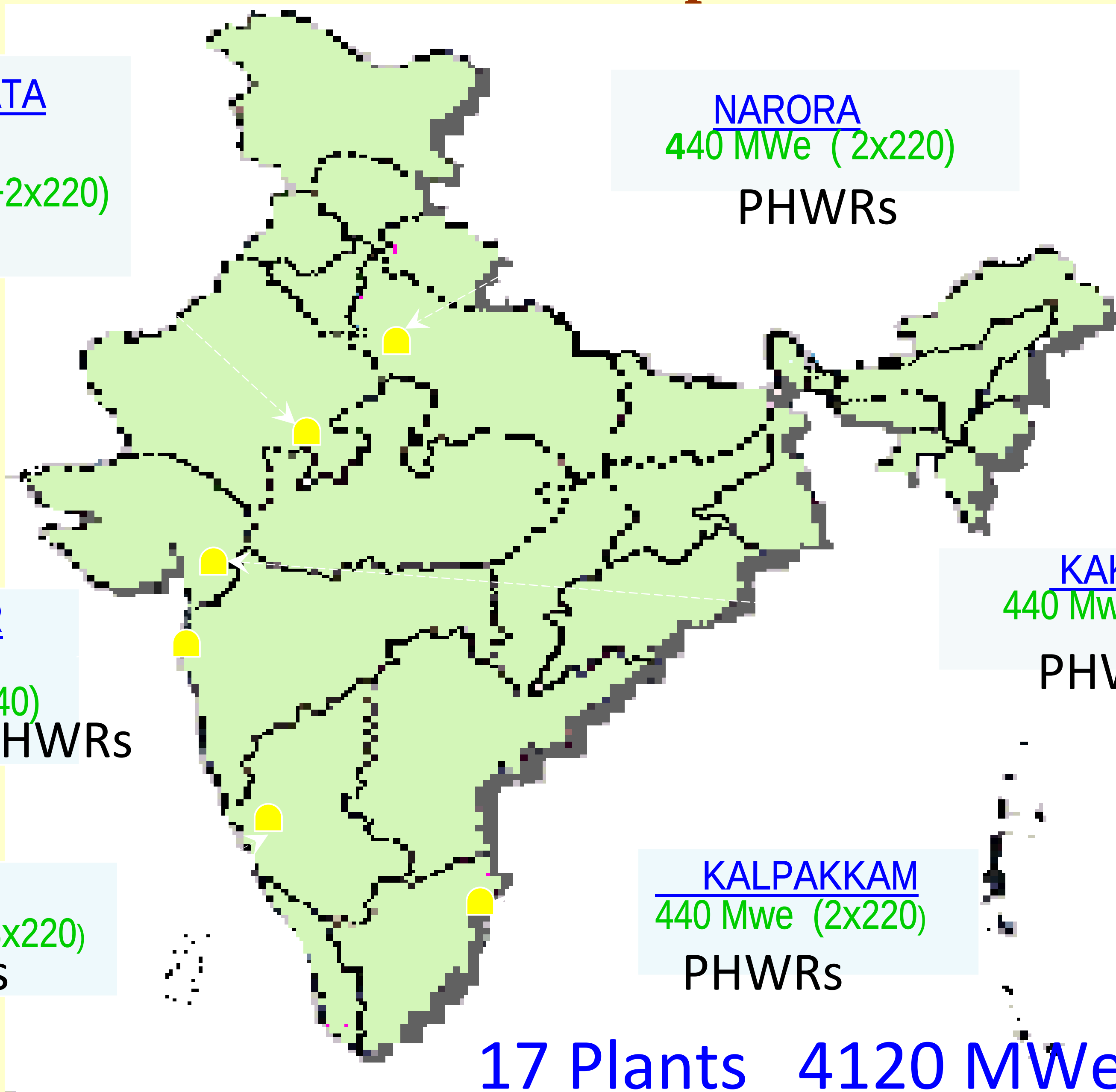
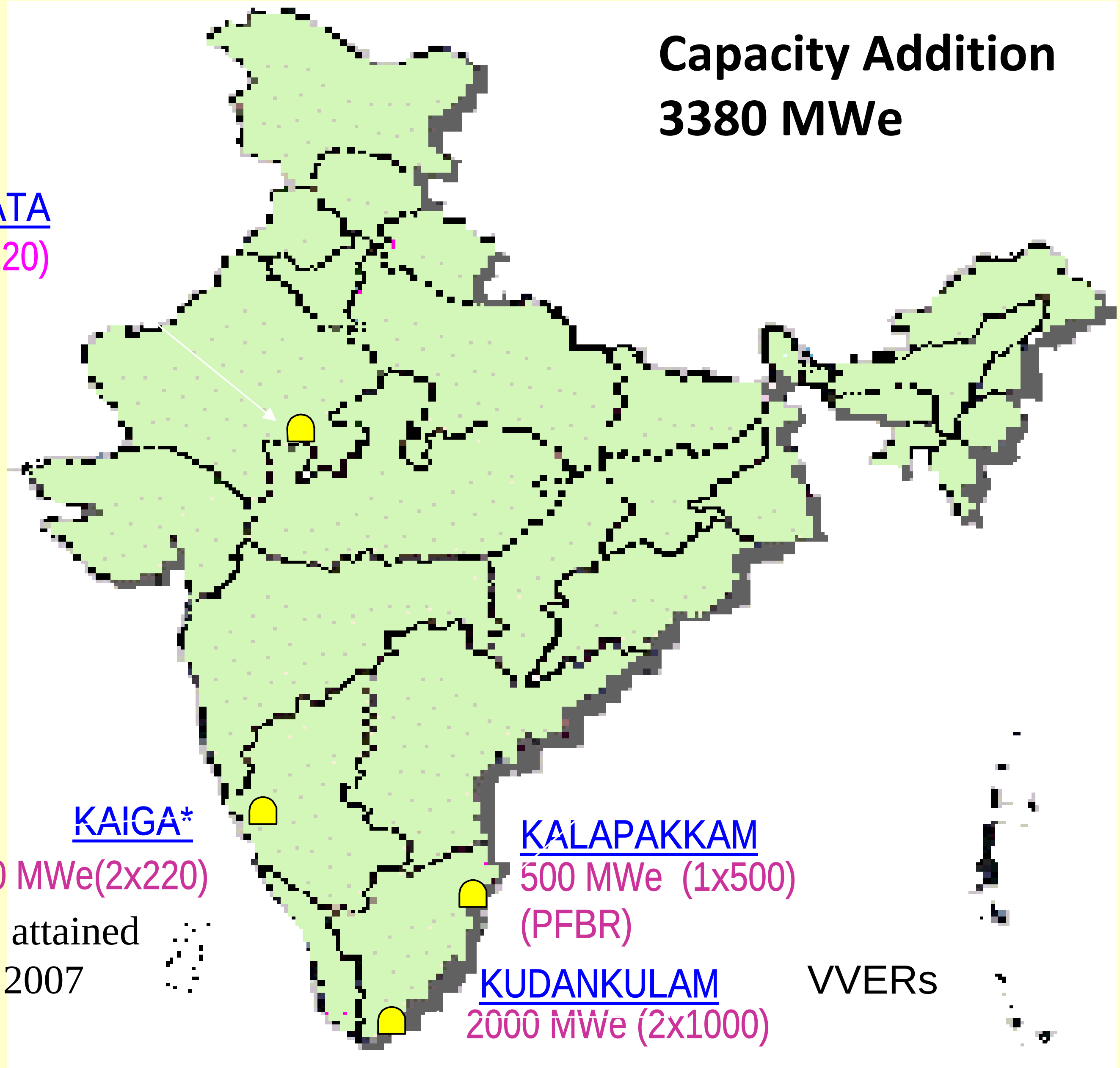
Fuel Element Designs For Achieving High Burnups in 220 MWe Indian PHWRs

P.N.Prasad, Rahul Mani Tripathi,
K.P.Dwivedi, A.N.Kumar
Nuclear Power Corporation of India Ltd,
Mumbai, India

