TWO DECADES OF OPERATING EXPERIENCE WITH THE FAST BREEDER TEST REACTOR
(ORU-31)

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Overview of Presentation

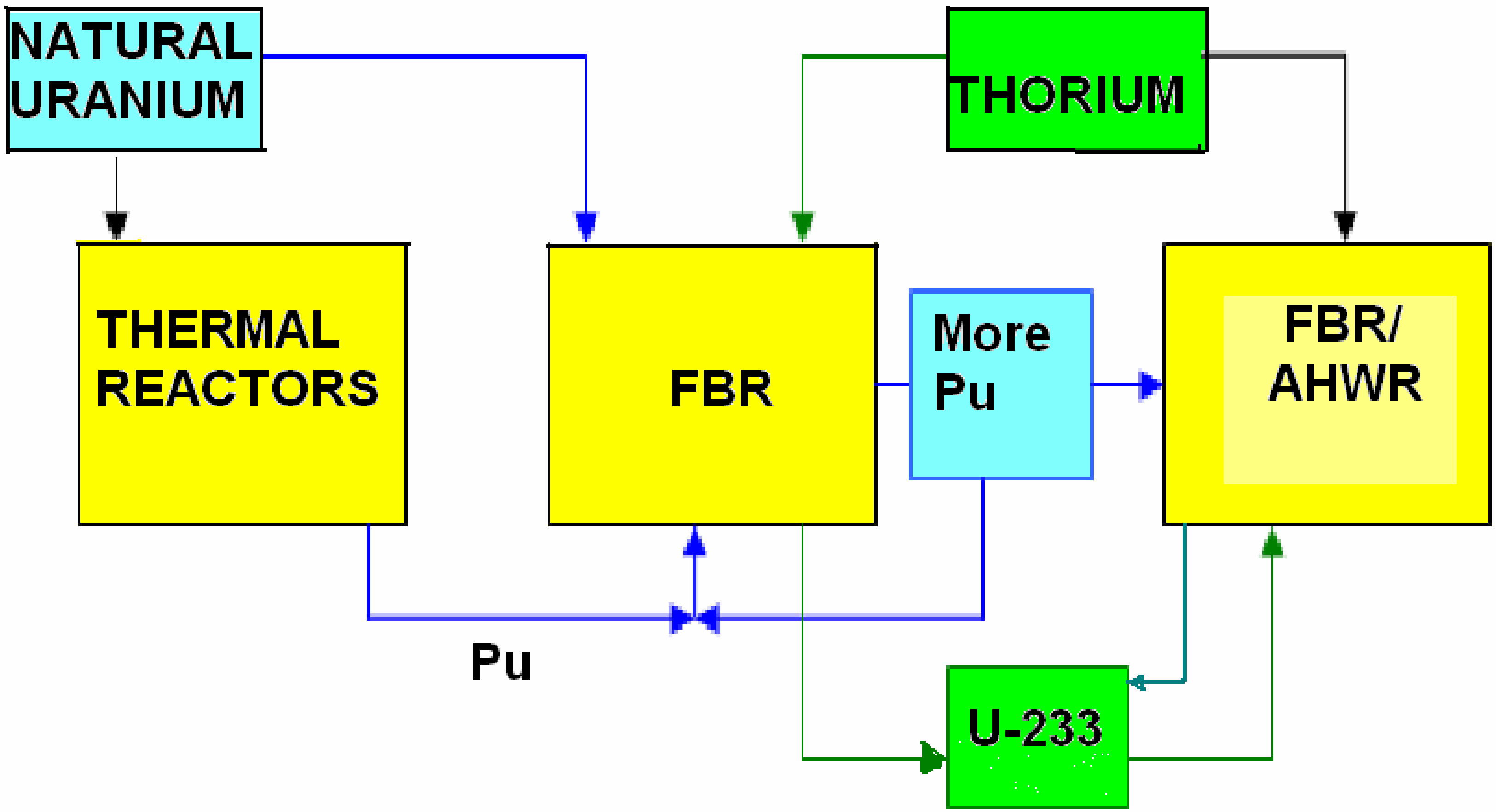
- India’s Three stage nuclear programme
- Overview of FBTR
- Performance Statistics
- Evolution of core
- Performance of carbide fuel
- Experiments
- Incidents
- Conclusion

Indian Nuclear Programme

The uranium reserves of India can sustain a programme of only 10 GWe through the PHWR route.

The Indian nuclear programme hence envisages three stages:

- ❖PHWR operating with natural uranium and heavy water
- ❖Conversion of U^{238} into Pu & deployment in sodium cooled fast reactors.
- ❖Conversion of abundantly available Thorium into U^{233} in fast reactors and Advanced Heavy Water Reactors as a long term strategy.



THREE STAGE NUCLEAR PROGRAMME

Overview of FBTR

- Built as a fore-runner to the second stage of India's Three-stage Nuclear programme
- 40 MWt sodium-cooled fast reactor, based on the design of the French reactor Rapsodie.
- Rapsodie had a sodium-air heat exchanger as the terminal heat sink. Instead, FBTR was designed with four steam generator modules and a steam water circuit with TG and bypass dump condenser to gain experience in operating a full fledged fast reactor power station

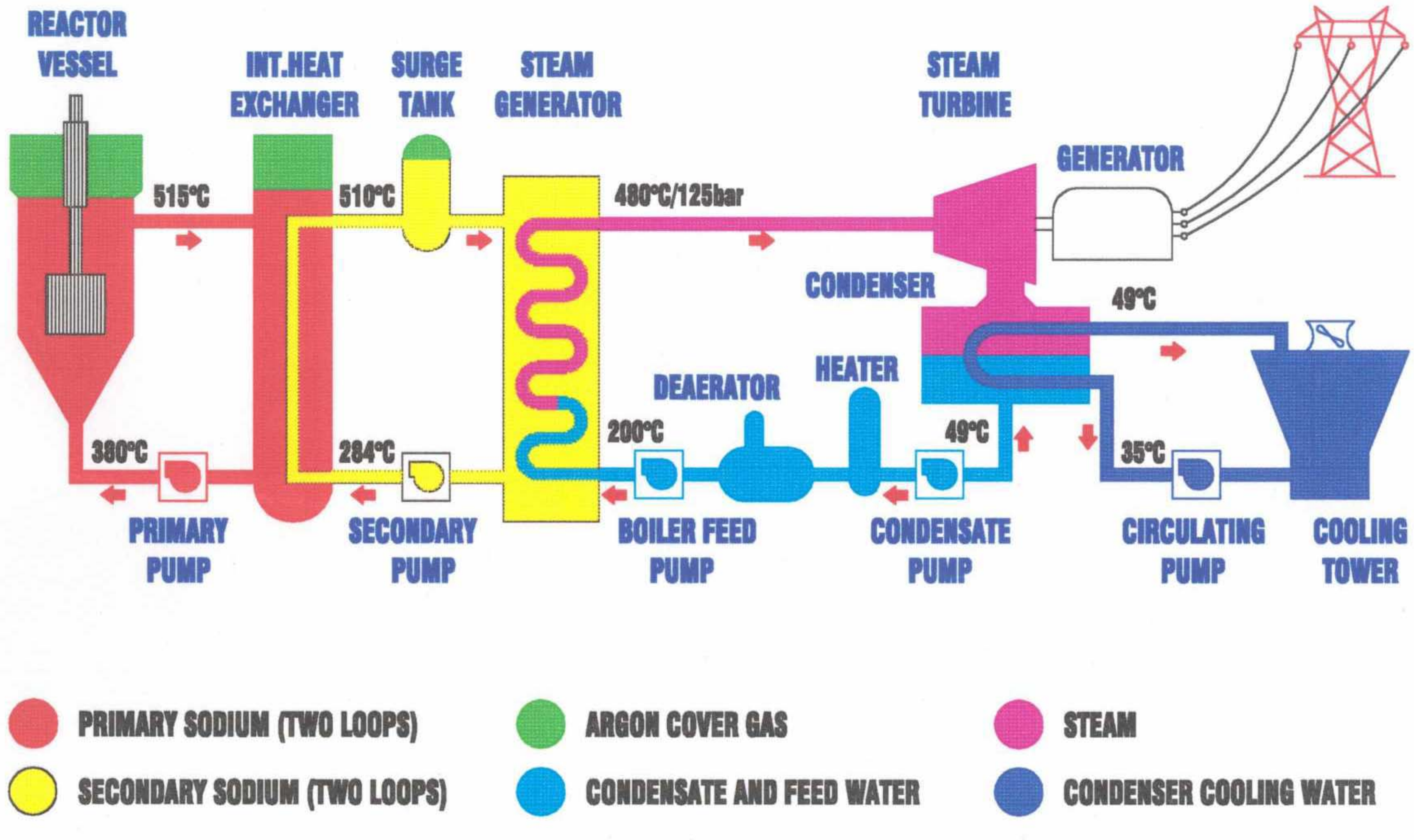
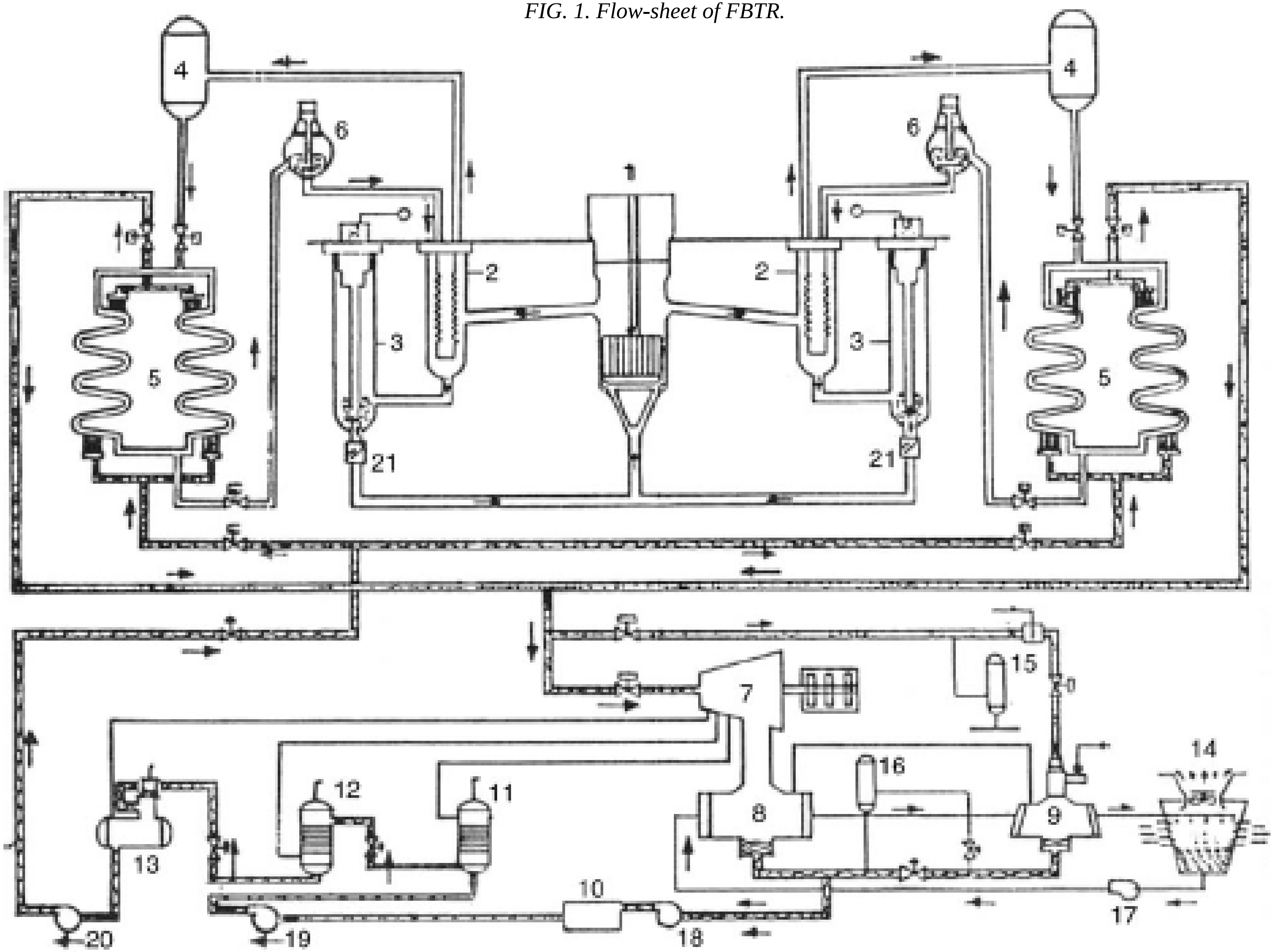


FIG.1.FBTR FLOW SHEET

FIG. 1. Flow-sheet of FBTR.



