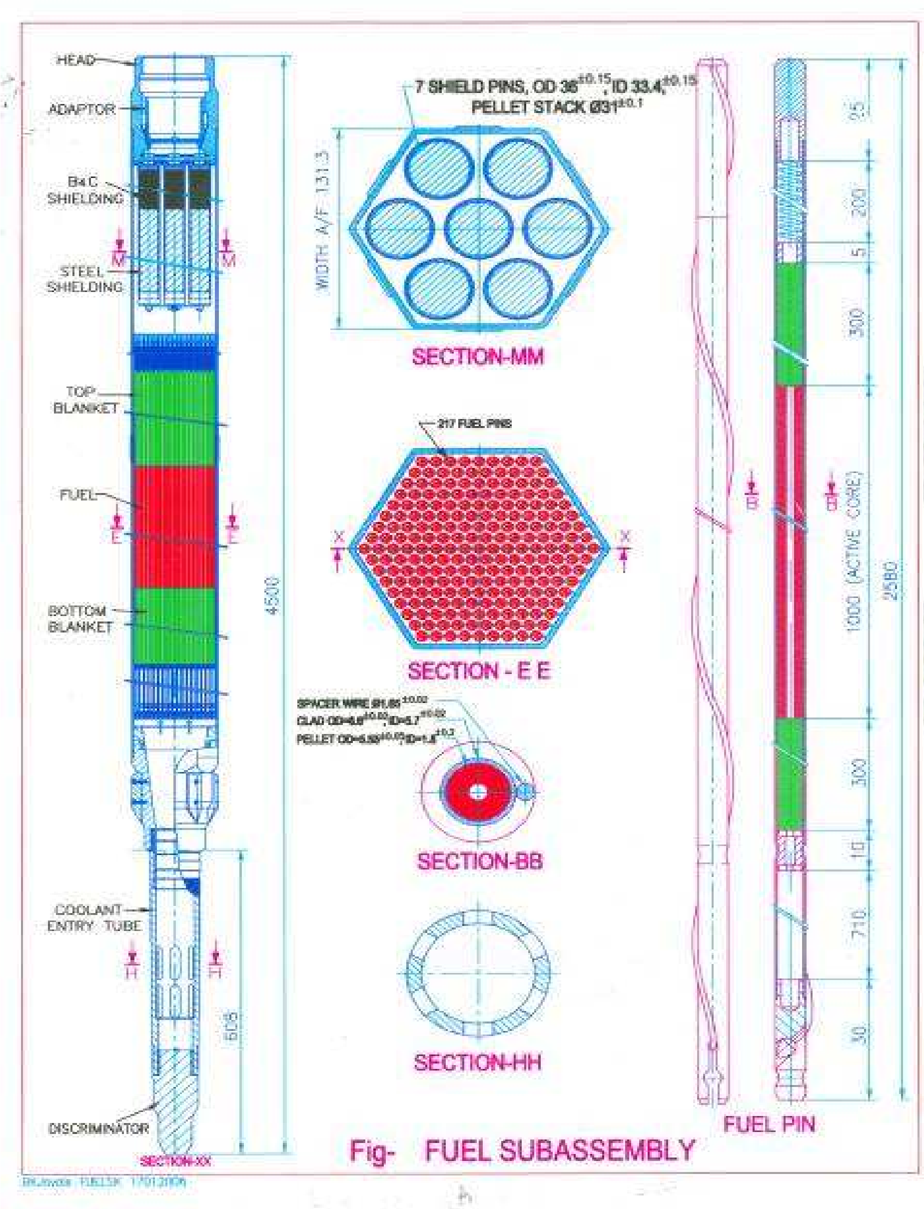
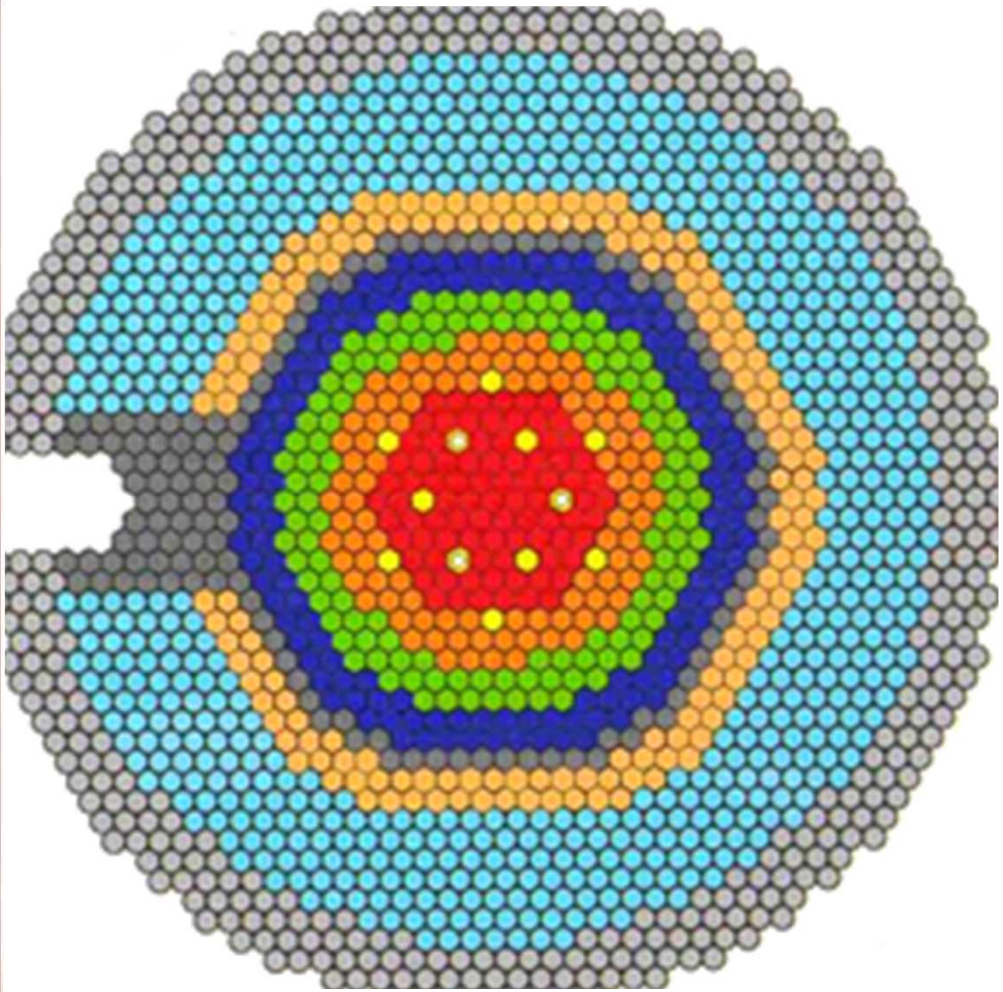