Nuclear Power Plants In Operation in INDIA

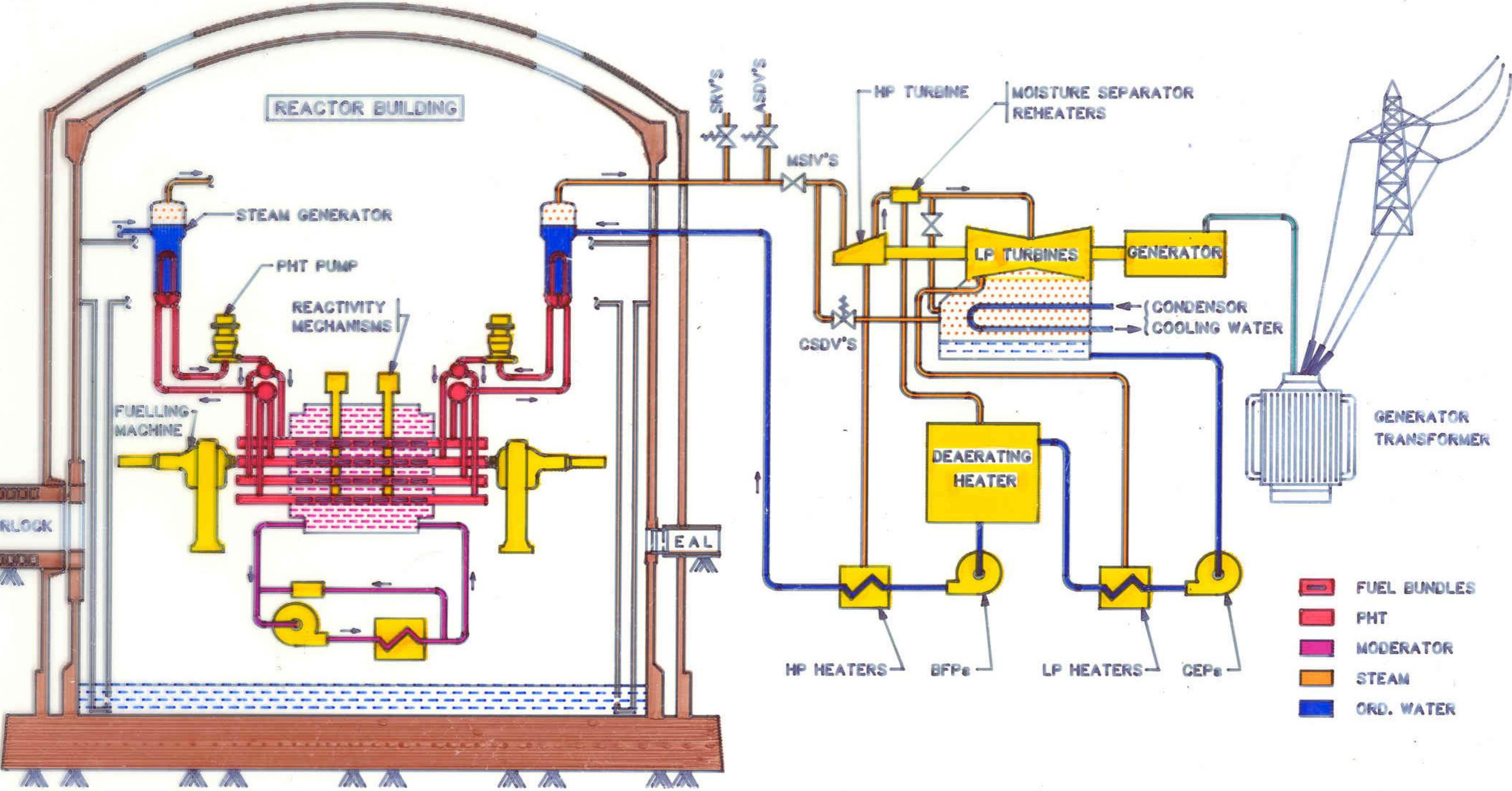


Nuclear Power Plants Under Construction



Future Plan

- PHWRs 8 units of 700 MWe
- FBRs 4 units of 500 MWe
- AHWR (300 MWe)
- VVERs/LWRs (1000/1600 MWe)



SCHEMATIC DIAGRAM OF INDIAN PHWR

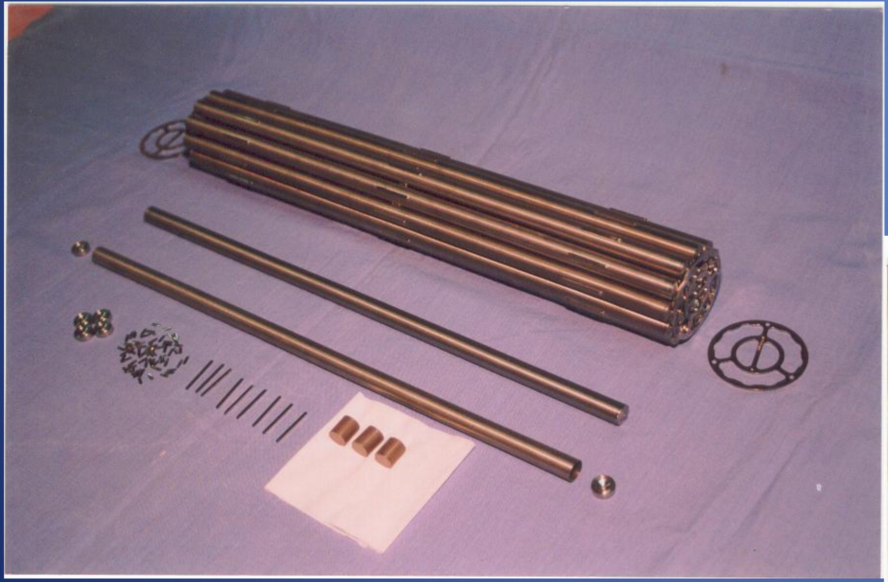
(COASTAL SITE)