Historical Milestones

Date	Milestone
18th Oct 1985	First criticality
Nov `89	Sodium Valved in into SG
Jan `93	Water Valved in into SG
Dec `93	Power of 10.5 MWt
94-95	High Power Safety Related experiments
May `96	MK-I reaches a burn-up of 25 GWd/t
Oct `96	Start of Loading of MK-II fuel
July ‘97	TG synchronized to grid

Historical Milestones

Date	Milestone
98-99	Zr-Nb irradiation
Apr `99	MK-I reaches a burn-up of 50 GWd/t
March 2002	Power of 17.4 MWt
Sep 2002	MK-I reaches a burn-up of 100 GWd/t
July 2003	Start of PFBR Test Fuel Irradiation
July 2006	MK-I reaches burn-up of 155 GWd/t without failure
Feb 2007	Eight High Pu MOX loaded
Oct 2007	PFBR Test Fuel reaches 62 GWd/t burn-up

Summary of Performance Statistics from 1985 (upto 31st March 2007)

Parameter	Unit	Cumulative Values
Maximum Power	(MWt/ MWe)	17.4/ 2.2
Maximum LHR	(W/cm)	400
Operating time	(h)	38313
Thermal energy produced	(GWh)	279
Electrical energy generated	(GWh)	5.425
Four Na Pumps operation time	(h)	581691
Steam Generator operating time	(h)	21529
Reactor Trips	No.	411

Evolution of Core

Rapsodie reactor had a core of 65 MOX fuel subassemblies with 30% PuO_2 & 70% UO_2. The uranium was highly enriched in U^{235} (85%).

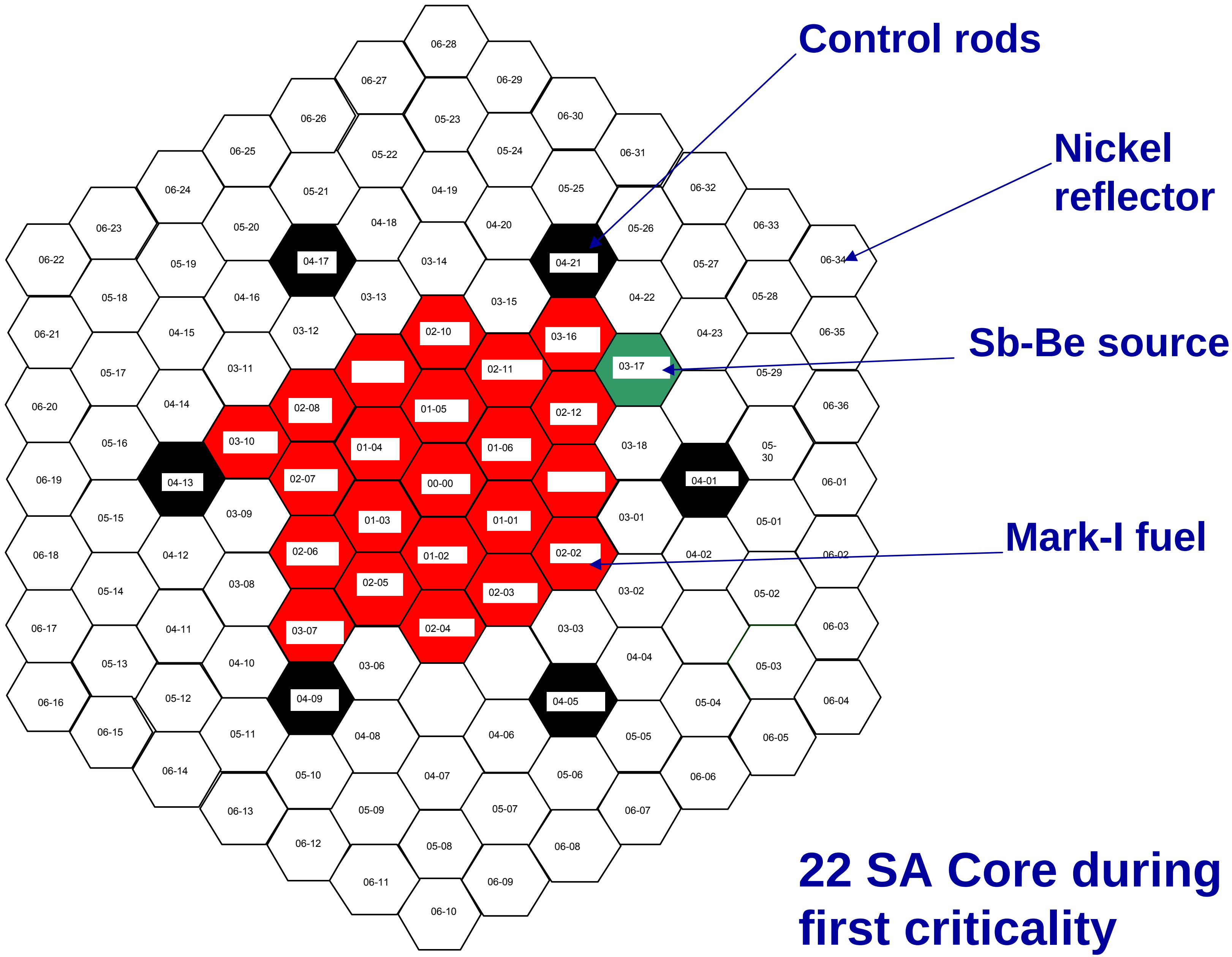
Since such highly enriched uranium was not available, FBTR core was designed with high Pu and natural U. From fabrication and sodium compatibility considerations, MOX fuel with high Pu content was not feasible. Hence the carbide option was chosen for FBTR after detailed studies. Mark-I fuel with 70% PuC & 30% UC was chosen for the initial core.

Core Evolution (continued)

- FBTR went critical on 18th Oct 1985 with 22 fuel subassemblies of Mark-I composition (70%PuC + 30%UC)
- The core has been progressively expanded by adding fuel subassemblies to compensate for reactivity loss due to burn-up.
- To increase the core size & power, Mark-II subassemblies with lower Pu composition (55%PuC+45%UC) were progressively inducted surrounding the Mark-I in 1996.

Core Evolution (continued)

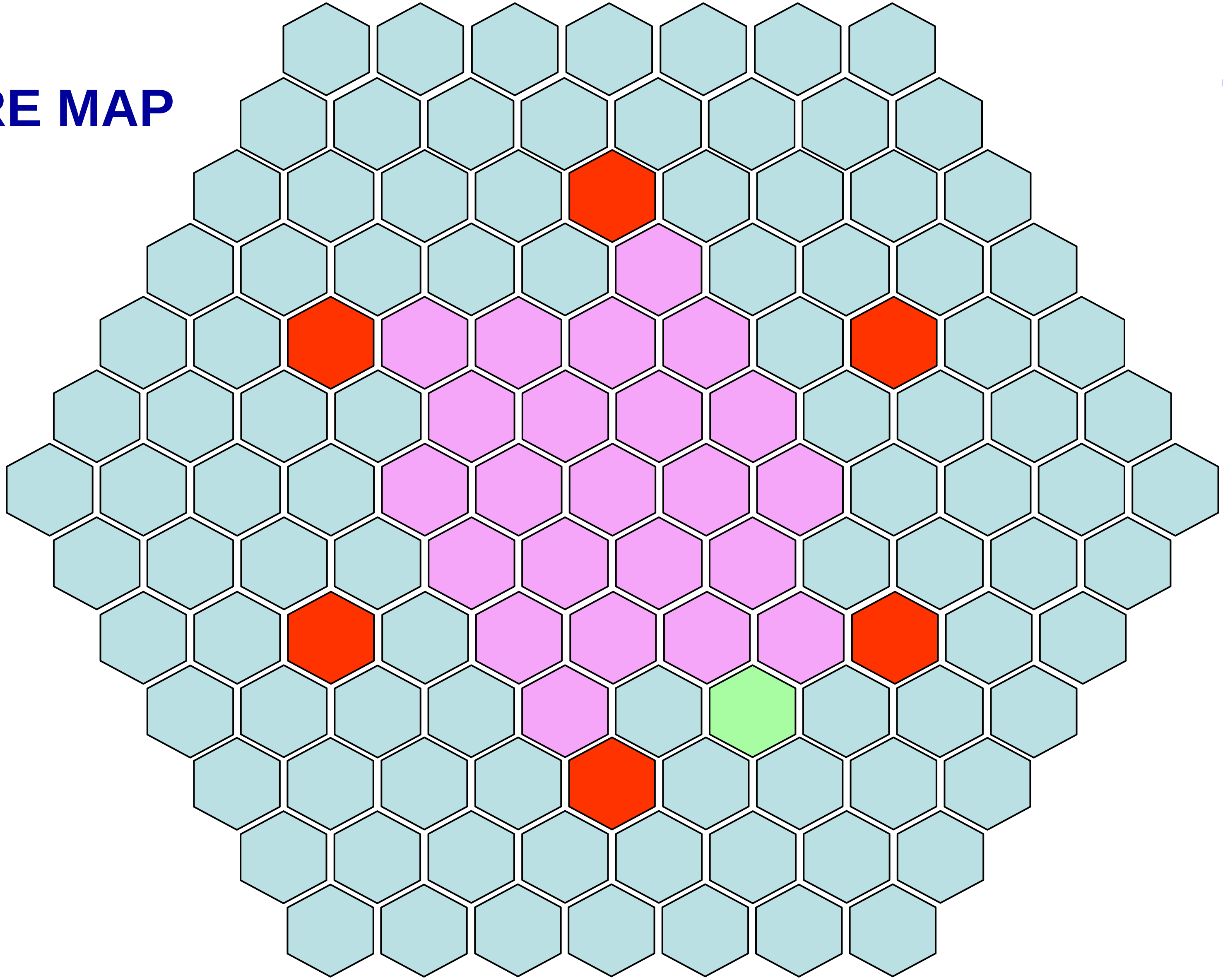
- It was decided to retain Mark-I till its endurance limit.
- As against the expected burn-up limit of 25 GWd/t, the Mark-I fuel reached 155 GWd/t without failure.
- 13 Mark-II could only be loaded so far to compensate for reactivity loss due to burn-up.
- In 2007, we loaded eight high Pu MOX (44% PuO_2) to gain experience in MOX fuel fabrication and reprocessing.
- The current core has 27 Mark-I, 13 Mark-II & eight MOX fuel, in addition to a test fuel simulating power reactor fuel.