Fig- FUEL SUBASSEMBLY



CORE

Effect of high burnup on various design parameters & economy

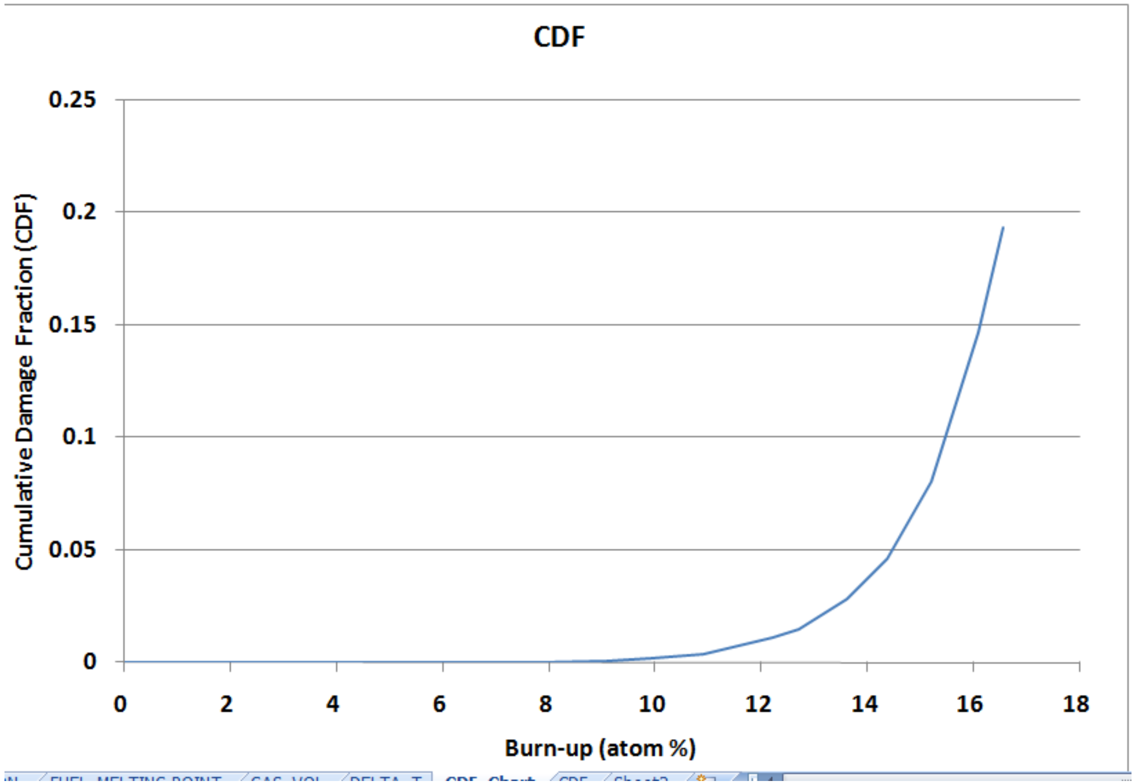
Pin Design

Clad Failure based on cumulative damage fraction ~ 0.25 for normal operation

Considers clad internal corrosion by FCCI and external corrosion by sodium

- Internal corrosion is 114 μm for 150 GWd/ t burnup
- External corrosion is 5 μm per annum