Type of PHWR Fuel Bundles in Use

19 ELEMENT BUNDLE

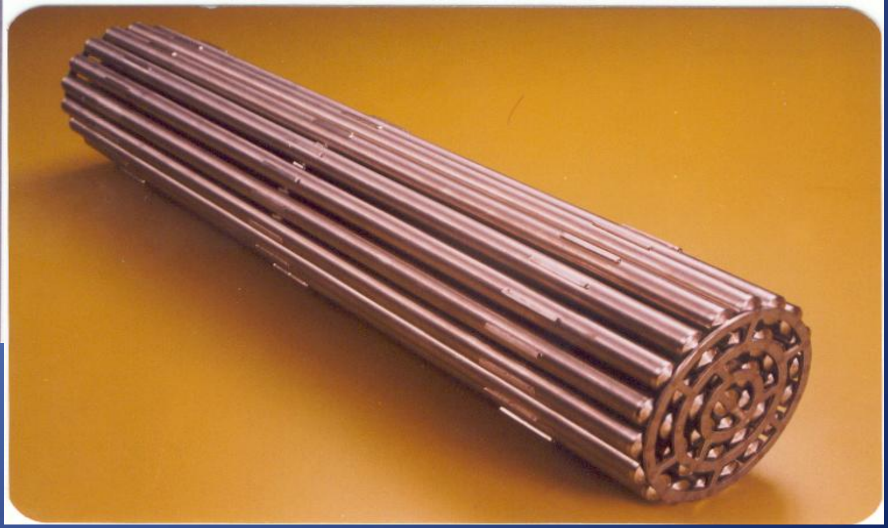
FOR 220 MWe REACTORS

Natural Uranium

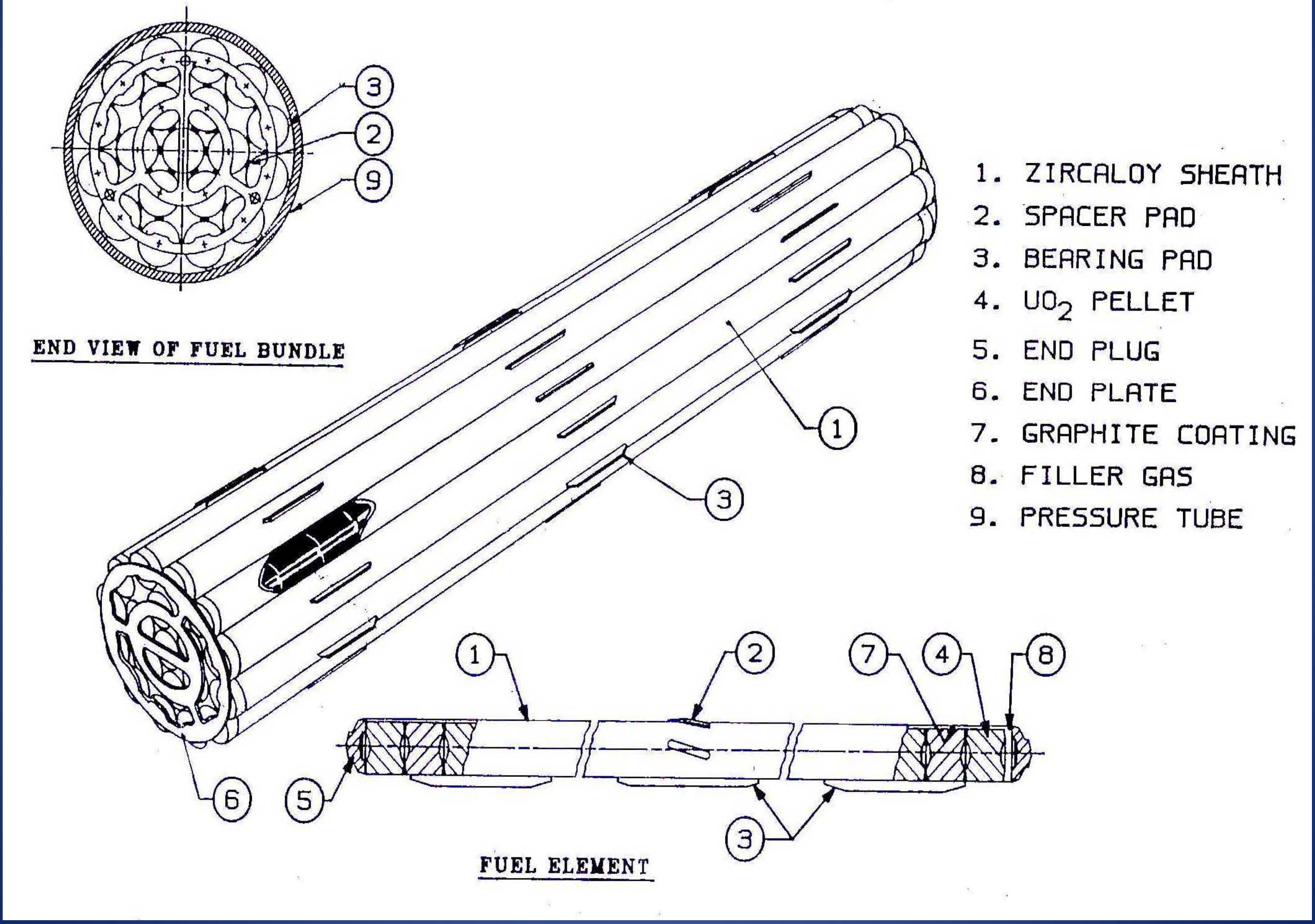


37 ELEMENT BUNDLE

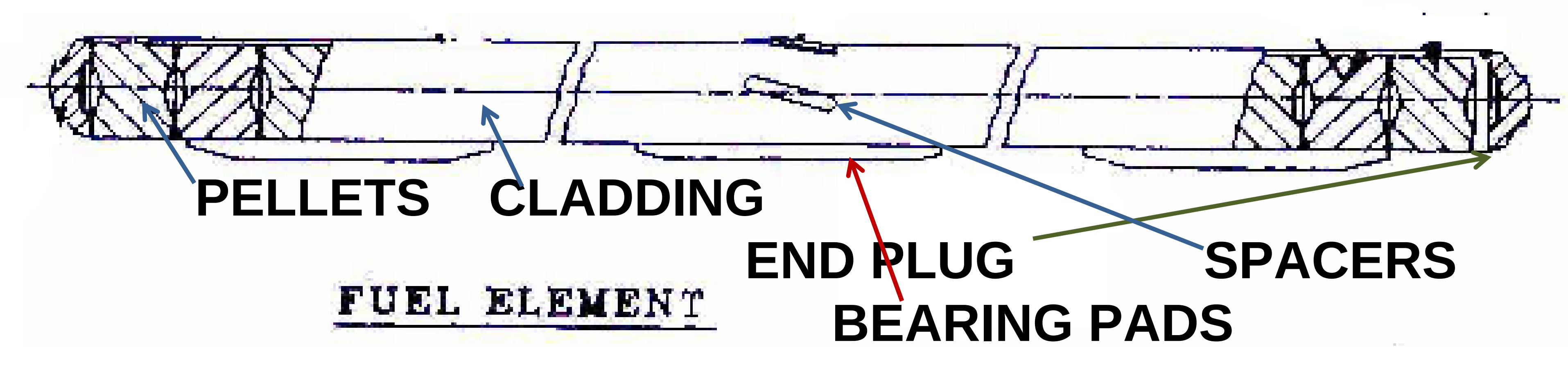
FOR 540 MWe REACTORS



19 ELEMENT PHWR FUEL BUNDLE

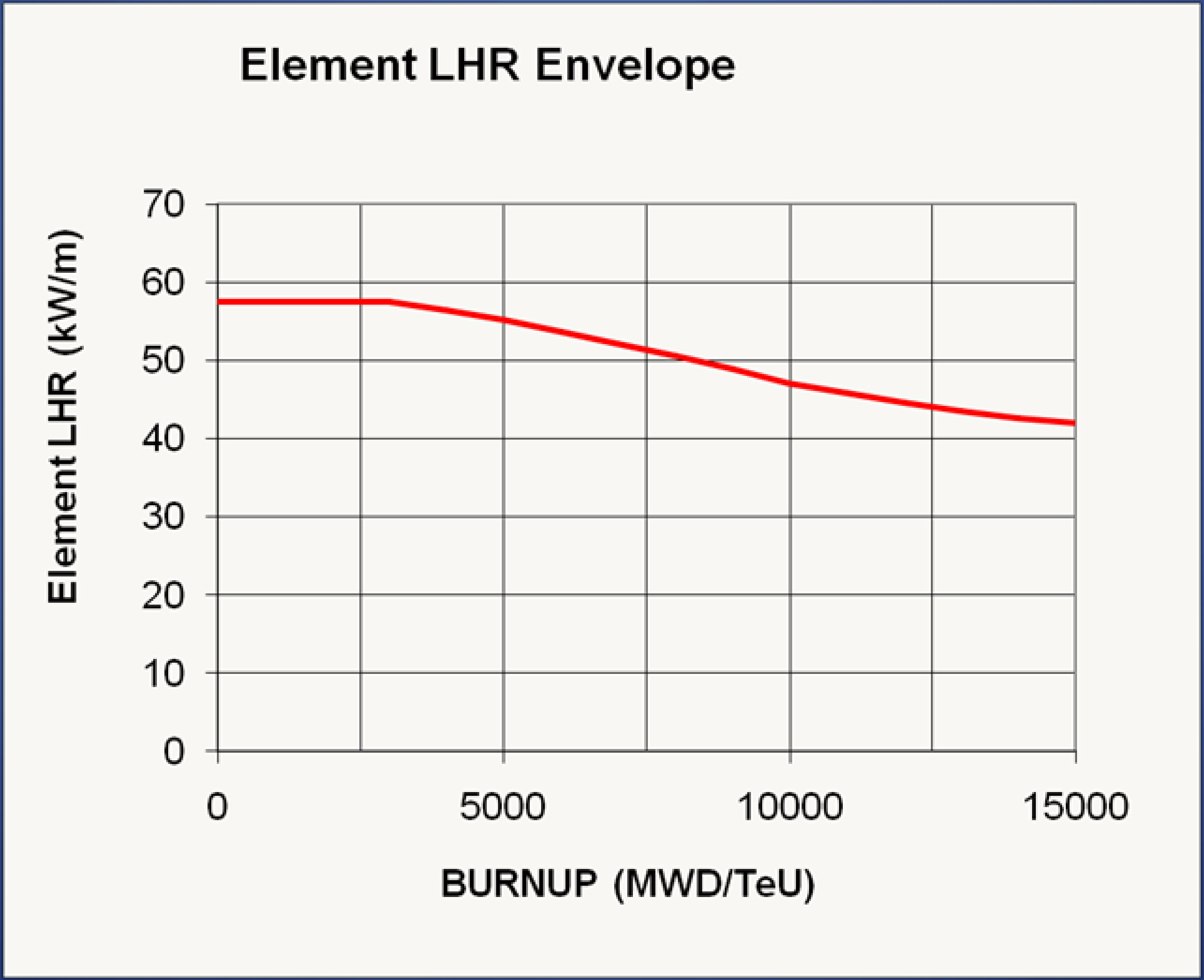


PHWR Fuel Element



- No Plenum Space
- Cladding Collapsible Type
- Pellet - Cladding Radial Clearance: Minimum
- Present Maximum Burnup : 15 GWd/TeU
- Higher LHR – Peak value 57 kW/m

The Fuel element/ Bundles in Reactor to follow such an envelope



HIGH BURNUP FUEL PLAN

- FUEL DESIGN TO BURNUPS BEYOND 15 000 MWd/TeU

  - 20 000 MWd/TeU TO 30 000 MWd/TeU
- OBJECTIVE : USE OF AVAILABLE AND IMPORTABLE RESOURCES
- MATERIALS - MOX , THORIUM, SEU
- DESIGN AND IRRADIATION STUDIES IN PROGRESS

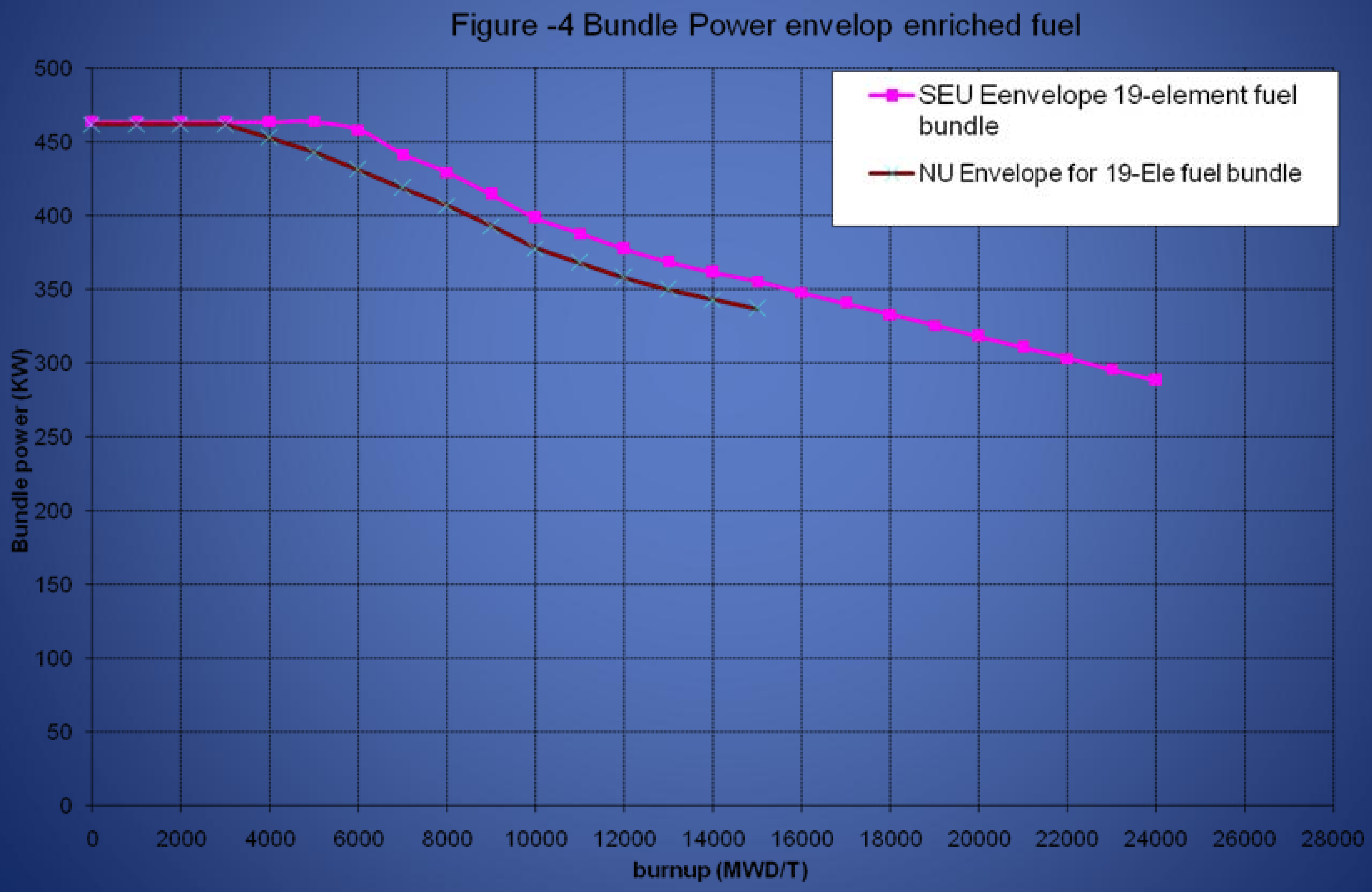
Effecting Parameters

- Limiting fission gas pressure within fuel Element
- Fuel swelling
- Axial and Radial Peaking

Pellet Parameters studied for High Burnup Irradiation

- Increase Void volume within Pellet by
  - Dish depth Increase
  - Density Reduction
- Grain size
- Annular Pellets
- Lower LHR (Linear Heat Rate)

Comparison of Bundle Power Envelope for SEU and NU Bundles



High Burnup fuel element analysis

LHR kW/M	Variable Parameter	Burnup MWd/TeHE	Centre Tempeatue (C)	Fisson Gas Rel()	Internal gas Pressure (Mpa)
58	Normal Parameters	20,000	2040	15.3	9.8
	Double Dish Pellet	20,000	2040	14.8	5.5
	Grain Size 40 Micro M	20,000	2040	14.7	8.9
	Low Fuel Density	20,000	2080	18.4	7.4
	Central Hole	25,000	1950	14.2	6.4
50	Normal Parameters	25,000	1668	3.7	6.4

Other Effecting Parameters

- Bundle Residence period increases
  - 3 to 5 years (depending on Bundle location) compared to 2.5 years presently.