22 SA Core during first criticality

CORE MAP

1



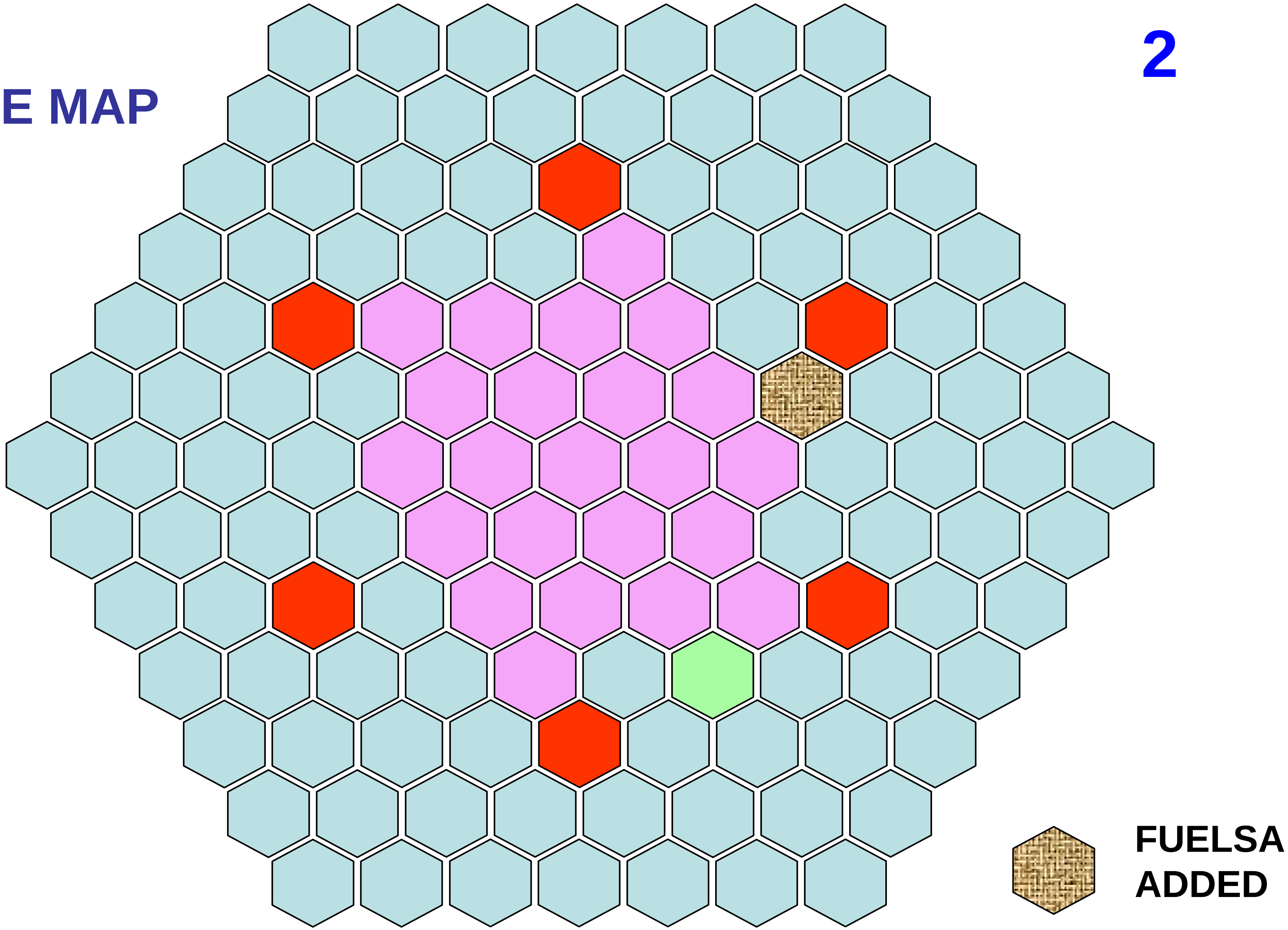
INITIAL CORE

23 FUEL SA CORE

S

CORE MAP

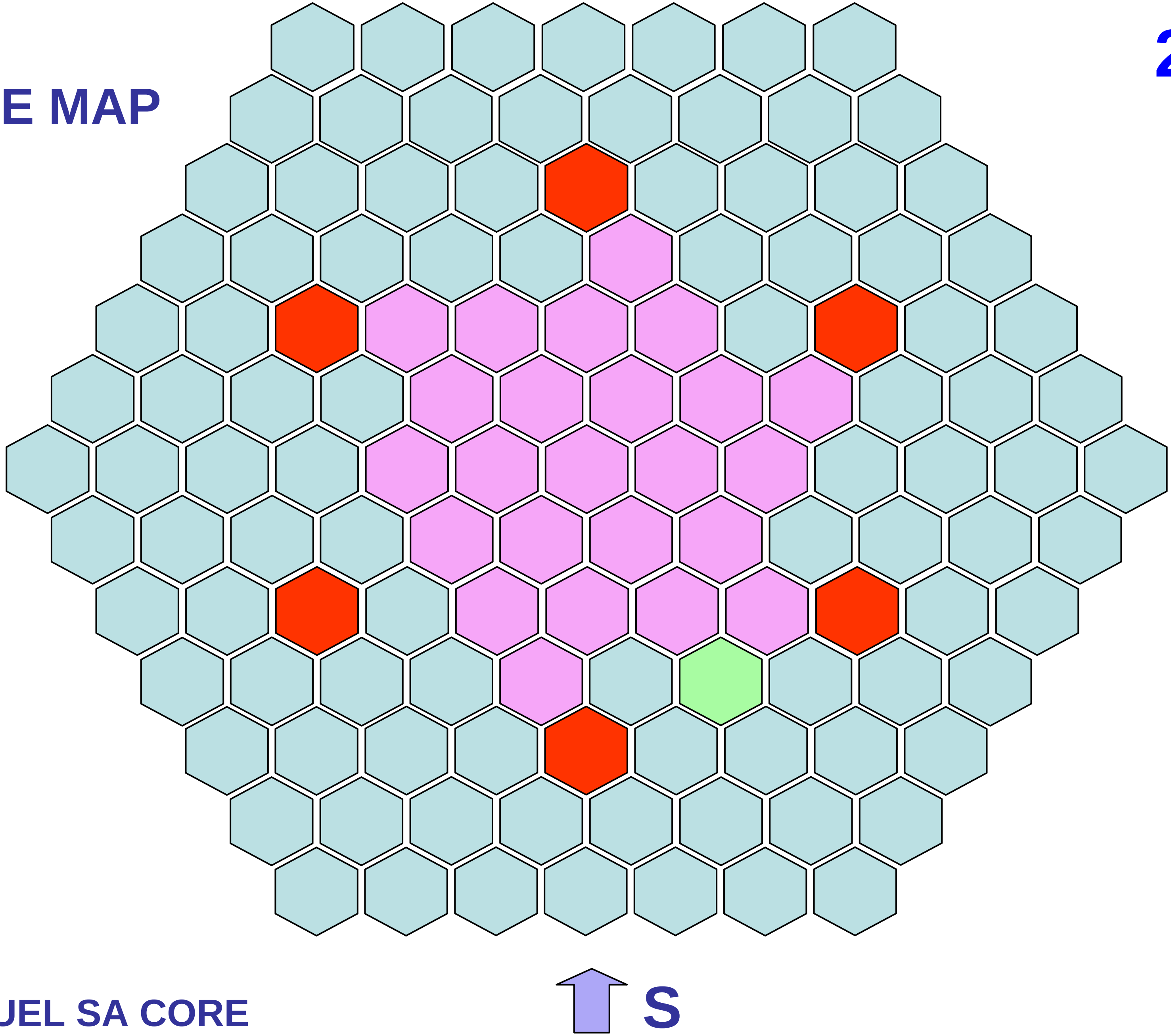
2



S

24 FUEL SA CORE

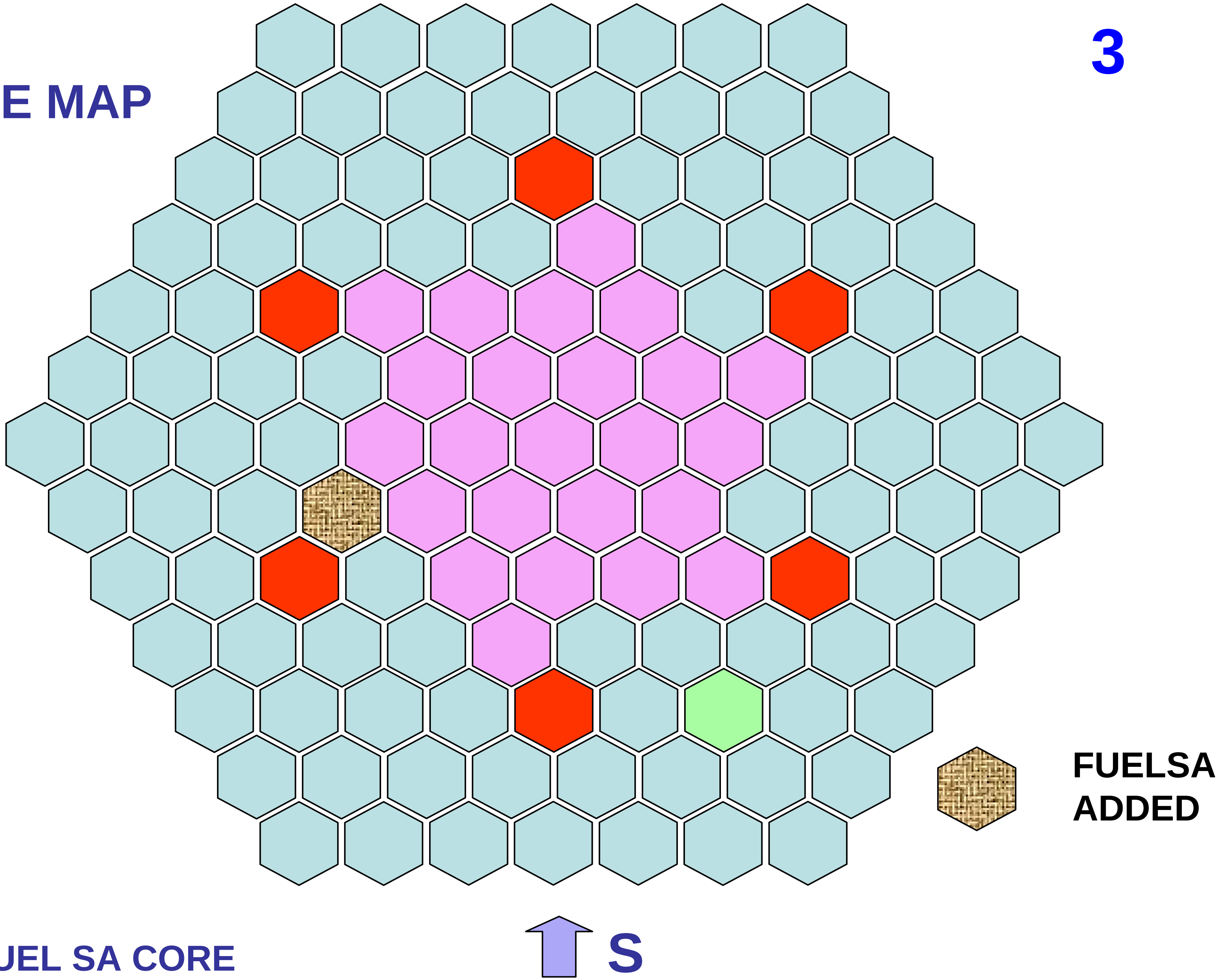
CORE MAP



24 FUEL SA CORE

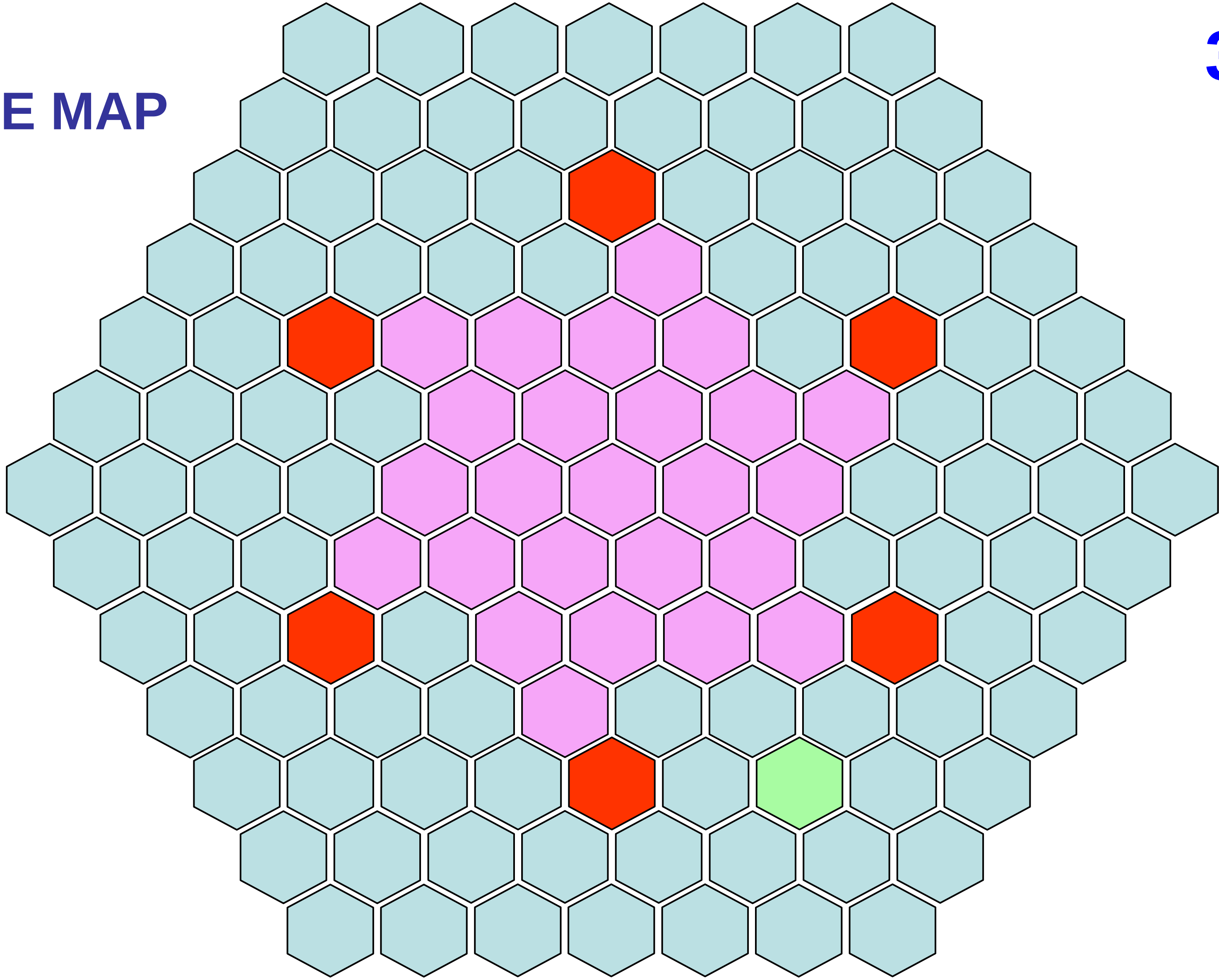
CORE MAP

3

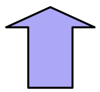


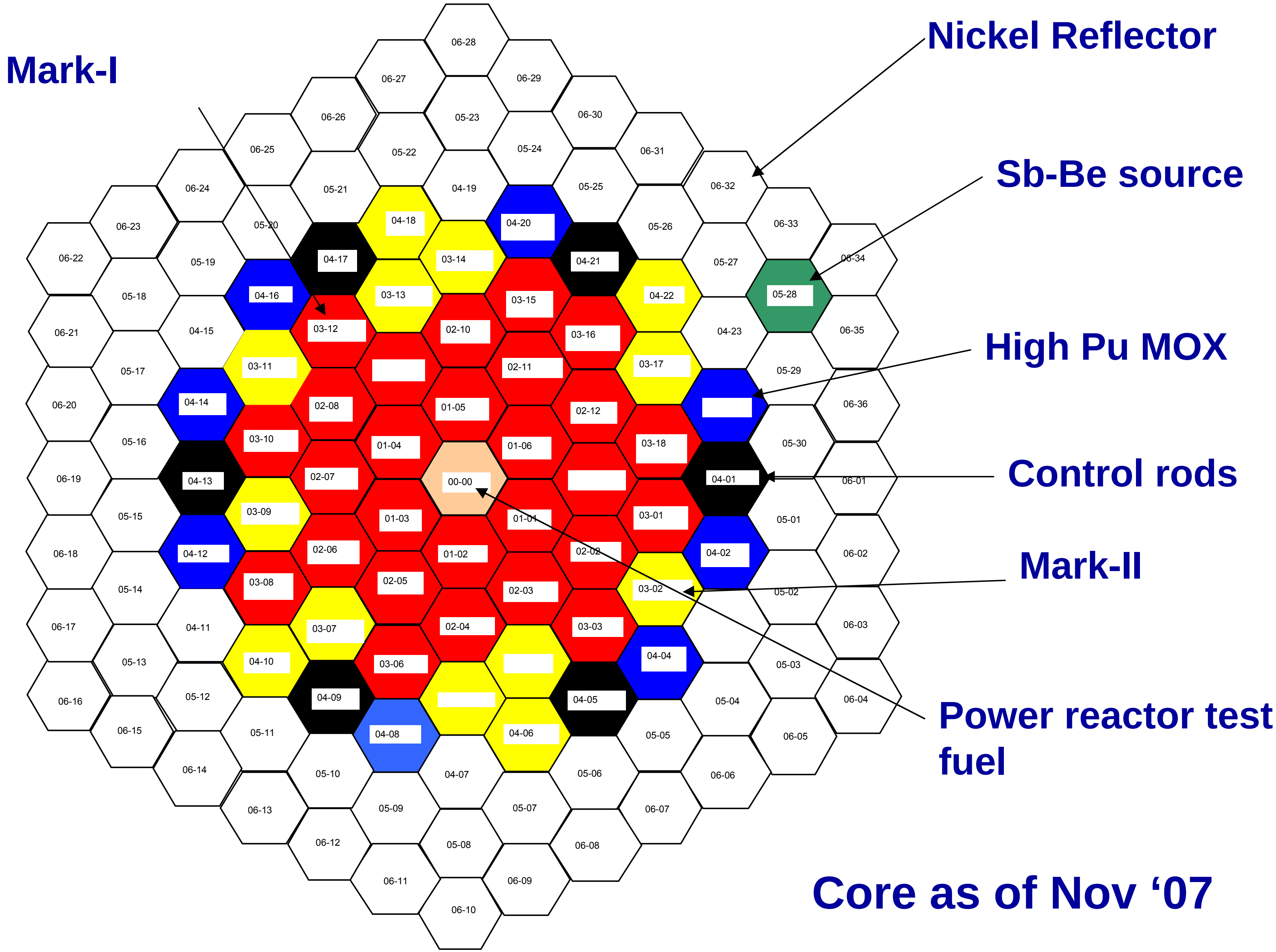