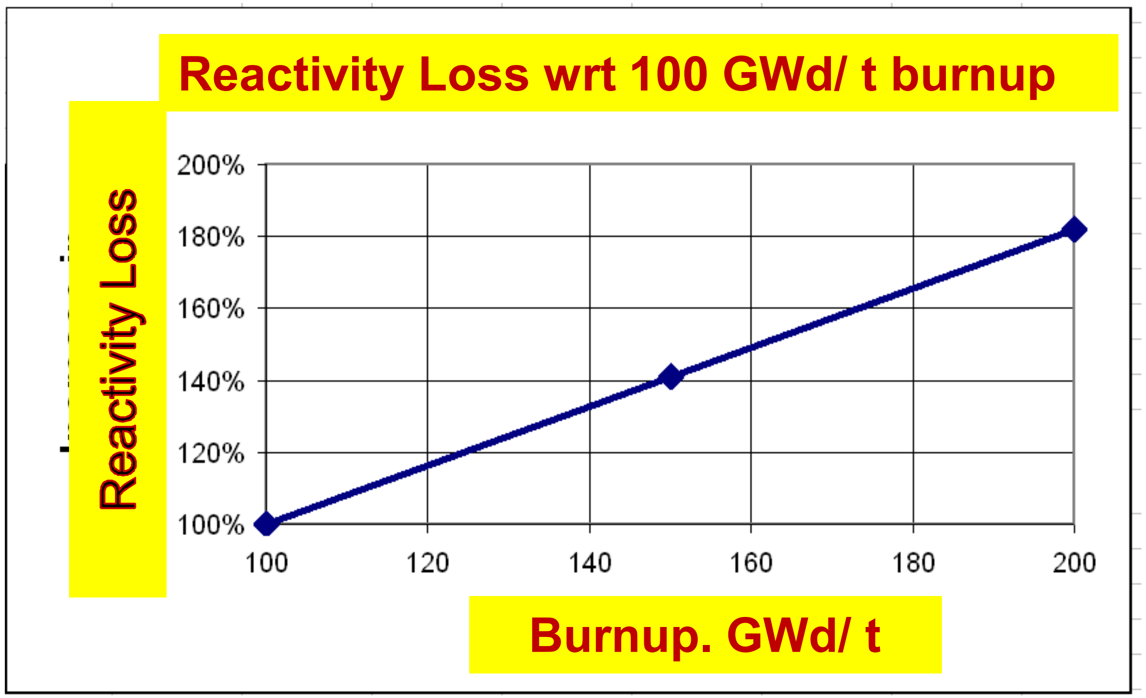
CDF= 0.19 by analysis at 150 GWd/ t



- Fuel pin dimensions like thickness, plenum volume, etc., can be modified for burnup > 150 GWd/ t for D9 class of materials.

Core Design Requirements for meeting High burnup

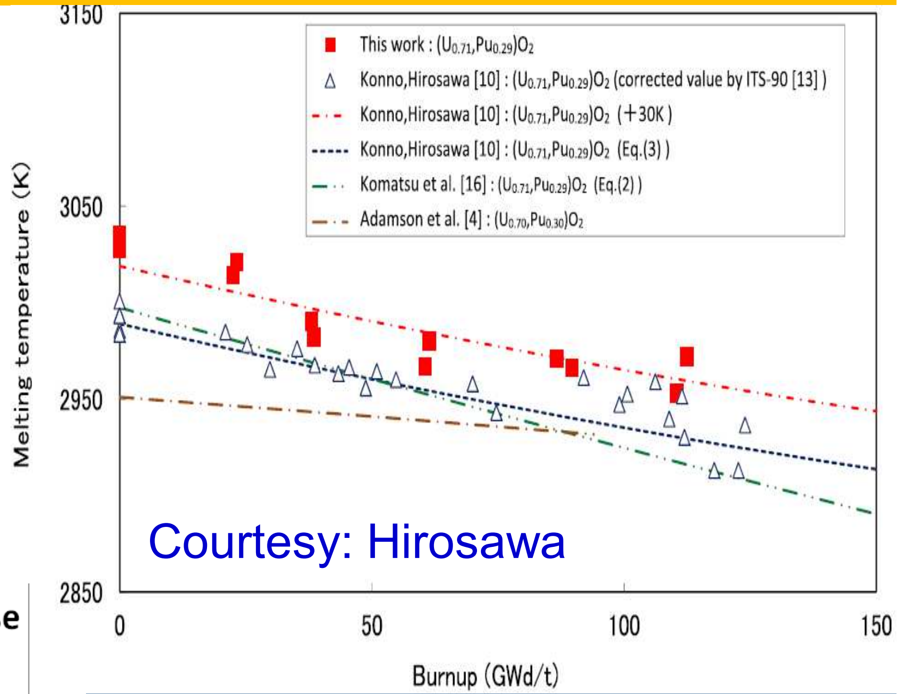
- **Core excess reactivity reduces due to increase in burnup**
  Compensation by adding 8 more Fuel SA (150 GWd/t) and 16 more Fuel SA (200 GWd/t) or increase in enrichment by 0.75%
- **Absorber Rod worth reduces - Shut Down Margin changes**
- **<u>Implications</u> - Boron enrichment of both CSR and DSR have to be increased to obtain**
  (i) SDM of 5000 pcm when all AR are available
  (ii) SDM of 1 $ during accidental situations