1) low cycle fatigue behaviour of fuel cladding & end plate
2) corrosion and hydriding behaviour of the fuel cladding and end plate --- New Zirconium Alloys
3) fretting damage of fuel bundle
4) power ramps at higher burnups. – Graphite Coating on Tube ID surface

HIGH BURNUP FUEL DESIGN STUDIES - conclusions

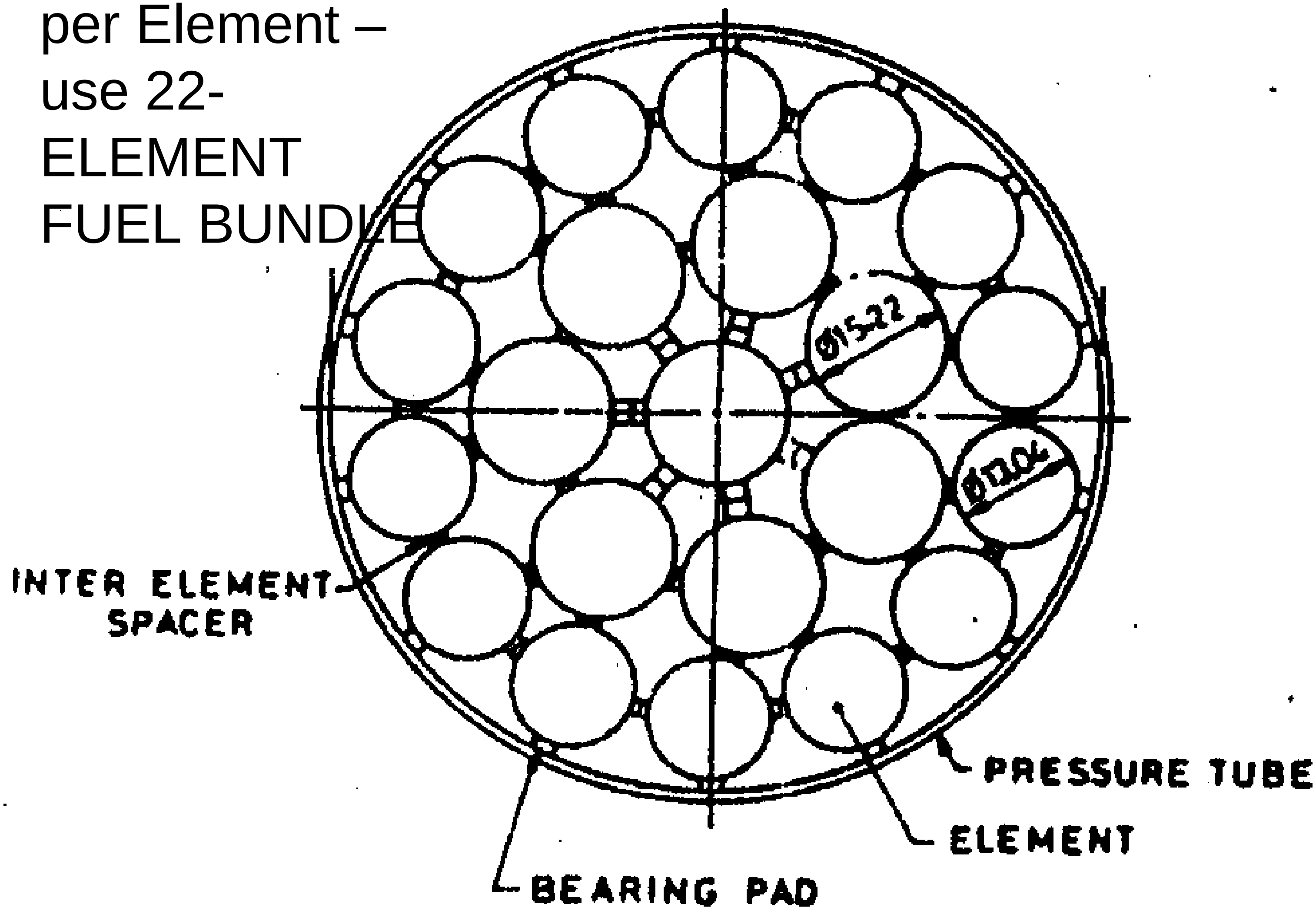
- PRESENT FUEL DESIGN ACCEPTABLE UPTO 25000 MWd/TeU
  - With Modification in Pellet dish volume
  - Density
  - Grain size
- BEYOND 25000 MWd/TeU

  19-ELEMENT BUNDLE WITH HOLLOW PELLET

  OR

22-Element Fuel Bundle

or Lower LHR per Element – use 22-ELEMENT FUEL BUNDLE



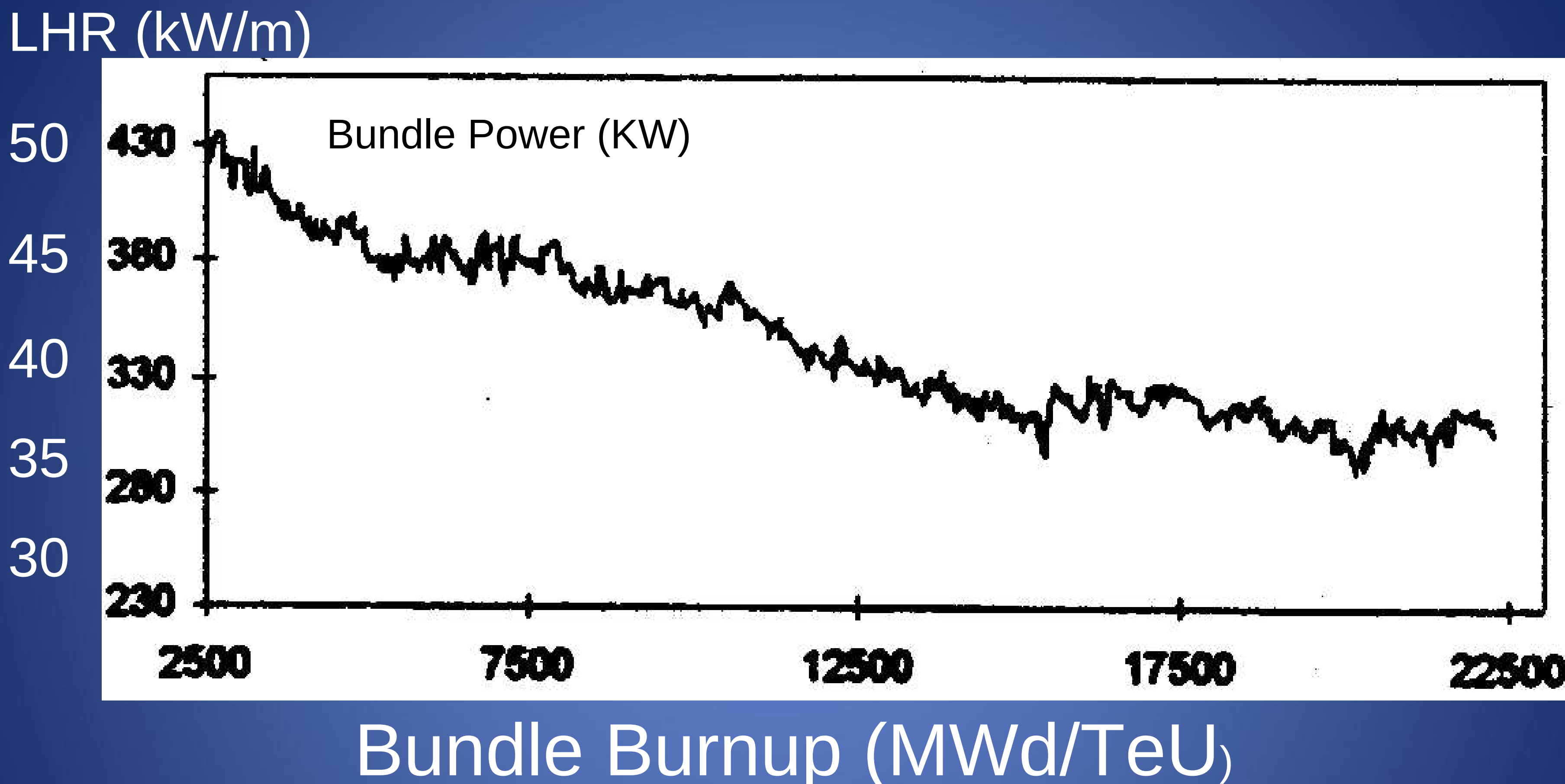
Irradiation Trials of High Burnup Fuels in the PHWRs

