EXPERIENCE IN THE PHYSICS DESIGN AND SAFETY ANALYSIS OF SMALL AND MEDIUM SIZED FBR CORES

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Technical Meeting on the Benefits and Challenges of Fast Reactors of the SMR Type, 24-27, September, 2019, Milan, Italy

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- Background and Introduction

Fast breeder reactors based on metal fuel are planned to meet the growing energy demand in India.

Additionally, it is planned to have the development of technologies required for launching commercial metal breeder reactors with closed fuel cycle.

- Merits of sodium cooled metallic fueled FBR cores
  - Harder spectrum and higher breeding
    - Lower doubling time
      - Better Fuel utilization
    - Reduces burn-up reactivity swing.
    - Reduces control rod worth
      - Severity of UTOPA is reduced

- Advantages ..
- Inherent passive safety features
    - Proved in EBR-II reactor
- Additional Merits
    - **Pyro reprocessing**
        - » **Proliferation Resistant**
    - **Actinide Incineration**
        - » **Reduction of Radio toxicity**

Challenges

1. The challenges of sodium cooled fast reactors in general
2. Limited operating experience with metal fuels (only from smaller experimental reactors)
3. High sodium void reactivity worth is of concern for metal fueled FBR cores
4. Containing high radio activity in commercial scale Pyro-processing plants
5. Possible safety degradation with higher actinides in closed cycle

1 $ criteria for sodium void worth has been accepted from the International community for safer fast reactor designs

- Possible Solution for the commencement of metal fueled program

  - Small power reactors for demonstration
  - Establish better irradiation behavior with higher safety
  - Continue with high power reactors with modified designs which can provide lower sodium void reactivity worth of 1$.

- A preliminary conceptual design of small power reactor of 120 MWe core with sodium void worth less than 1 $ is presented.
- Its relative merits are explained with the performance of a medium sized FBR core with respect to its:
  - Basic Core Physics Parameters
  - Performance during a ULOF accident

Reference Core	**:**	**120 Mwe (320 MWt)**
Medium Size Core Used for comparison		: 500 Mwe (1250 MWt)

Calculation Scheme

Core Physics Analysis :

2D Diffusion Codes

- Core multiplication factor
- Power, LHR, Breeding ratio
- Normal and adjoint Fluxes

Perturbation Calculations

- Material Worths and its distribution in the core
- Kinetic Parameters
  - Delayed neutron fraction
  - Prompt neutron life time
  - Doppler constant
  - etc.,

Safety Analysis :

Point Kinetics Model

- Use results of perturbation and thermo-dynamic properties
- Feed back reactivities
- Temperature and Power coefficients
- Dynamic response during ULOF transient

Metallic Fuel and Fuel Pin Properties used in the Analysis

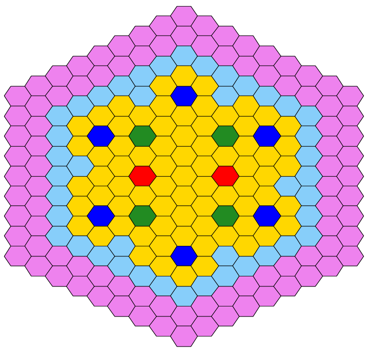
Number	Parameter	Value
1	Fuel Type	Metal U-Pu-Zr
2	Zr Content (wt %)	6
3	Fuel pin bonding	Sodium
4	Peak LHR (W/cm)	450
5	Cycle Length (days)	180
6	Pin Radius -Fuel (mm)	6.6
7	Pin Radius -Blanket (mm)	14.33
8	Number of Fuel Pins/SA	217
9	SA Pitch (cm)	13.5
10	Volume Fractions-Fuel (%)	26/24/50
11	Volume Fractions-Blanket (%)	42/19/39

Thermo-Physical Properties of Metallic Fuels used in the Analysis

No.	Parameter	Value
1	Fuel Density (g/cm^3)	17.1
2	Smeared Density (g/cm^3)	12.8
3	Melting Point (^0C)	1067
4	Boiling Point	3932
5	Thermal Conductivity ($W/cm/^0C$)	0.25
6	Linear Expansion Coefficient ($^0C^{-1}$)	$19.7*10^{-6}$
7	Gap Conductance ($W/cm^2/^0C$)	27
8	Specific Heat ($J/g/^0C$)	0.2
9	Latent Heat of Fusion (J/Kg)	38
10	Latent Heat of Vaporization (J/g)	1641

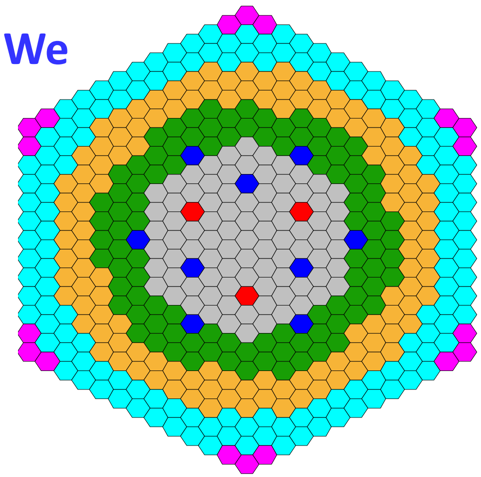
Basic Core Configuration and Core physics Properties