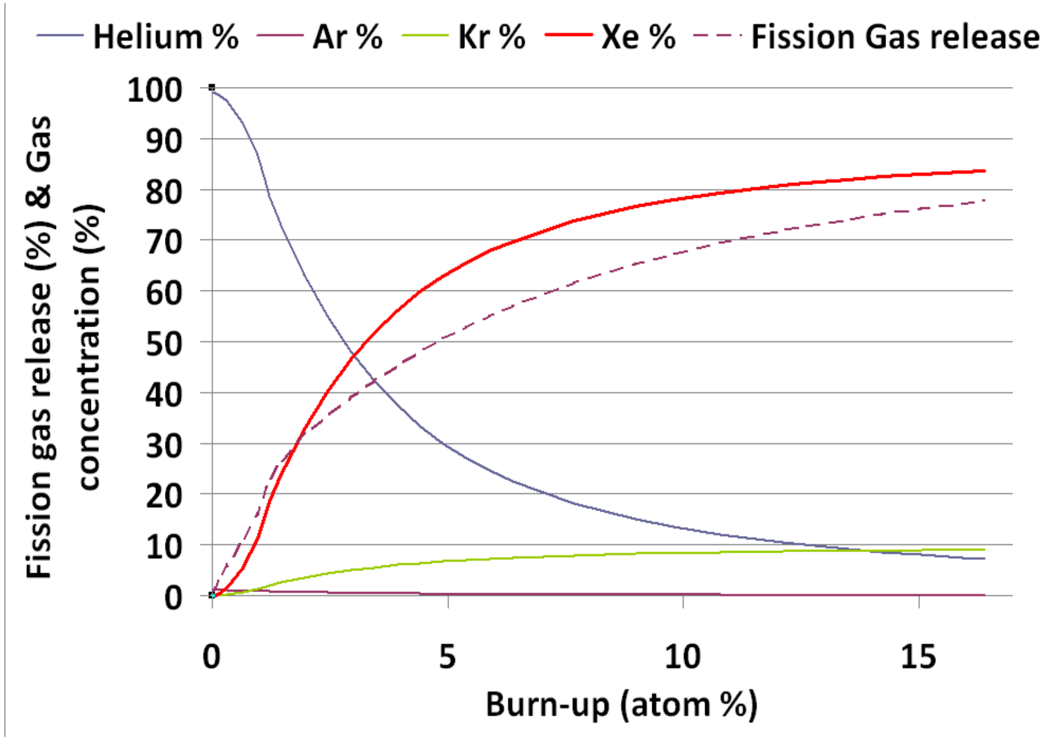
BU	Enrichment	
	CSR	DSR
100	65%	65%
150	65%	70%
200	90%	70%

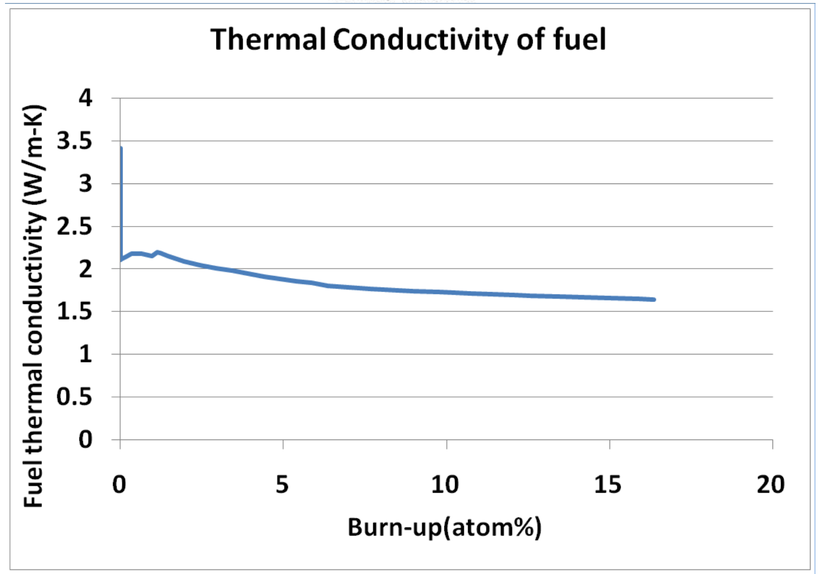
Fuel performance

- Melting Point
- Thermal conductivity of fuel
- O/ M
  - Analysis shows that O/M is equal to 2 at 150 GWd/ t burnup throughout the fuel radius. O/ M ratio influences fuel thermal conductivity, melting point and Fuel- Clad Chemical Interaction (FCCI)
- Fission gas release (~80 % at 150 GWd/t burnup)