- NU Bundles
- ThO2 Bundles
- MOX Bundles
- SEU Bundles

Core Map showing Differential Fuelling with two burnup zones

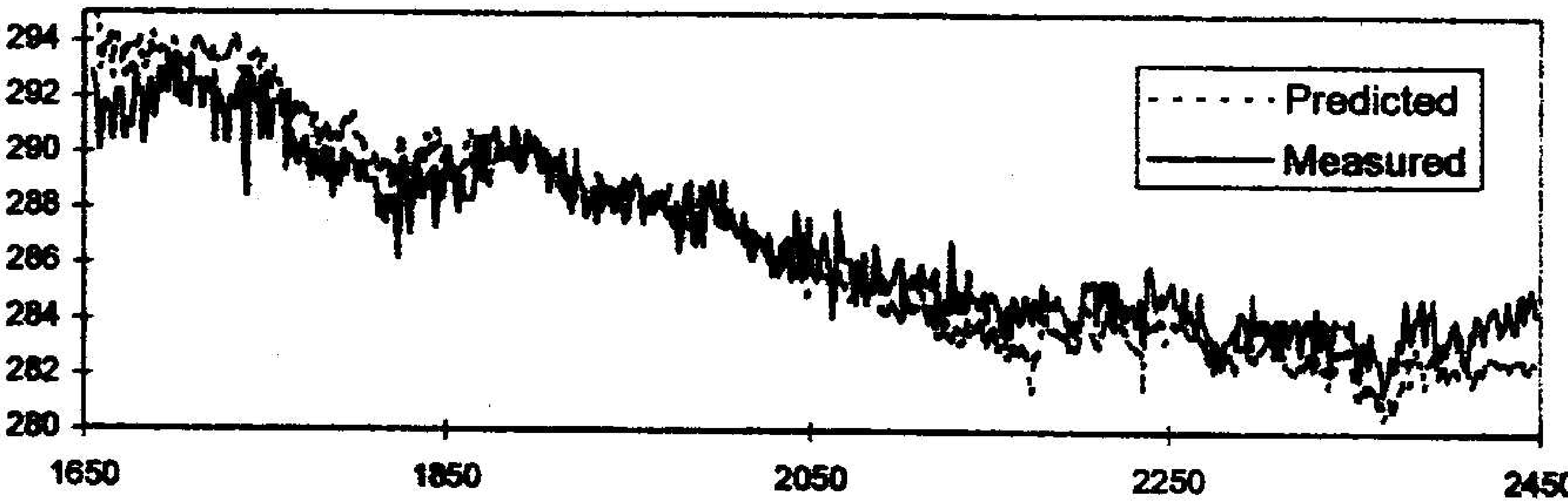
High burnup NU irradiation

- Natural uranium 19-element fuel bundles in two channels in KAPS unit are irradiated to burnups of 22000 MWD/TeU.
- After irradiation bundles both the channels discharged as a normal channel refuelling.
- Channel powers and bundle powers varied as expected



Bundle Power variation with Burnup for 7th bundle of Channel O-8

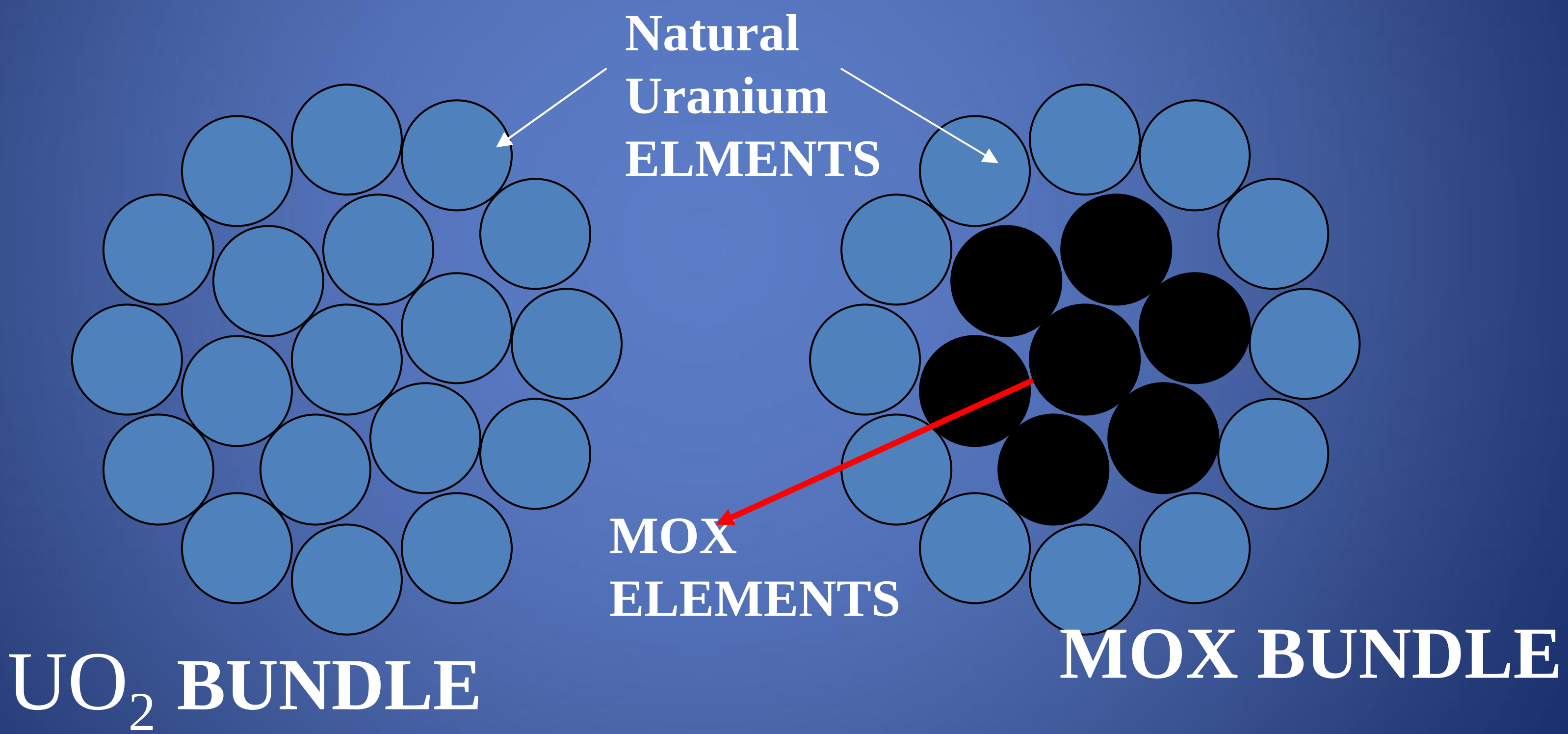
Temperature (C)



Full Power Days (FPDs)

Variation of Channel Outlet Temperature With Reactor Operation of O-8 Channel

MOX-7 is a 19-element fuel bundle similar to present Nat U 19-element bundle



The MOX constitutes 0.4% PuO2 mixed in Natural UO2.

MOX FUEL BUNDLE and CORE DESIGN

- The core average discharge burnup increases to 9000 MWD/TeHE
- savings in the usage of natural uranium bundles
- REACTOR control, shut down system performance with full core MOX loading checked and safety analysis carried out