Ref. Core:
120 MWe



- Core -- 73
- Blanket -- 42
- Reflector -- 90
- CSR -- 6
- DSR -- 2
- Expt.SA -- 4

500 MWe



- Core-1 (85)
- Core-2 (96)
- Blanket (120)
- Steel SA (138)
- B4C -78 (not all shown)
- CSR (9)
- DSR (3)

Parameter	Reactor Size	
	Small	Medium
Core Enrichment (wt%)	19.6	13.6/18.2
Breeding Ratio	1.1	1.36
In core Breeding	0.63	0/83
Core radius (Fuel) cm	60	95

Results of perturbation Analysis

Material Void Worth (pcm)

Material	Core Size	
	120 MWe	500 MWe
Sodium	+164	+1830
Steel	+972	+4128
Fuel	-2186	-1923

Safety Parameters (pcm)

Material	Core Size	
	120 MWe	500 MWe
Doppler constant	-336	-470
Delayed neutron fraction	385	403

Distribution of sodium void in 120MWe Core (in RZ geometry)

-2	-12	-21	-21	-14	-11	-2	-1
-3	-13	-24	-27	-20	-23	-5	-1
1	4	-3	-14	-11	-26	-8	-2
6	24	23	2	-1	-27	-10	-3
10	42	46	17	8	-28	-12	-4
12	52	61	26	14	-29	-13	-4
12	53	62	27	15	-29	-14	-4
10	45	51	20	11	-28	-13	-4
7	29	30	7	2	-28	-11	-3
2	9	4	-8	-8	-26	-8	-3
-2	-10	-20	-21	-17	-24	-5	-2
-2	-9	-13	-12	-12	-11	-2	-1

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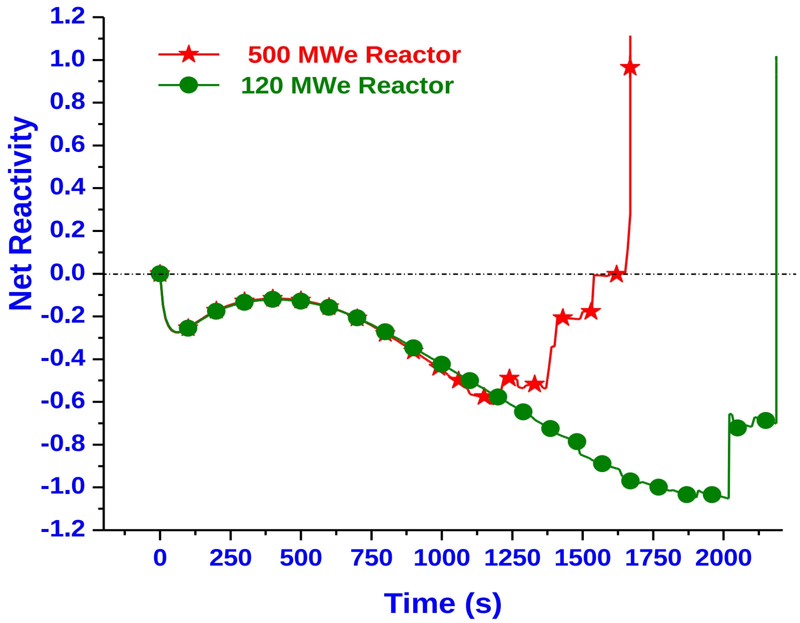
Reactor Size	Components of Sodium Reactivity Change				Total (pcm)
	Leakage	Absorption	Fission	Scattering	
120	-5956	+2368	0-	+4560	+972
500	-4780	+2829	0	+6079	+4128

Reactor	Region wise Contribution (pcm)				Total (pcm)
	Core-1	Core-2	Axial Blanket	Radial Blanket	
120	+389	-	-114	-111	+164
500	+1761	+231	-95	-67	+1830

Main Components of Reactivity Feedbacks

- Fuel Doppler Feedback
  - Depends on temperature change
- Coolant Density
  - -ve in periphery and +ve in core centre
- Fuel Axial Expansion
  - -ve
- Core Radial Expansion.
  - Grid plate expansion and flowering effects
  - -ve



Coefficient	Reactor Size (Power –MWe)	
	Small (120)	Medium (500)
Temperature (pcm/C)	-2.598	-1.549
Power (pcm/MWt)	-0.616	-0.213

Net Reactivity Change with Time during ULOFA

Main Conclusions

- Basic core physics design of 120 MWe FBR core is presented.
  - The core can provide a breeding ratio of 1.1.
- Better safety performance during loss of flow accident is demonstrated.
  - More time margin to CDA during an un-protected transient of loss of flow accident.
- With respect to fuel breeding and safety aspects, smaller cores give better performance.

Future Studies ..

- **UTOP Analysis and Optimization of Control Rods**
  - Smaller core
  - Low internal breeding and high excess reactivity requirement
    - High fuel enrichment
      - High CR enrichment
        - High withdrawal worth

  - Severity of UTOPA has to be minimized
    - Limit withdrawal worth below 1 beta margin
      - Margin of prompt criticality

Challenges

- Obtaining high fuel burn-up without fuel failure
- Safety performance in closed cycle
  - Higher actinides
    - Degradation of safety parameters from ideal values
      - increase of sodium void worth from 1 $ margin
      - Possible in delayed neutron fraction
      - Reduction of Doppler feedback
      - Ensuring safety in closed cycles for longer oprations

Thank You