Courtesy: Hirosawa



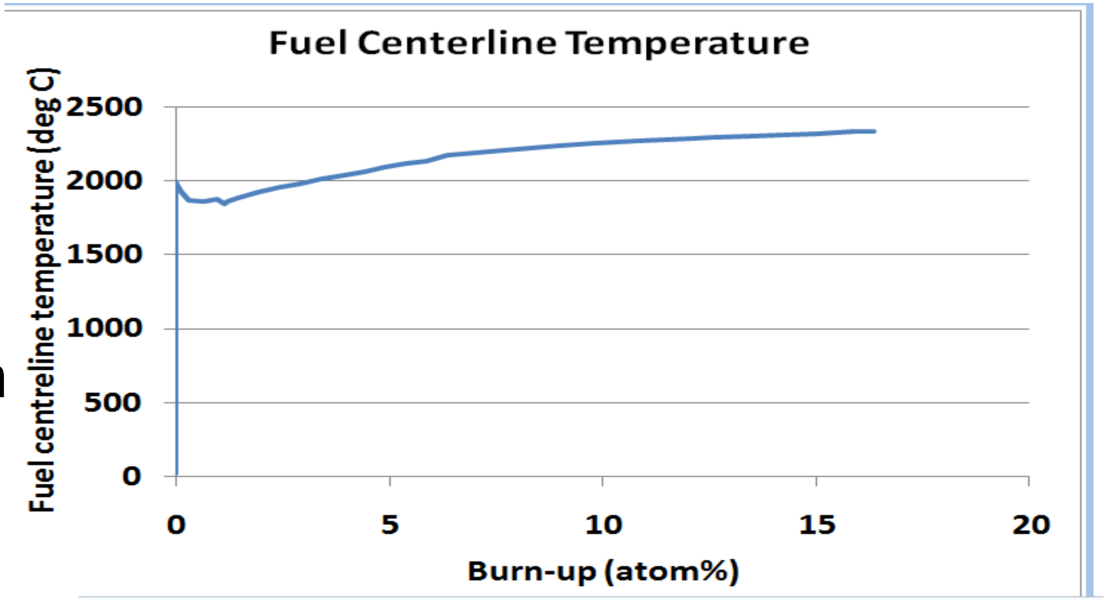


Courtesy: Carbajo

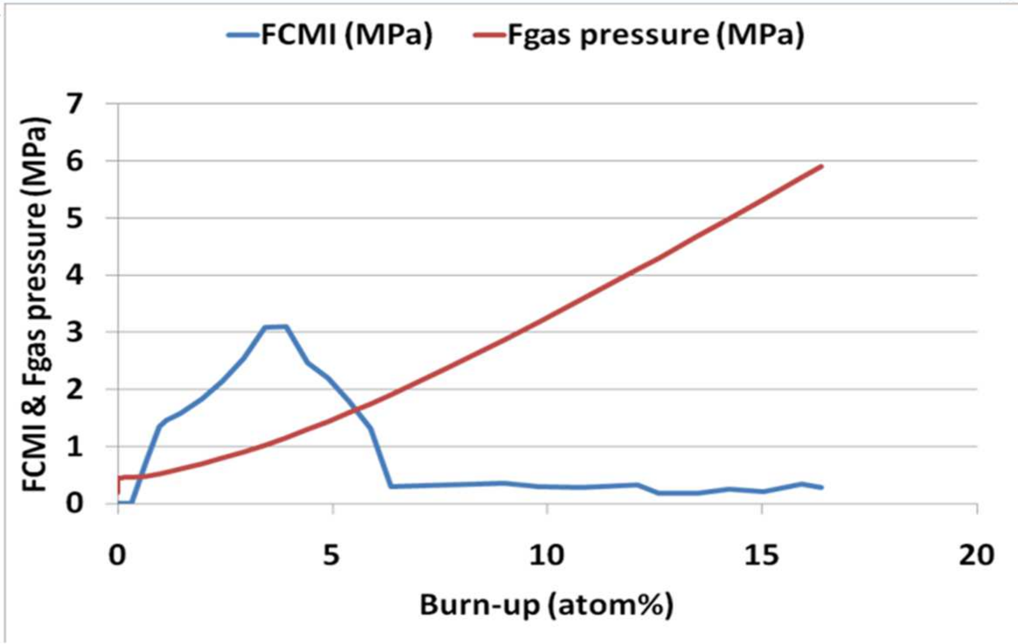
PENALTY ON THE FUEL PERFORMANCE DUE TO HIGH BURNUP

At 150 GWd/ t burnup

- Melting point of the fuel is less by 3 % than fresh fuel
- thermal conductivity of the fuel is 22 % less than fresh fuel
- TCL – 2362 ^{o}C
- Hotspot >> T_{melt}

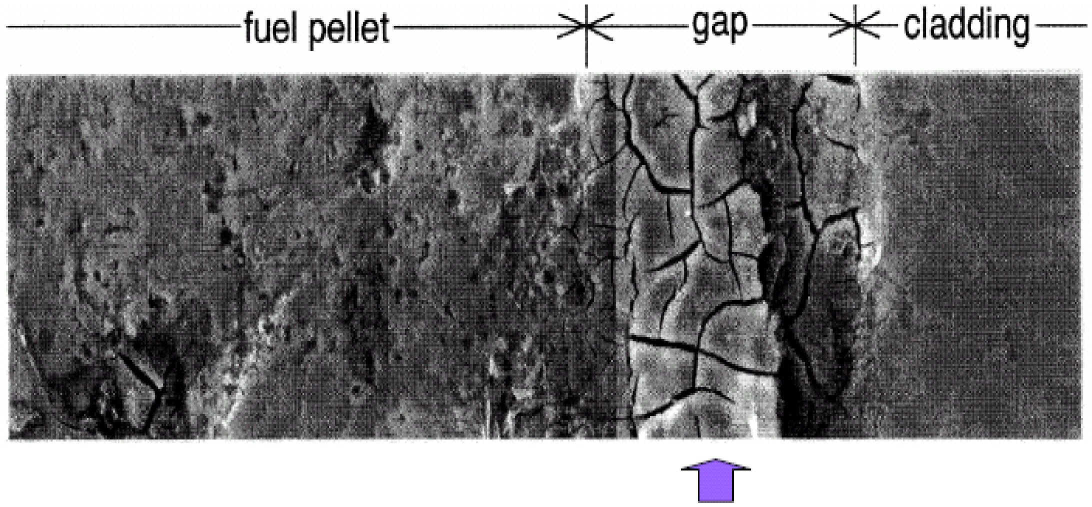


- JOG presence > 70 GWd/ t to be studied
- Hotspot factors to be reviewed after reactor operation
- Resulting swelling in the fuel due to retained FP are to be assessed for higher burnup.