BUNDLE POWER ENVELOPE

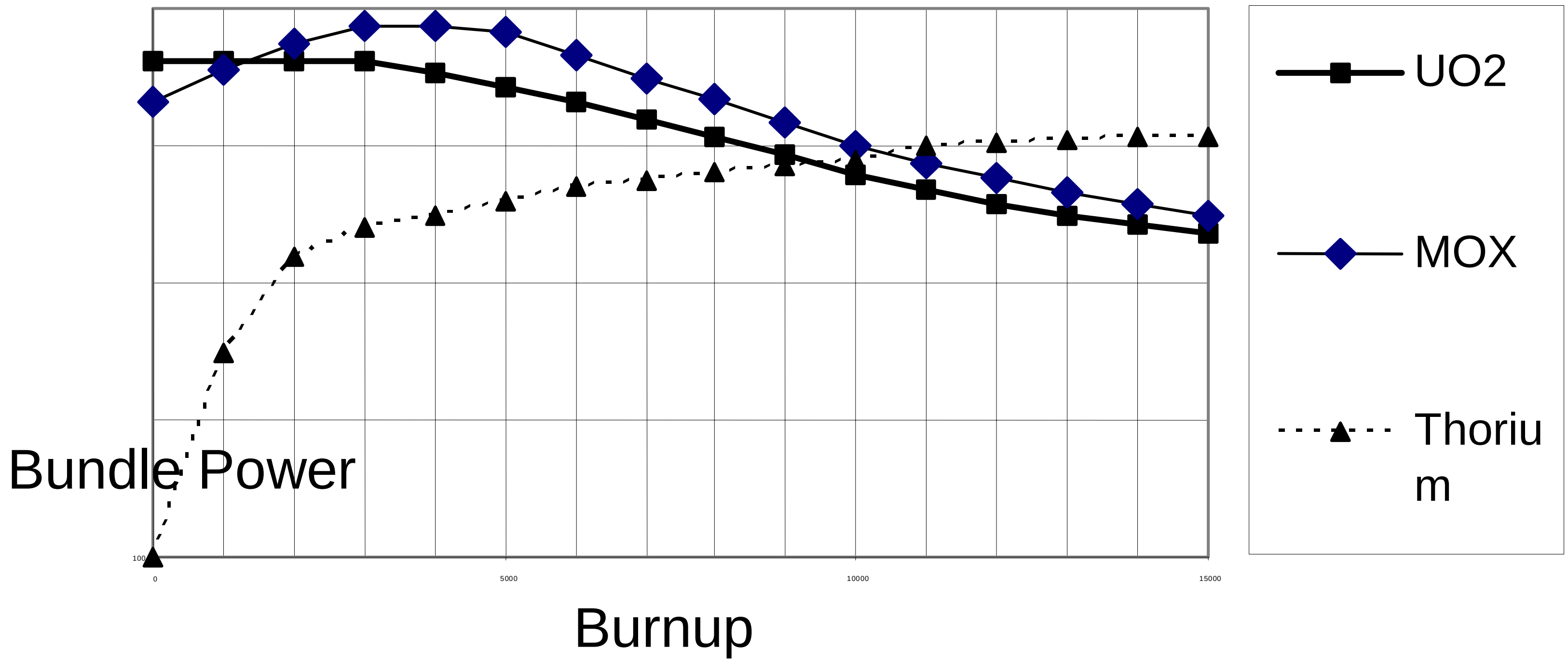


FIGURE 1. Bundle Power Envelopes for Different Fuel Types

TRIAL IRRADIATION
OF 50 MOX-7 BUNDLES

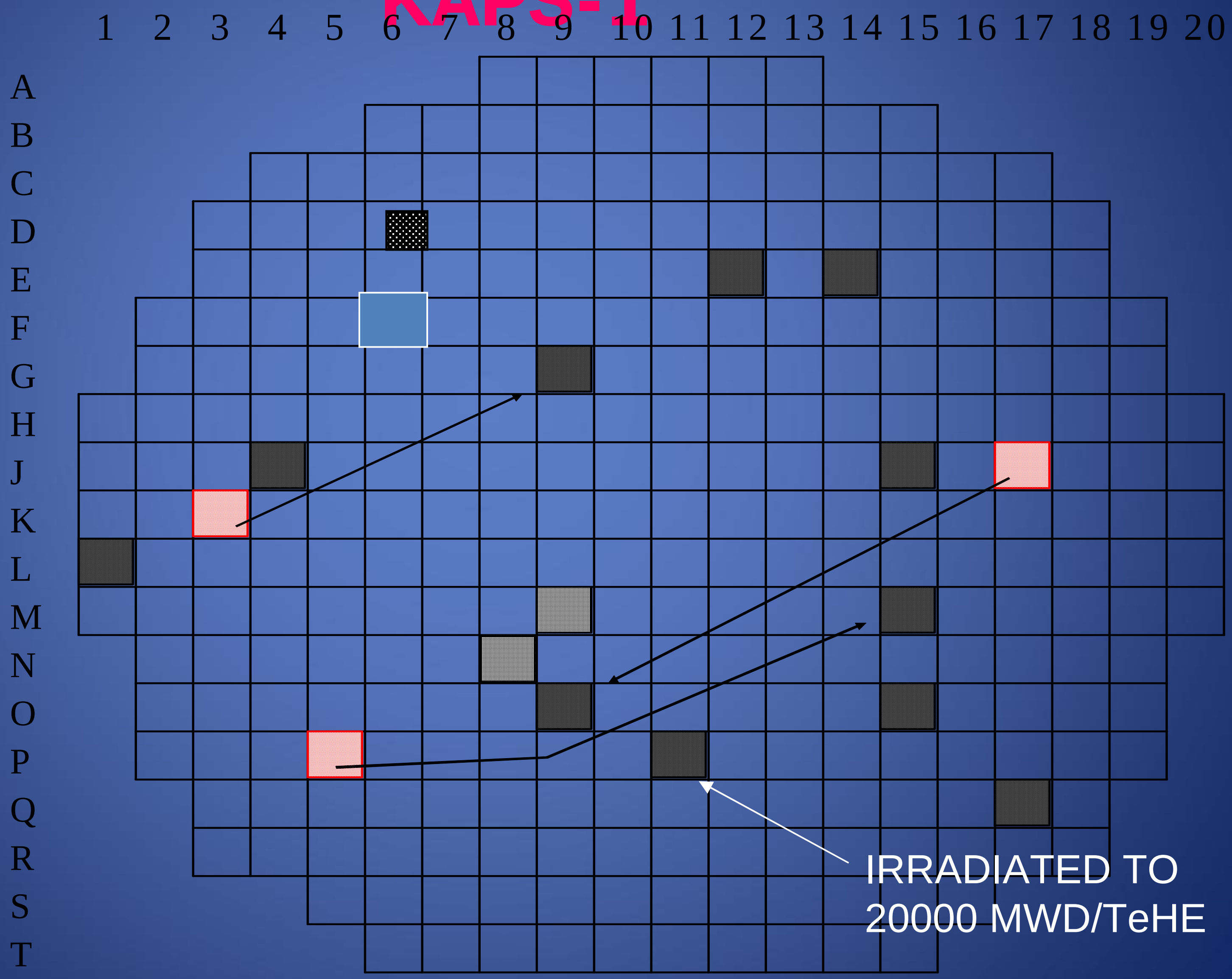
- **Reactor Loading Plan For 50 Bundles For Initial Trials**
- **To Obtain Feed Back On Their Performance Prior To Large Scale Utilization Of MOX-7 Bundles In Phwrs**
- Fabrication Drawings And Specifications
- Transport Procedure Developed
- Bundles Fabricated At NFC and BARC

The loading of 50 MOX-7 bundles in KAPS-1

channels contain 4 MOX-7 bundles at 5-8 string positions

These channels contain only one MOX-7 bundle

Initially 4 MOX-7 bundles were loaded and recycled to the marked channels



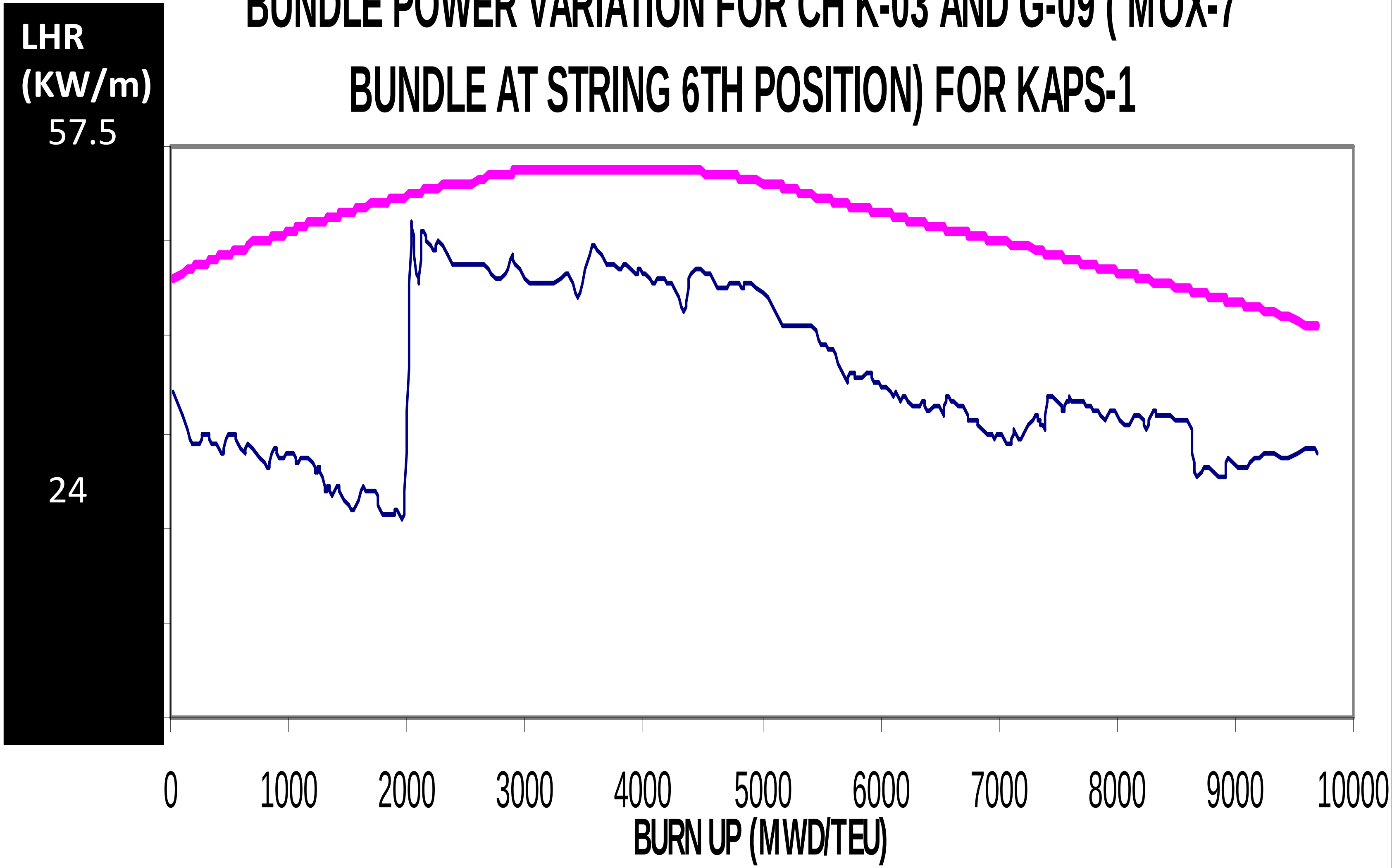
Data of 50 Discharged Bundles

Residence Period	3 years
Maximum LHR	53.6 kW/m
Maximum Burnup	20000 MWd/TeU
Maximum Power ramp	20 kW/m

MOX Experience

- THE 50 DISCHRGED BUNDLES WET SNIFFED and OBSERVED TO BE NORMAL
- NONE OF THESE BUNDELS FAILED.
- Observed Channel Outlet Temperature of MOX-7 loaded channels matches well with the estimated values
- The worth of S/D systems not affected due to loading of MOX-7 bundles.