25 FUEL SA CORE

CORE MAP

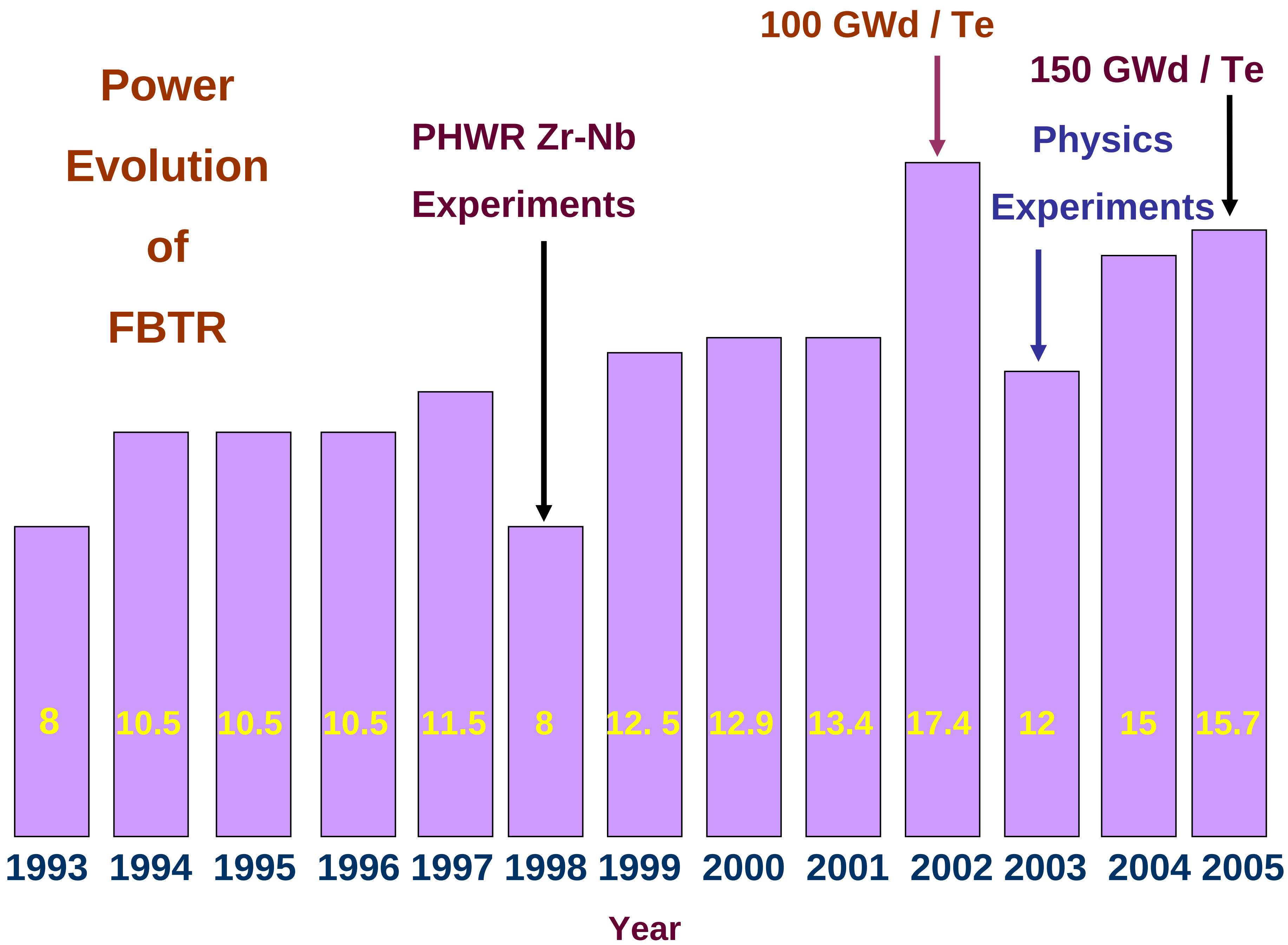


25 FUEL SA CORE





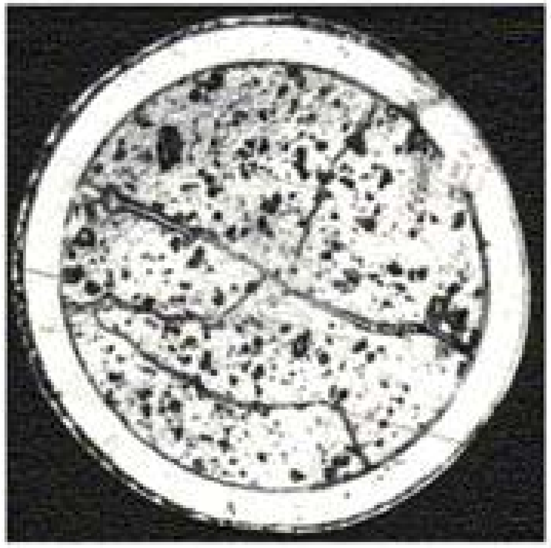
Core as of Nov ‘07



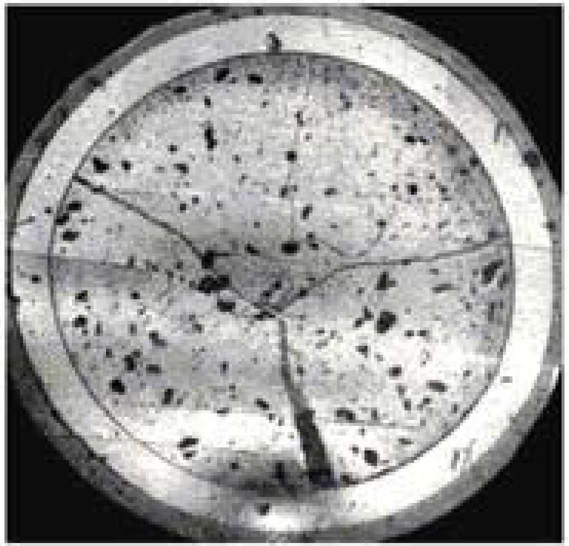
Power
Evolution
of
FBTR
PHWR Zr-Nb
Experiments
100 GWd / Te
150 GWd / Te
Physics
Experiments
8
10.5
10.5
10.5
11.5
8
12. 5
12.9
13.4
17.4
12
15
15.7
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