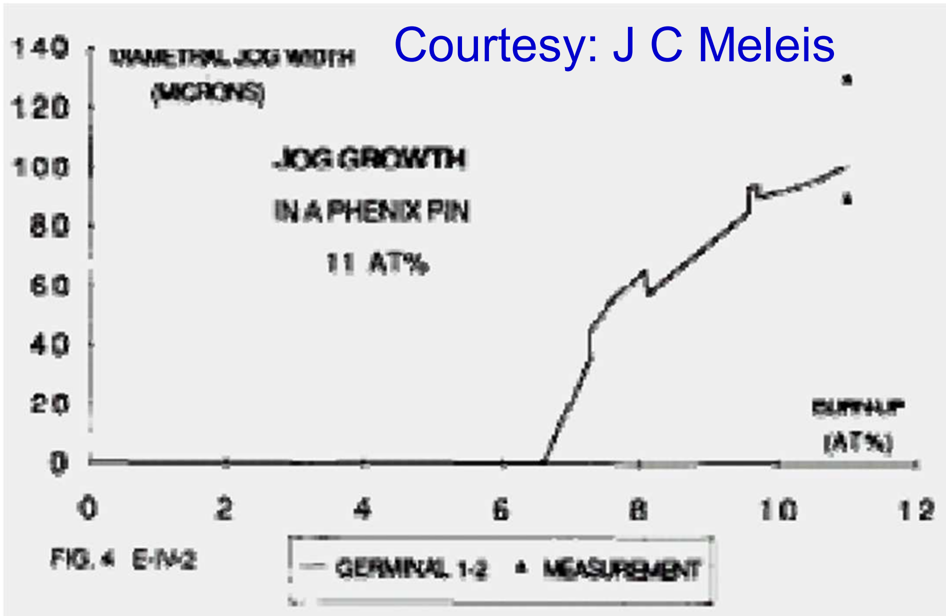
Joint Oxyde Gaine (JOG)

- JOG is Cs_2MoO_4
- Low Density- 4.36 g/ cc
- T_{melt} JOG= 942 K
- Formed between fuel-clad gap at
  - BU > 7at%
  - T_{clad} < 600 °C
  - O/ M > 1.985 (at surface)
  - T_{clad} > 1100 °C migrates to cooler regions