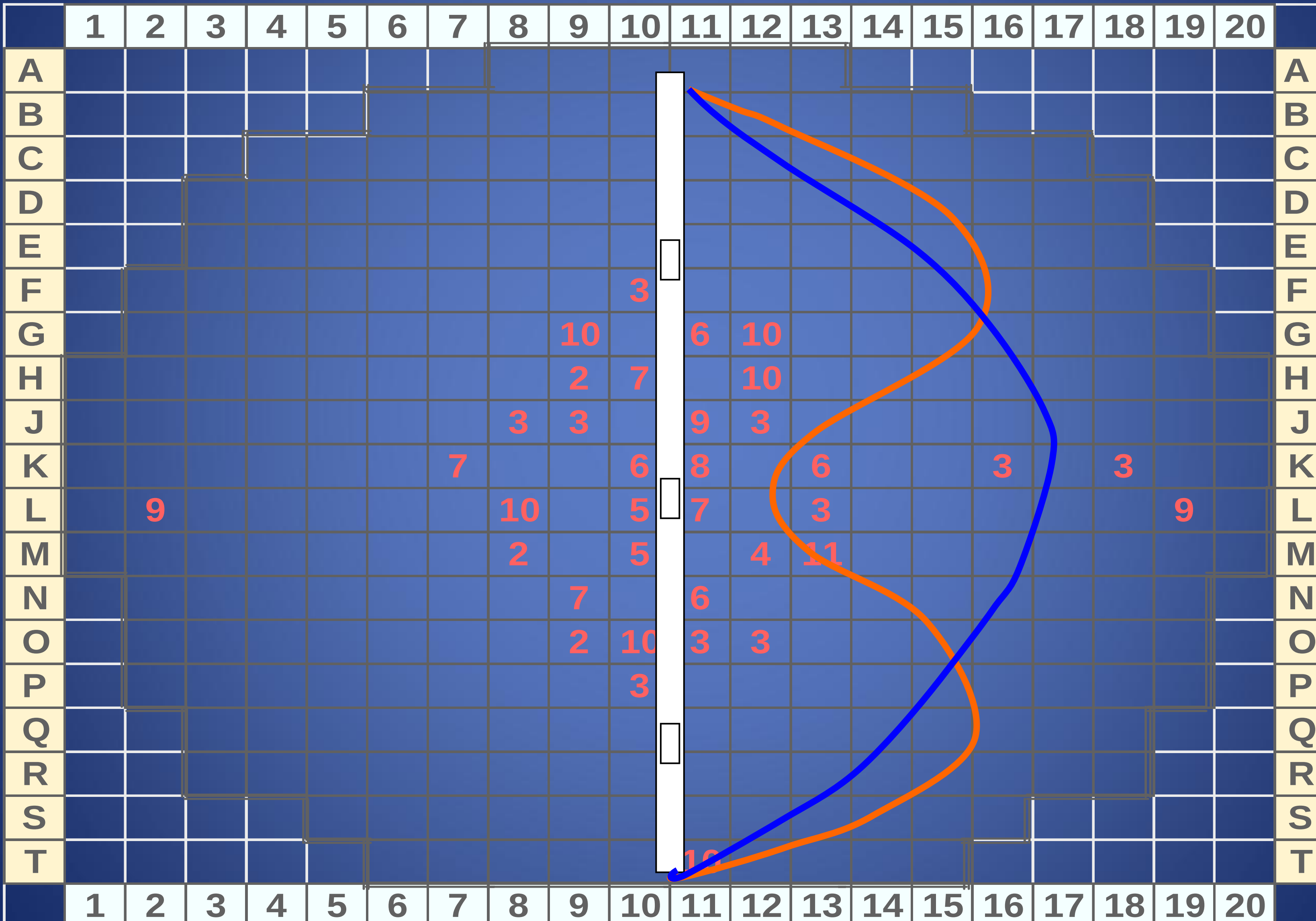
BUNDLE POWER VARIATION FOR CH K-03 AND G-09 (MOX-7 BUNDLE AT STRING 6TH POSITION) FOR KAPS-1



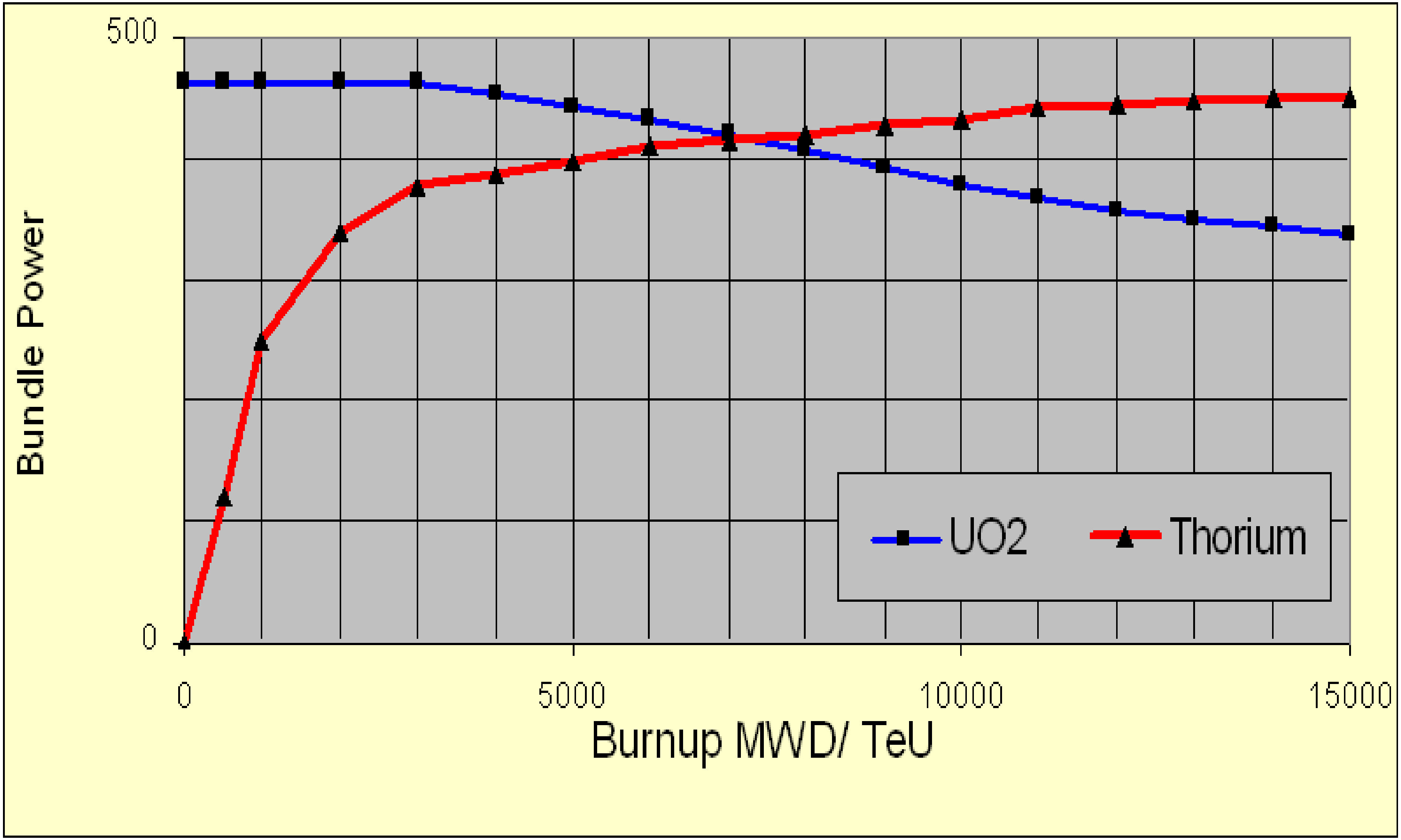
ThO_2 Bundles Objective

- Experience of Fabrication and irradiation of Thorium
- Flux flattening in the initial core such that the reactor can be operated at rated full power in the initial phase

Th Bundle Loading Plan - 35 Bundles



Bundle Power Envelopes for Natural UO2 and ThO2 Fuels



ThO2 Bundle Engineering

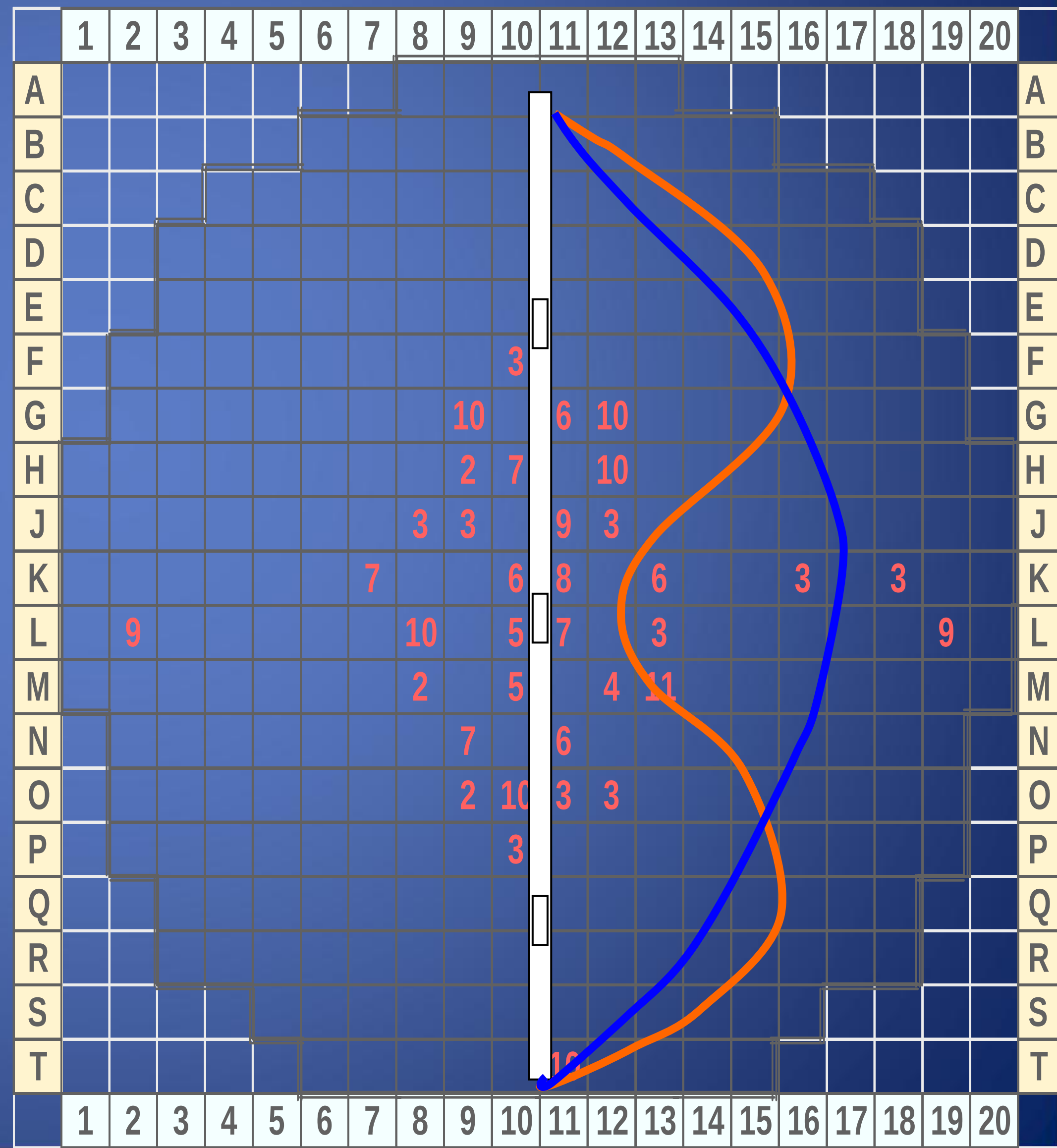
- **DESIGN SIMILAR TO NAT. U BUNDLE DESIGN**