Performance of the Carbide Fuel

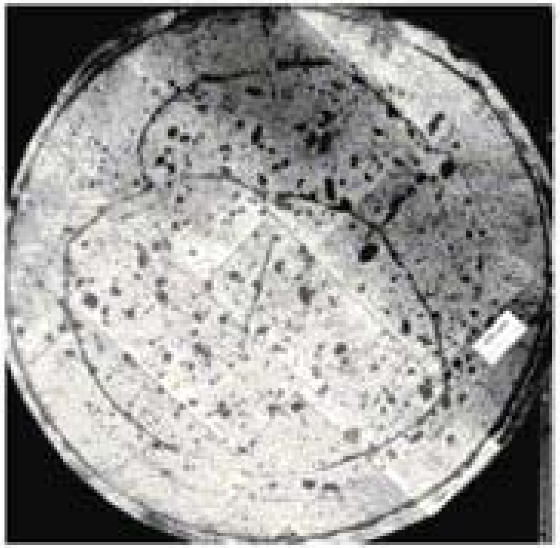
- The fuel chosen for FBTR is unique and without any international parallel.
- Due to lack of irradiation experience, LHR was initially limited to 250 W/cm and burn-up 25 GWd/t.
- LHR was raised to 320 W/cm in 1995 after out-of-pile simulation tests
- Burn-up limit progressively raised upto 155 GWd/t based on Post-Irradiation Examination at 25, 50 & 100 GWd/t.
- Fuel has reached this limit without any failure
- PIE @ 155 GWd/t in progress. Probably no further scope due to clad ductility



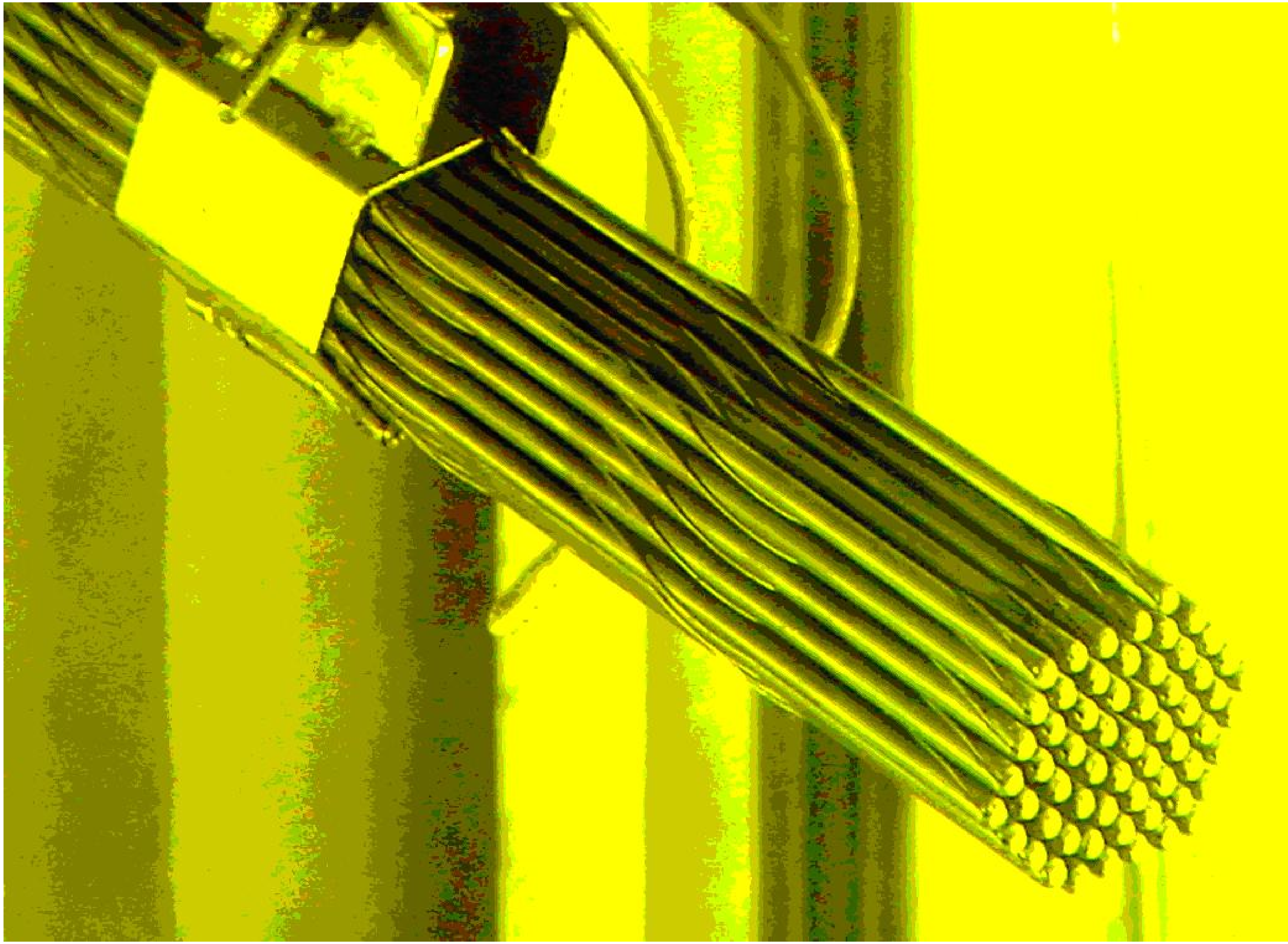
25 GWd/t

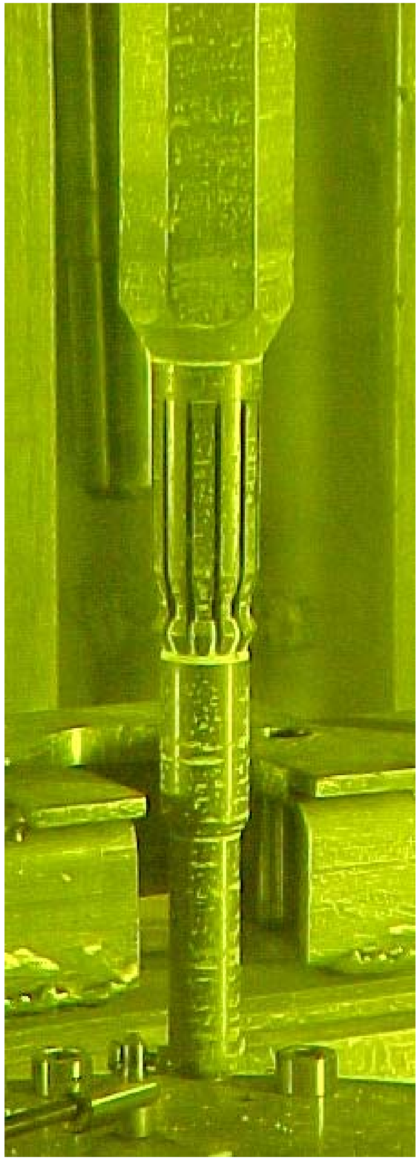
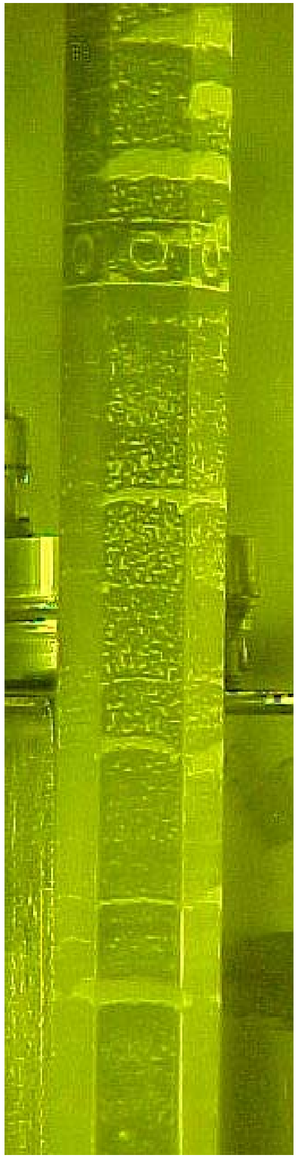
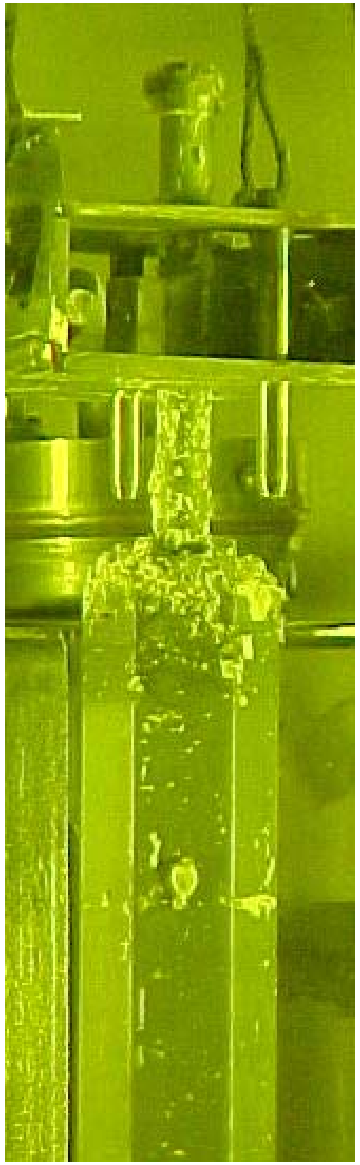


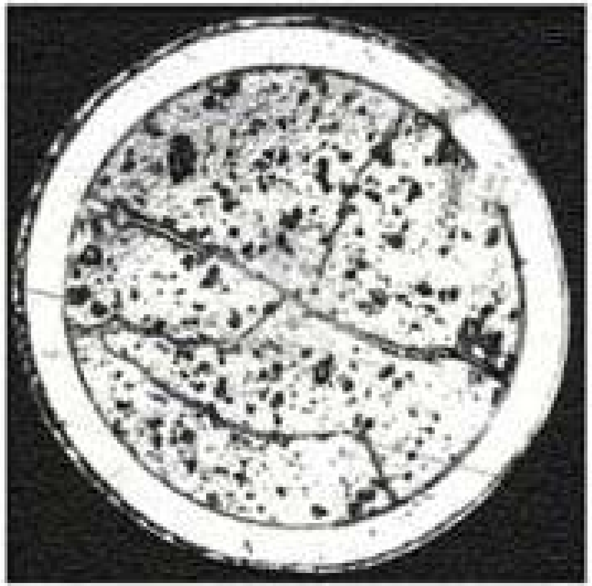
50 GWd/t



100 GWd/t

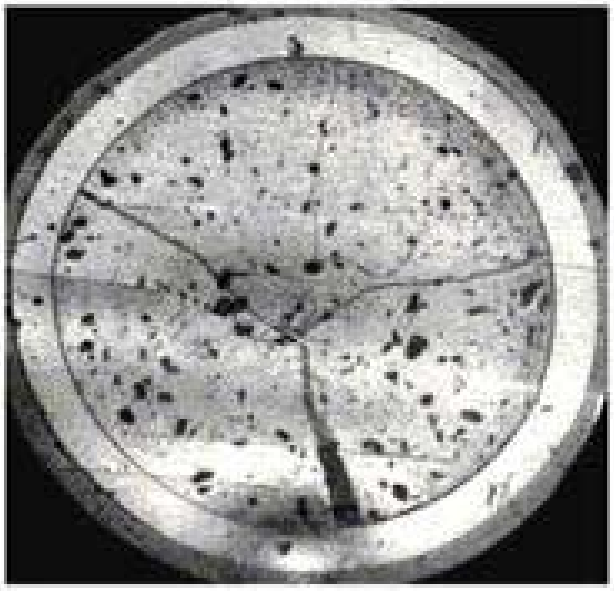




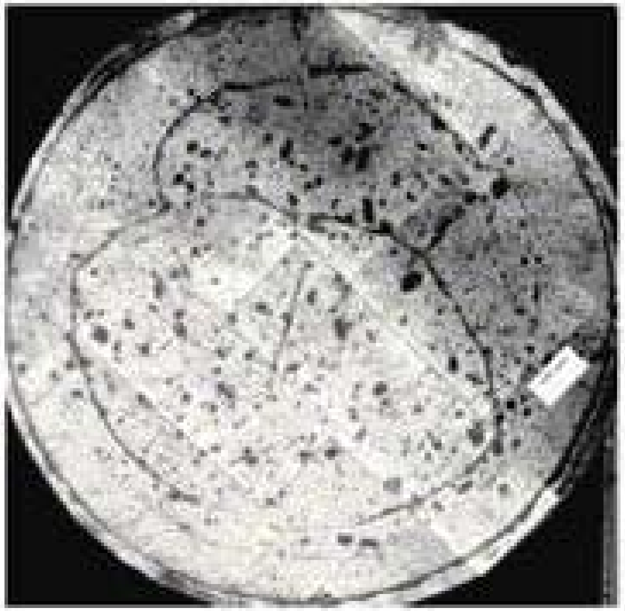
25 GWd/t

- ❖ No increase in clad diameter
- ❖ Fuel swelling: 1.2 % per atom percent burn-up
- ❖ Fission gas release: Negligible
- ❖ Burn-up limit raised to 65 GWd/t.
- ❖ LHR limit raised to 400 W/cm after a burn-up of 35 GWd/t