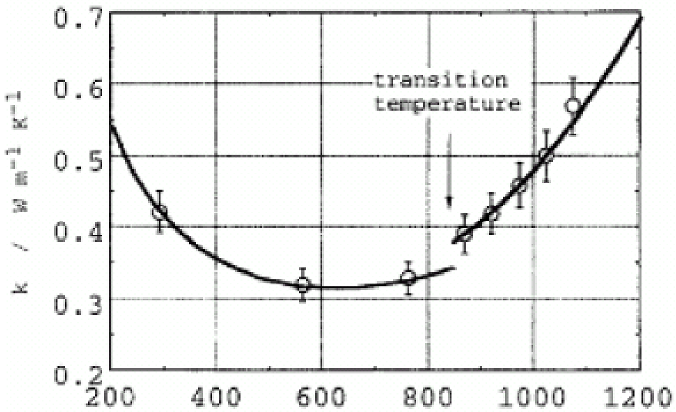
JOG

Courtesy: J C Meleis



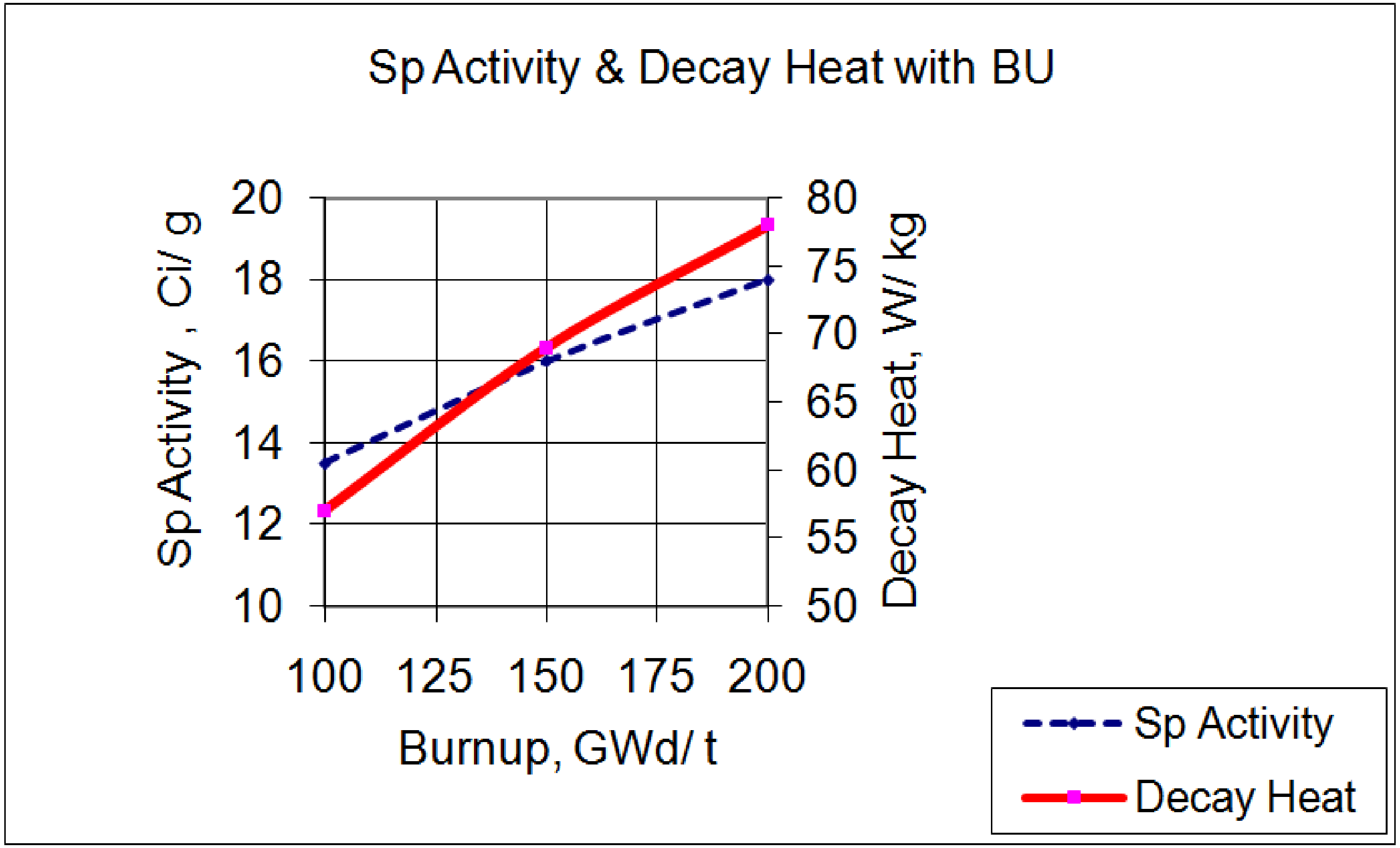
JOG WIDTH VS BURNUP

Courtesy: Tetuys Ishii & Tomoyasu Mizuno



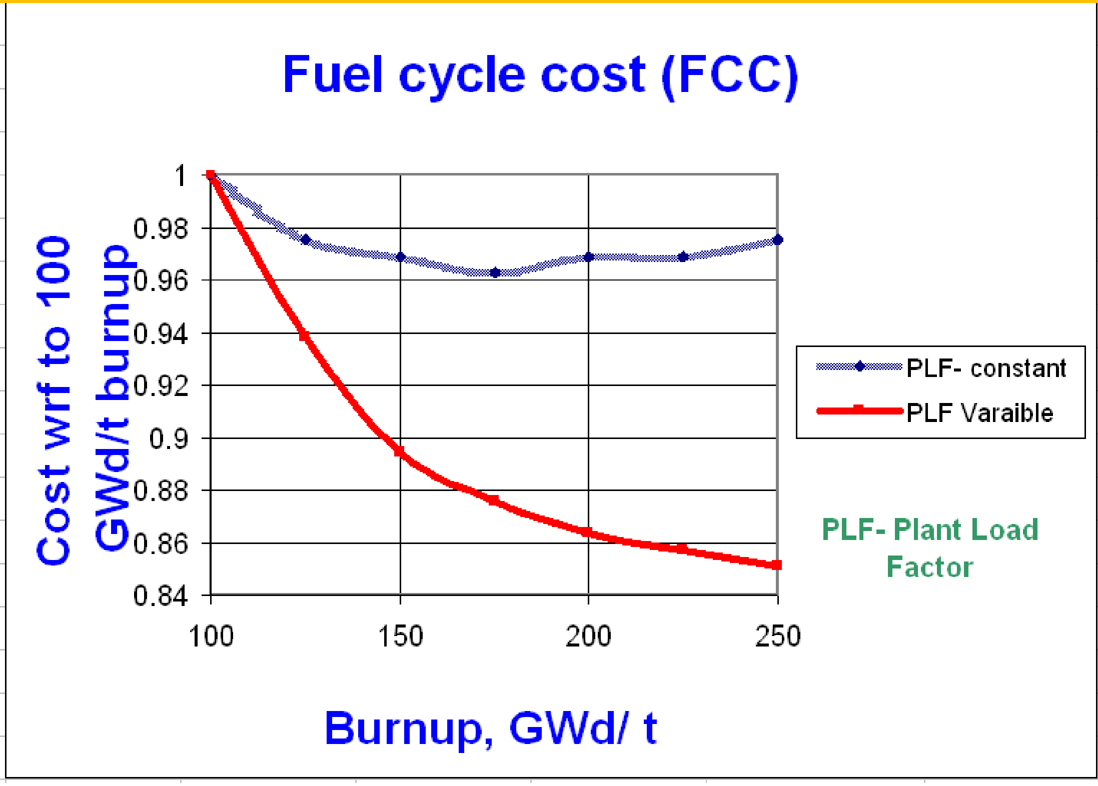
JOG THERMAL CONDUCTIVITY

CONCERNS FROM REPROCESSING



- Specific Activity
  - Increase in specific activity is about 19% and 33% for 150 and 200 GWd/t burnup in comparison with 100 GWd/t
- Decay Power
  - Increase in decay power is 21% and 37% for burnup levels of 150 and 200 GWd/t