1. Flat, low density pellets used for test irradiation in MAPS-1 in 1986
2. Standard dished pellets with high density - used Subsequently
3. Pellet specification evolved at BARC
4. Element axial and radial gaps specified
5. Bundle identification

Bundles fabricated by NFC

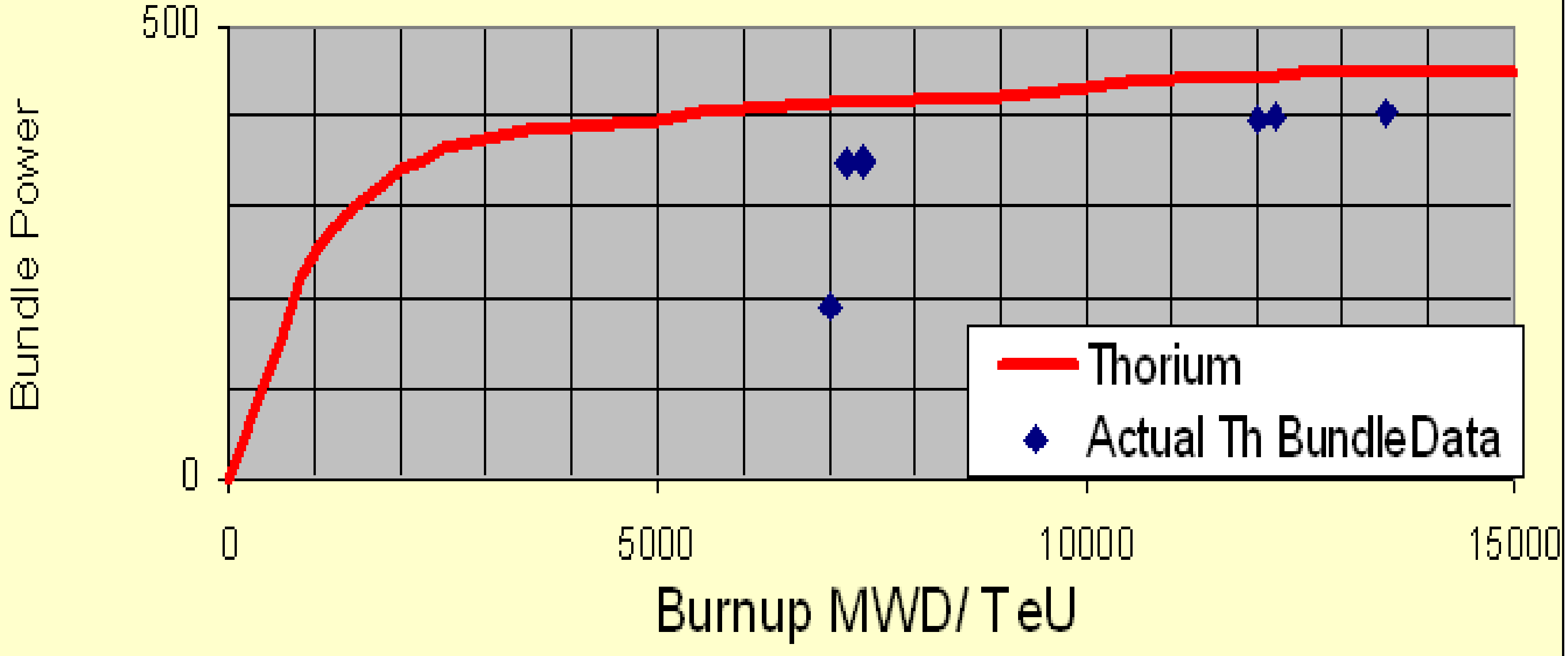
IRRADIATION EXPERIENCE

Reactor	No. Of Bundles Loaded
• MAPS-1	4
• KAPS-1&2	70
• KGS-1 & 2	70
• RAPS 3&4	70
• RAPS-2	18
• Total	232



IRRADIATION EXPERIENCE

Bundle power	410 KW
Peak LHR	50.6 KW/m
Bundle Burnup	13000 MWD/Te Th
Residence Period	3 years



Thorium Bundle Powers and Envelope

•24 OUT OF 35 BUNDLES SEEN POWER RAMP DURING FUELLING

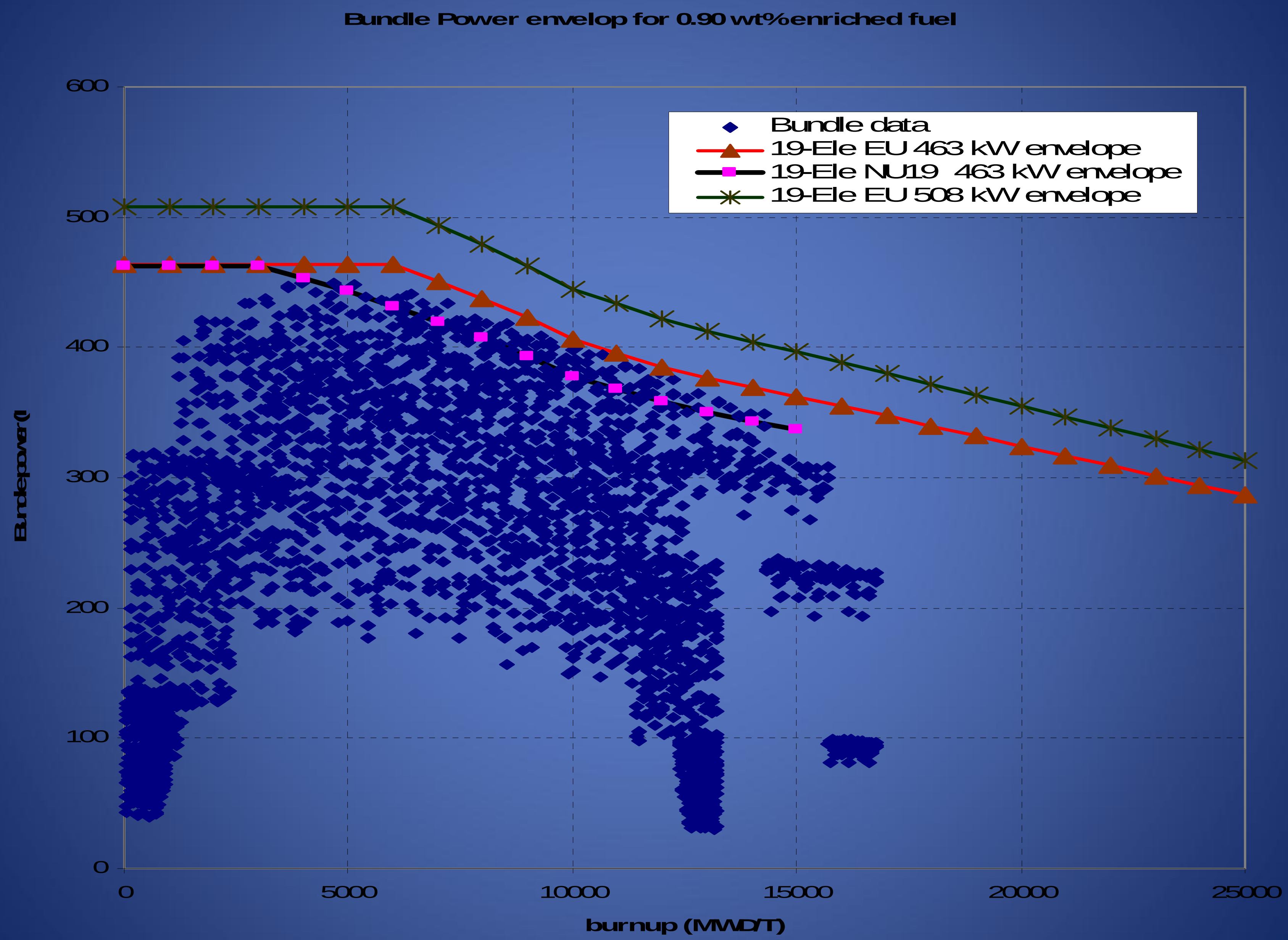
19-Element SEU Fuel Bundle

- Full core Loading studies carried out in respect of 0.9% to 1.1 % U-235 isotopic content
- higher burnup and consequently less annual fuel requirement and spent fuel inventory. The core average discharge burnup increases to 14000 MWd/TeU with 1.1% U235
- Refuelling rate comes down to 4 bundles/FPD
- 2/4 bundle fuelling scheme proposed instead of present 8 bundle fuelling scheme

19-Element SEU Fuel Bundle

- Fuel design and fabrication issues reviewed.
- 19-element and 22-element fuel bundle use
- Studies on reactor physics characteristics like reactor control, shut down margin, fuel and other systems thermal-hydraulic and material compatibility carried out
- Peak Element Burnup expected 20000 MWd/TeU

Bundle Power Envelope



SEU Bundles

- Trial Loading Taken up
- Bundles Fabricated By NFC
- 0.9% SEU 19-element bundles
- Collapsible cladding
- Pellet Design changes - Void volume increased
  - Dish depth – increased
  - Density - Reduced by 1%
- NU pellets kept at the ends of the fuel stack inside the clad to avoid flux peaking
  - Loaded in MAPS-2 Reactor recently

SEU Bundles' Performance

- Fuelled along with NU and in-core recycled bundles
- The bundle powers of all the SEU bundles are within the bundle power limit.

Other Bundle Types Test Irradiated in the PHWRs

Bundle Type	Maximum burnup (MWD/TeU)	Maximum LHR (W/cm)
MOX-7	20000 MWD/TeHE	536
Thorium	13000 MWD/Te Th	488
Recycled Uranium	7000 MWD/TeU	550
Natural Uranium	22000 MWD/TeU	550
SEU BUndles	1800 MWD/TeU(so far)	425

Thank you

pnprasad@npcil.co.in