50 GWd/t

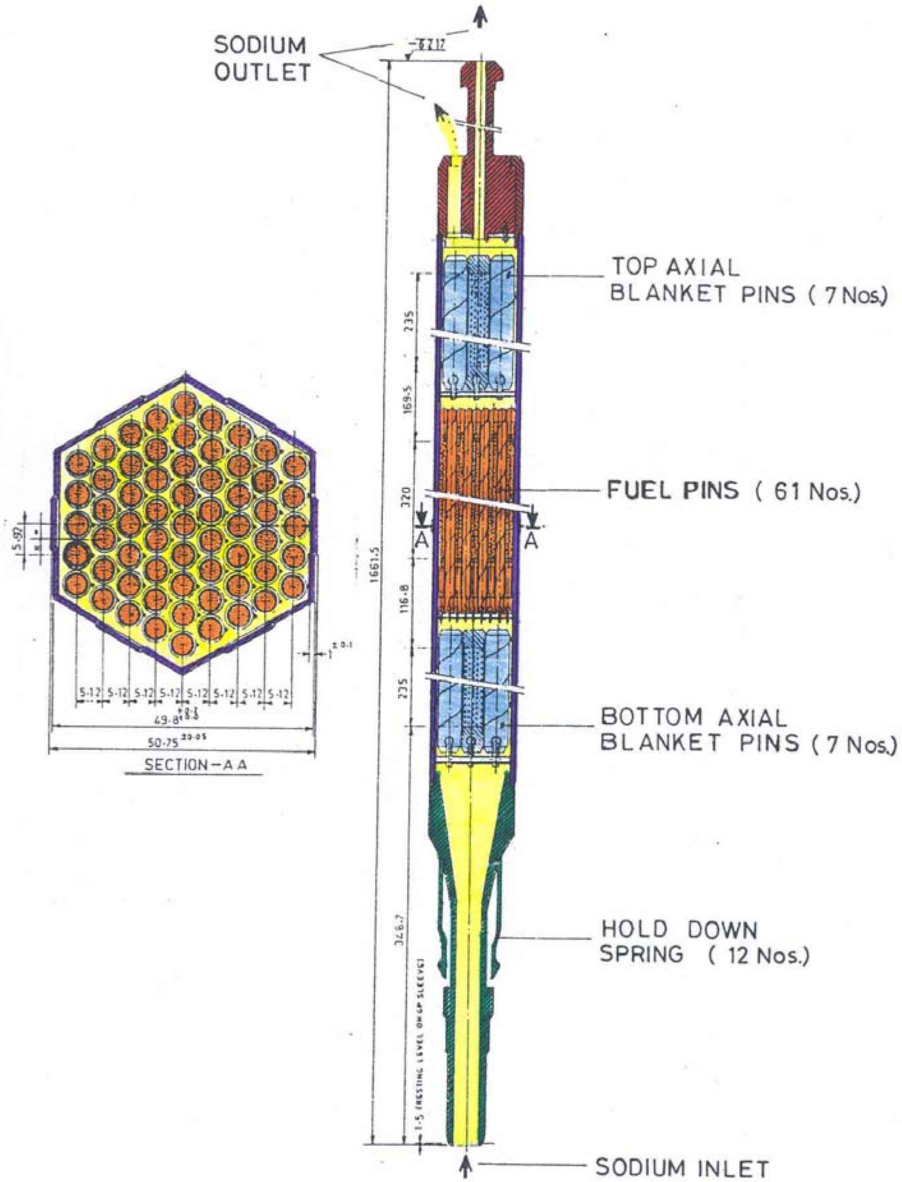
- Fuel-Clad gap: 20-30 μm
- No significant increase in clad diameter
- Fuel swelling rate: 1.5% per atom percent burn-up
- Fission gas release: 5 to 6%
- No measurable increase in the flat-to-flat distance across the hexagonal wrapper of the sub-assembly



100 GWd/t

- Clad diameter increase by 1.2 – 1.6%
- No fuel-clad gap, but no clad carburization
- Fuel swelling rate: <1% per atom percent burn-up
- Fission gas release: 14 %

(Continued)



FBTR FUEL SUBASSEMBLY

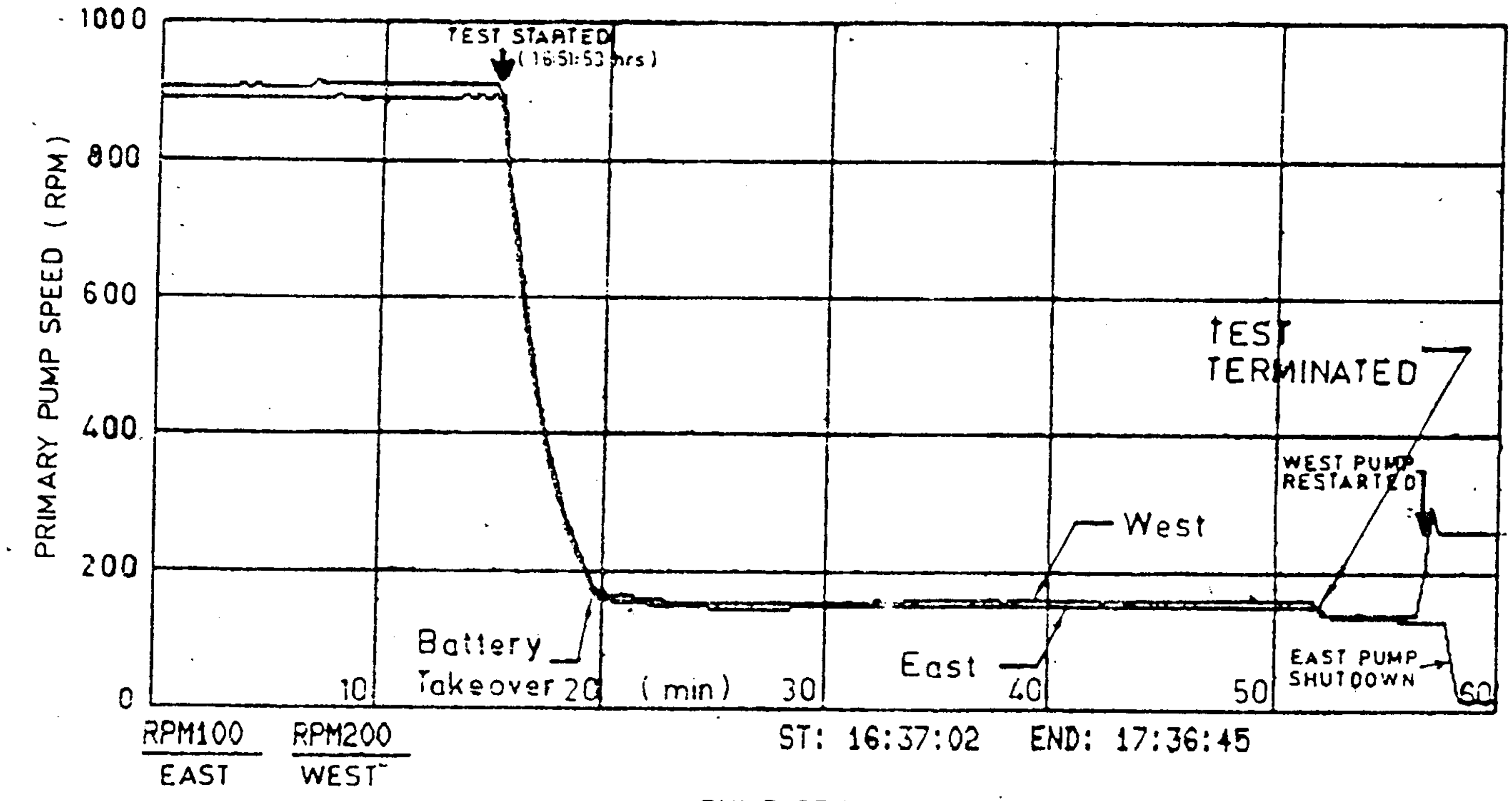
- Flat-to-flat distance across the hexagonal wrapper of the sub-assembly: 0.7 %
- There was a 4.3 mm head-to-foot misalignment of the subassembly due to differential swelling of its faces
- Wrapper ductility @ 430ºC: 3% (Uniform elongation)
- Burn-up limit raised to 155 GWd/t.
- To take care of difficulties in fuel handling due to swelling of the wrapper faces, the force required to extract the subassemblies was periodically monitored and trended.
- Burn-up of 155 GWd/t reached without any failure

Physics Experiments

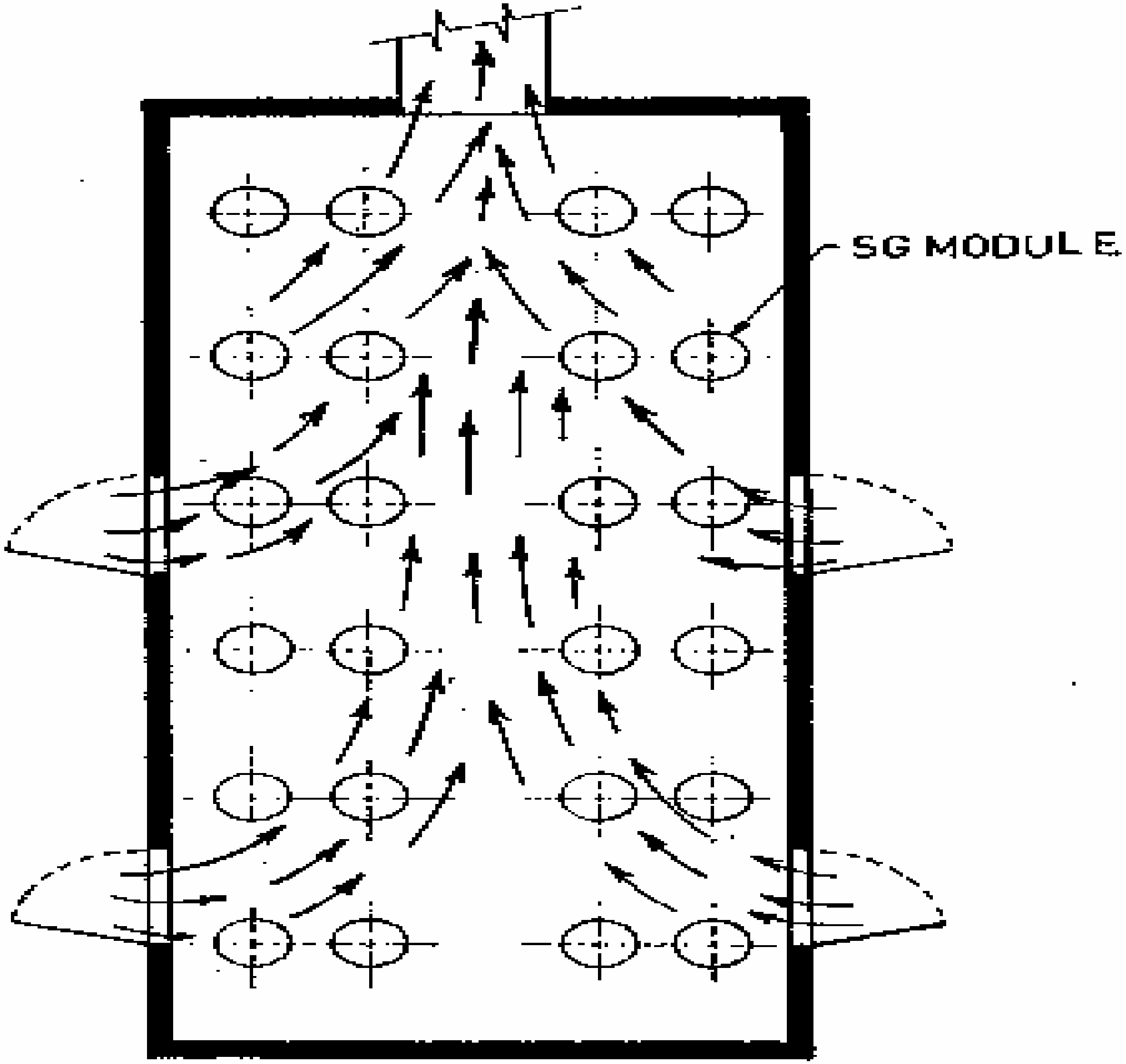
- Control rods calibrated after every fuel handling
- Temperature & power feed-back coefficients measured at the start of each campaign
- Void coefficient measured at various locations and confirmed to be negative
- Flux mapping above core
- Validation of the Delayed Neutron Detection System to detect and identify failed fuel
- Measurement of fast flux at the core support location as a part of Plant Life Assessment (in progress)