BURNUP VS FUEL CYCLE COST

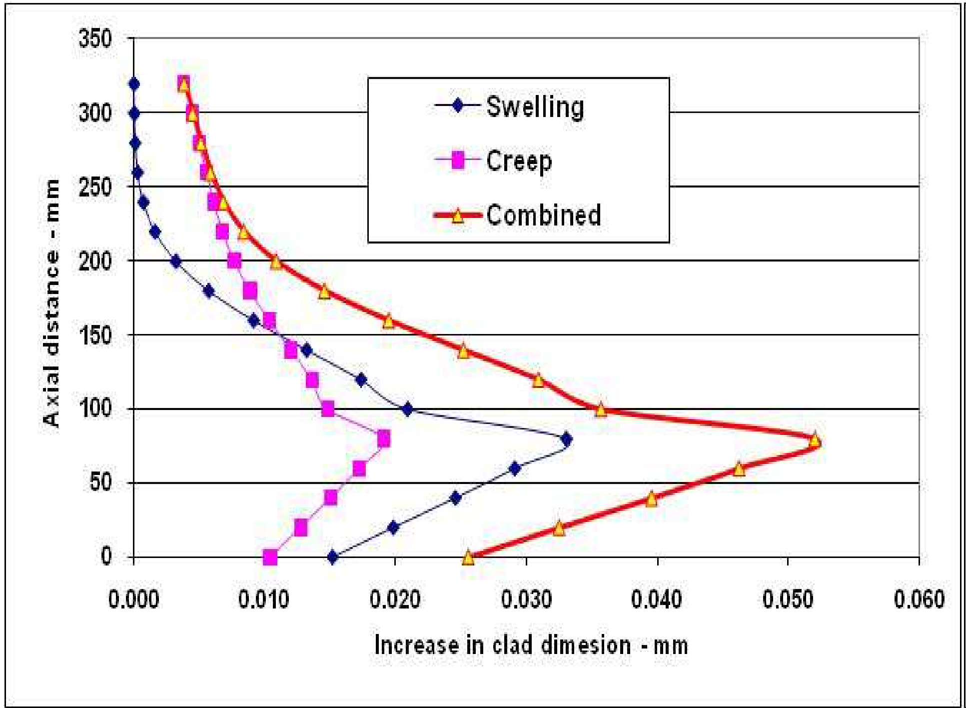


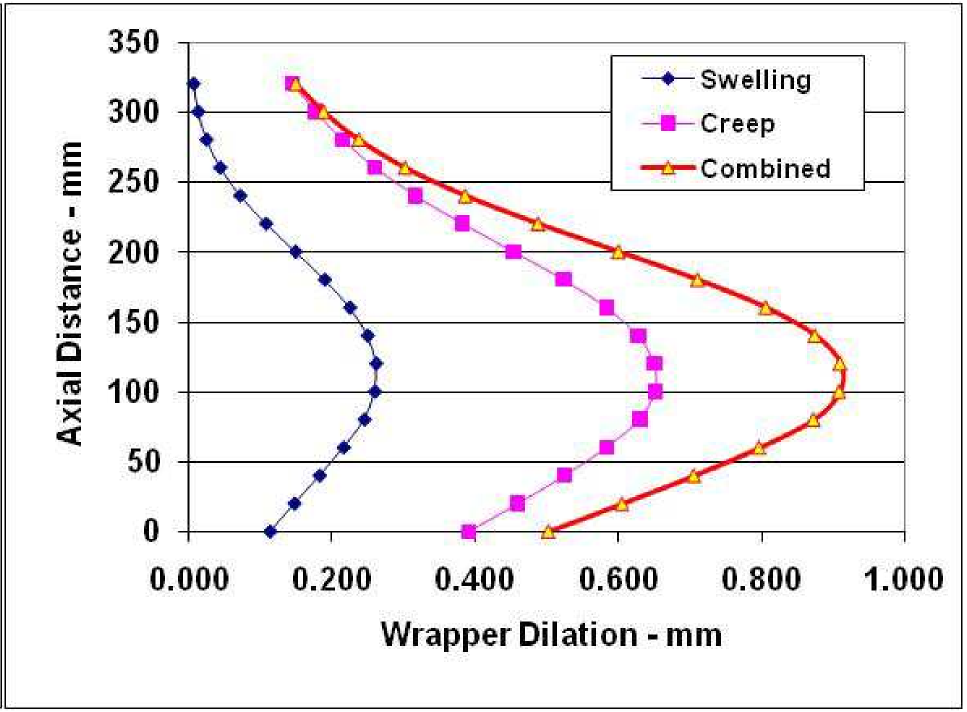
- Reduced annual fuel requirements-reduces variable cost in fuel fabrication
- Idling of created capacity- increases fuel processing cost in reprocessing and fabrication
- Increased fuel handling interval- lesser annual downtime resulting in higher plant load factor which means increased electricity export

- If variation in PLF is considered, then at 200 GWd/ t, FCC is cheaper by 17%.
- If one considers the same plant caters to the needs of 3 Fast Reactors with slight increase in the investments then FCC works out to be highly attractive and is cheaper by about 57%.
- FCC seems to be bottoming out at 150 GWd/ t burnup for constant load factor
- FCC appears to be saturating at10- 200 GWd/ t burnup for variable load factor
- **Optimum burnup in the range of 150- 200 GWd/ t for MOX fuels**

Clad & Wrapper Deformation by analysis in PFBR test SA

- Existing D9 material is expected to serve its objective for 150 GWd/ t burnup
- For burnup beyond150 GWd/ t, D9I material is likely to be infused
- For future metallic core, ferritic steels are considered





Summary

For a typical MOX fuelled SFR of power reactor size, Implications due to higher burnup have been quantified

Advantages

- Improvement in the economy is seen upto 200 GWd/ t

Dis- Advantages

- Design changes > 150 GWd/ t bu
- Need for 8/ 16 more fuel SA at 150/ 200 GWd/ t bu
- Higher enrichment of B_4C in CSR/ DSR at higher bu
- Reduction in LHR may be required at higher bu
- Structural material changes beyond 150 GWd/ t bu
- Reprocessing point of view- Sp Activity & Decay heat increase

Need for R & D is a must before increasing burnup

bu- refers burnup

Summary (Contd..)

- Efforts to increase MOX fuel burnup beyond 200 GWd/ t may not be highly lucrative
- MOX fuelled FBR would be restricted to two or four further reactors
- Imported MOX fuelled FBRs may be considered
- India look towards launching metal fuel FBRs in the future.
  - Due to high Breeding Ratio
  - High burnup capability

R & D REQUIREMENTS

- **Essential**:
  - Data measurement with great accuracy on fuel & structural materials
  - JOG formation and its behaviour under various conditions besides its property
  - FCCI for different types of steel
- **Desirable**:
  - Formation of any low melting phases in the fuel at high burnup
  - Fission gas release and retained measurement in the irradiated fuel

Thank You