Safety Related Experiments

- Plant Transients
  - Offsite power failure
  - Tripping of feed water, secondary sodium & primary sodium pumps
- Safety Related Tests
  - Heat removal capacity through natural convection of air around the steam generators
  - Primary pump coasting down & battery take-over
  - Natural Convection in the primary system and secondary system



PUMP SPEED Vs TIME

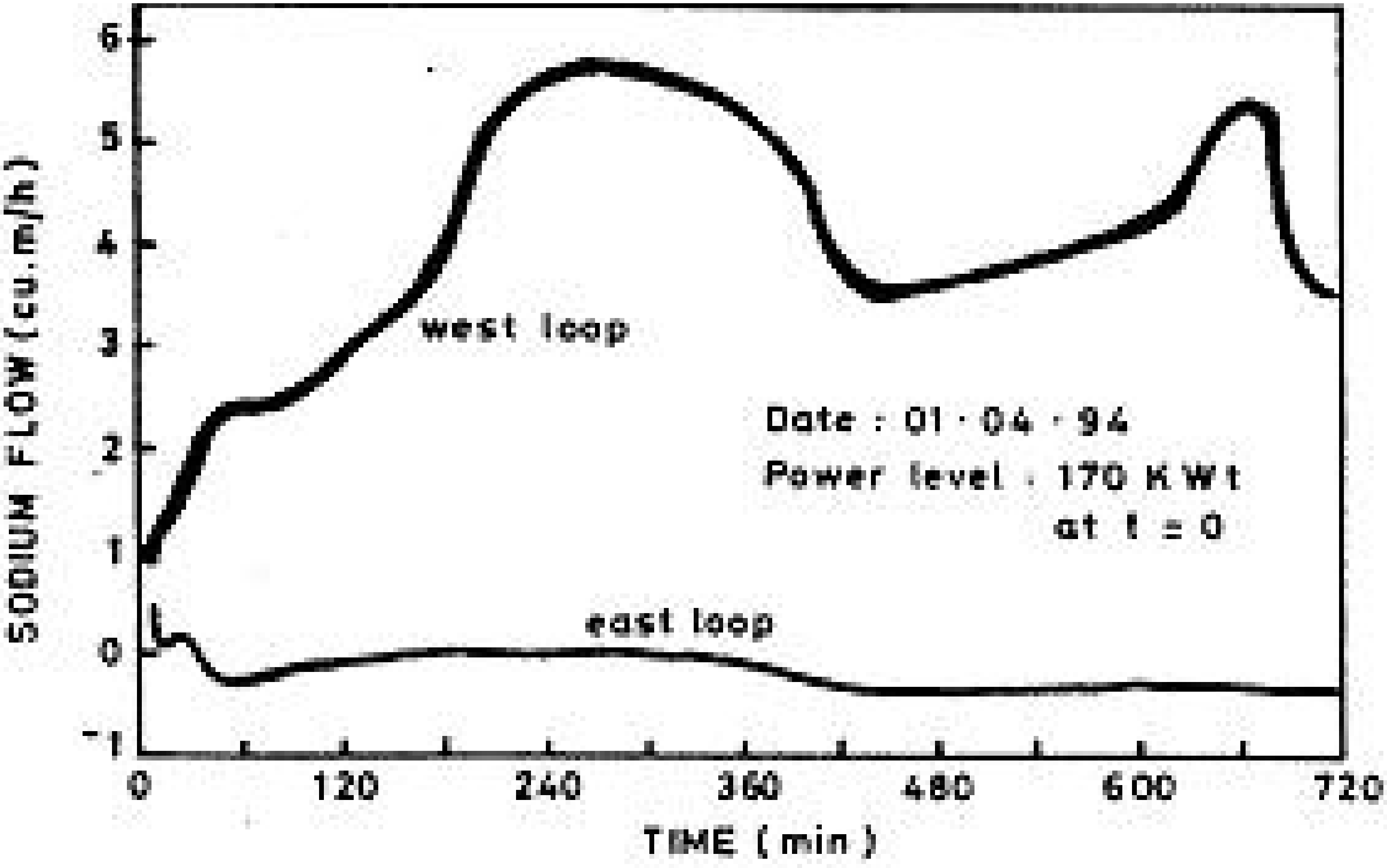


AT 350°C 606 KW

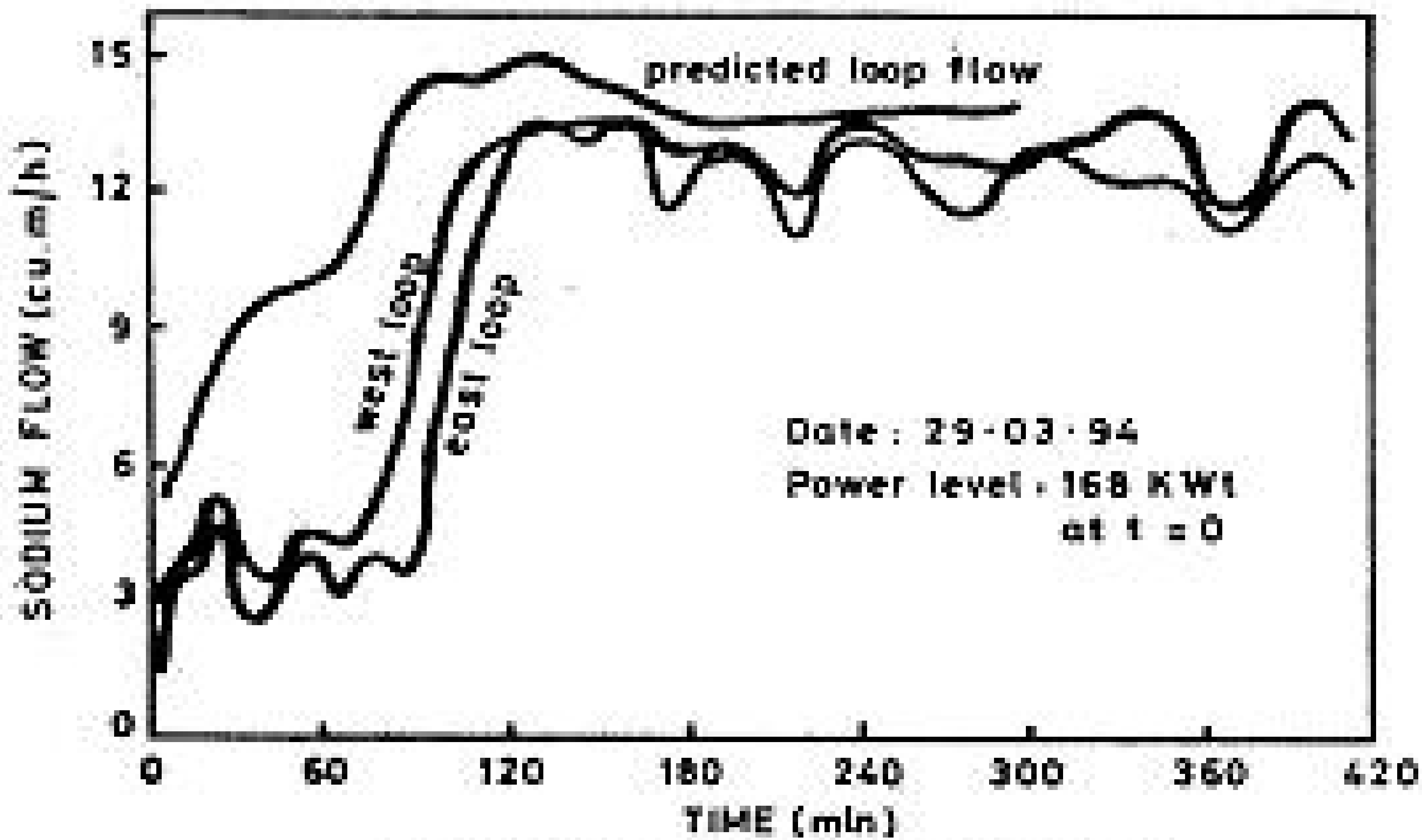
215°C 280 KW

TOTAL AIR FLOW 11000 m^3/h

AT 350°C



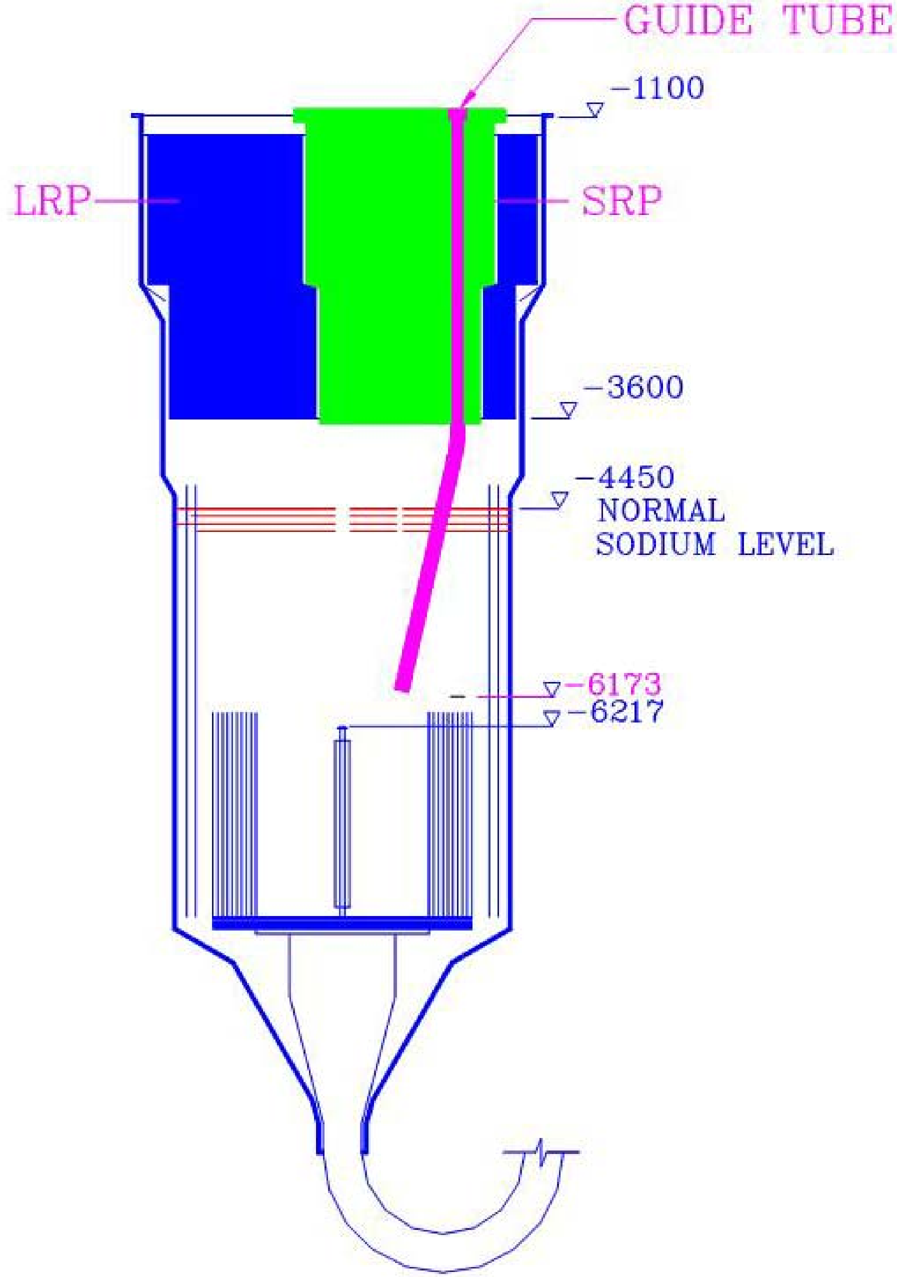
PRIMARY SODIUM LOOP FLOWS



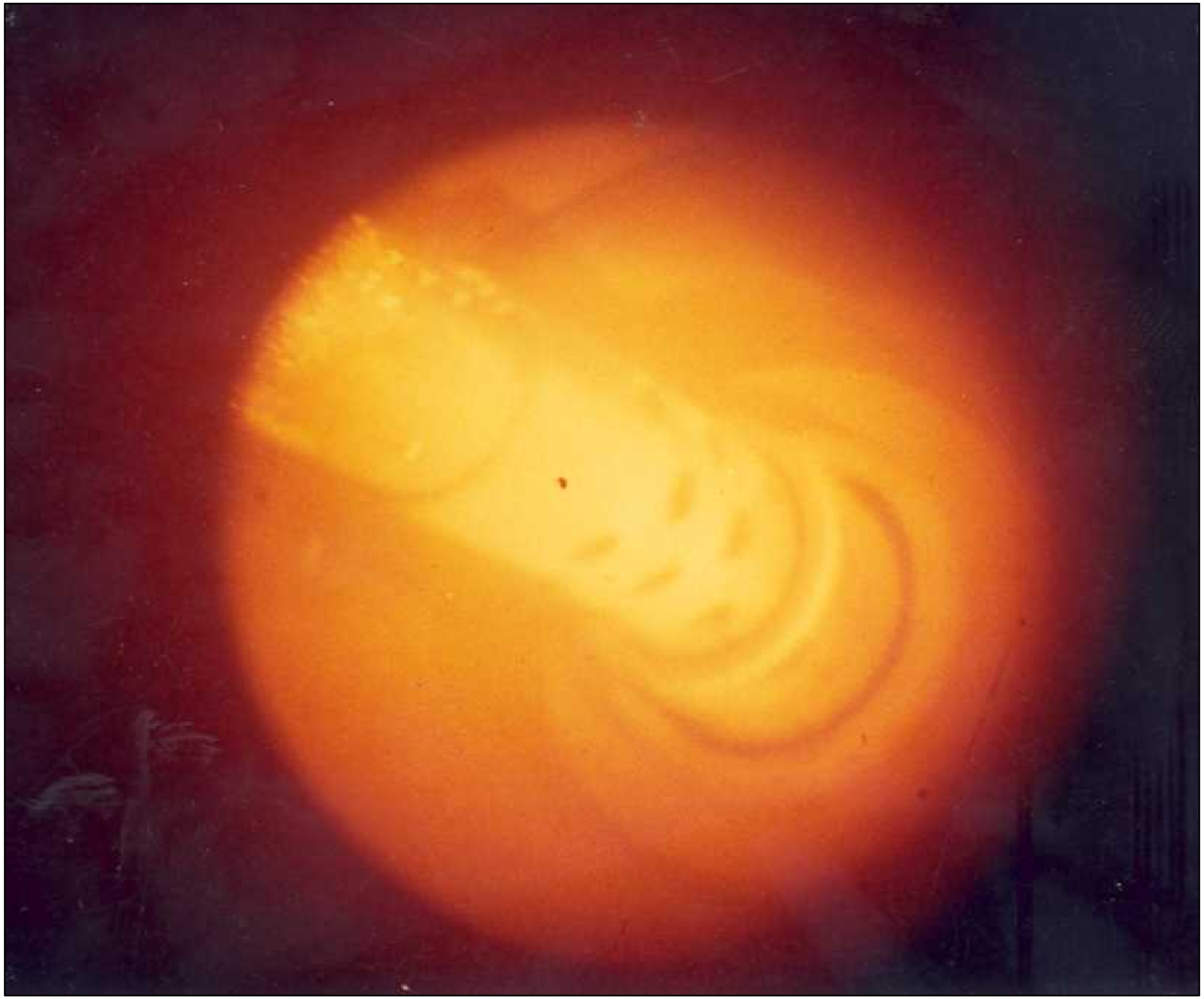
SECONDARY SODIUM LOOP FLOWS

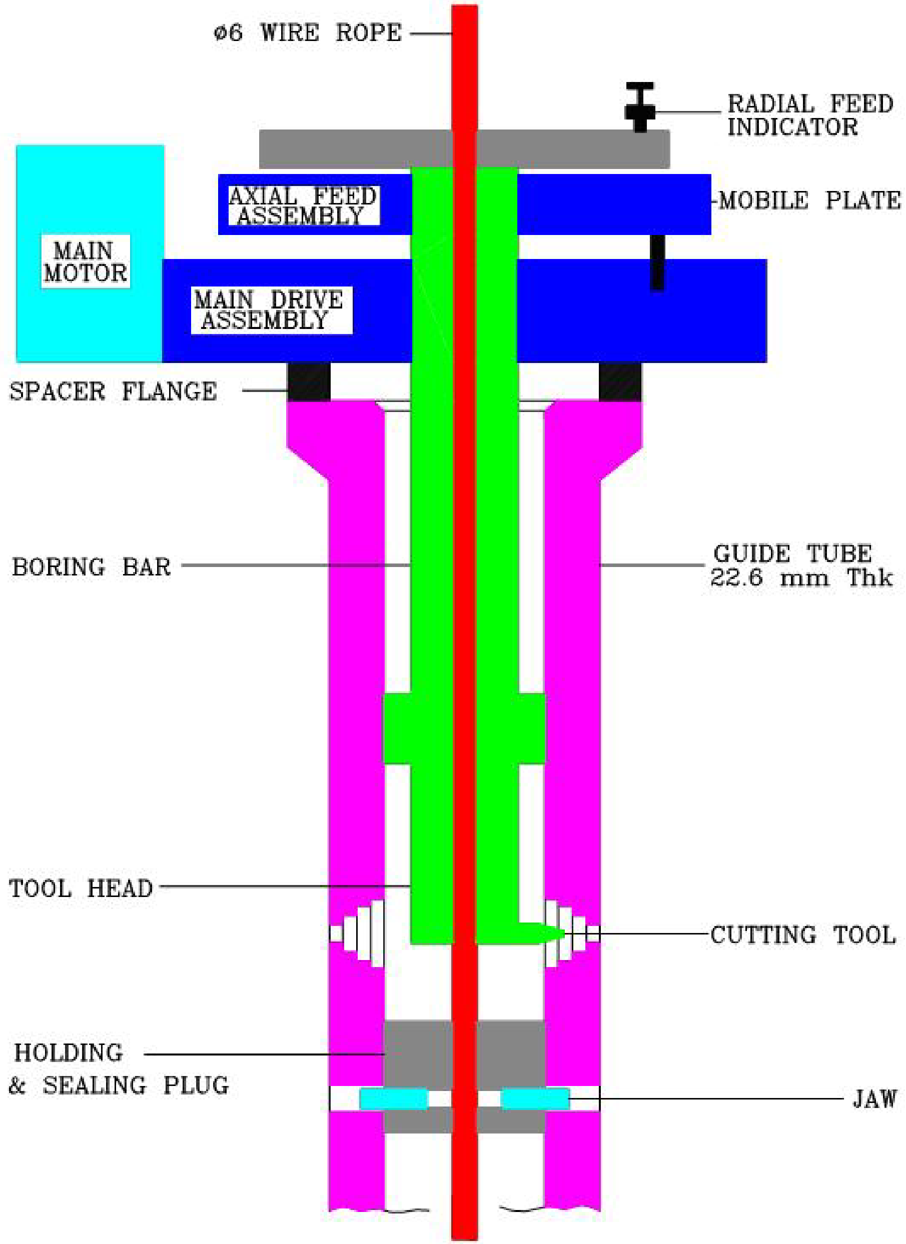
Incidents

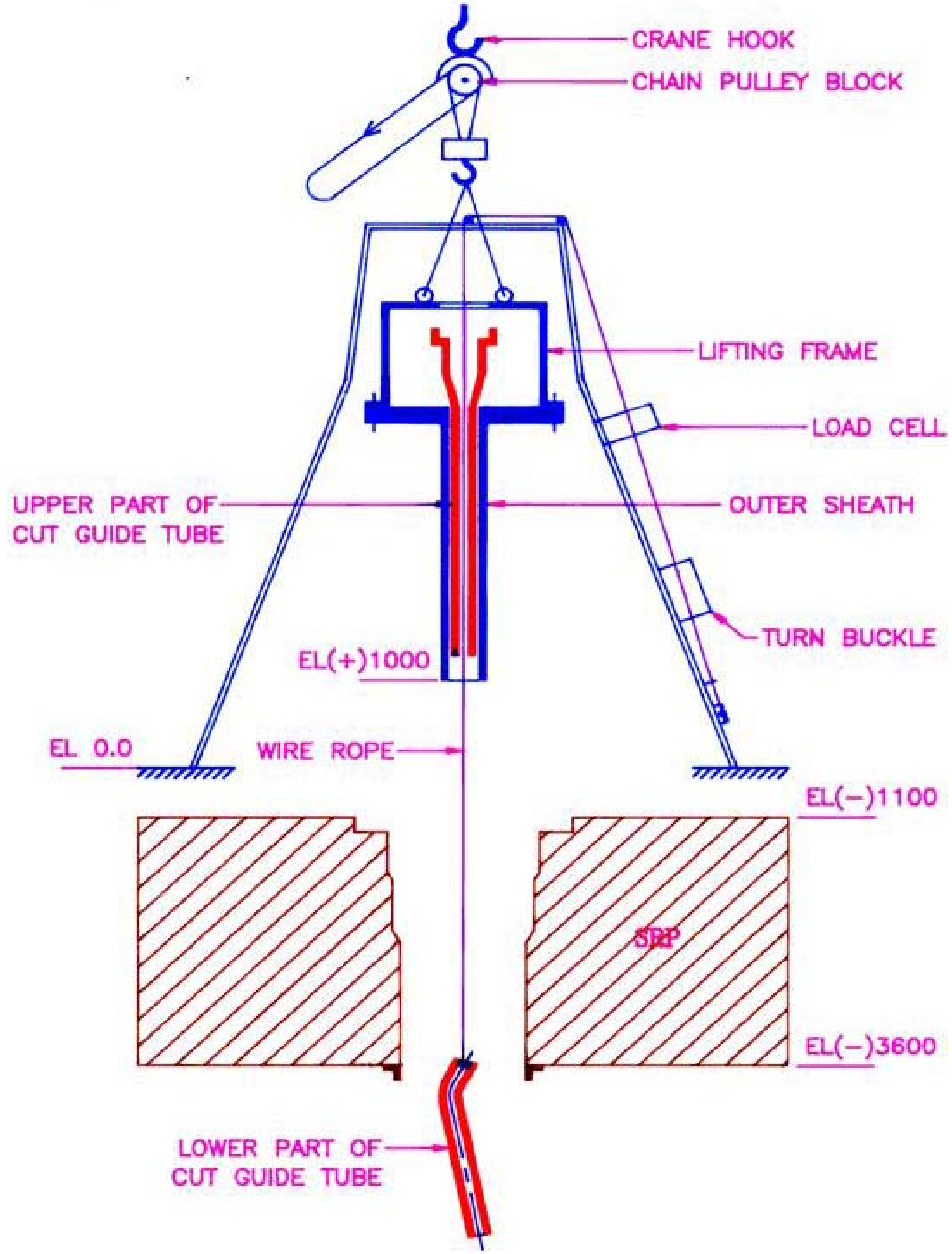
- Two Major Incidents
  - Fuel Handling Incident (1987)
  - Primary Sodium Leak from Purification Cabin (2002)
- Three Reactivity Incidents (1994-95, 1999)



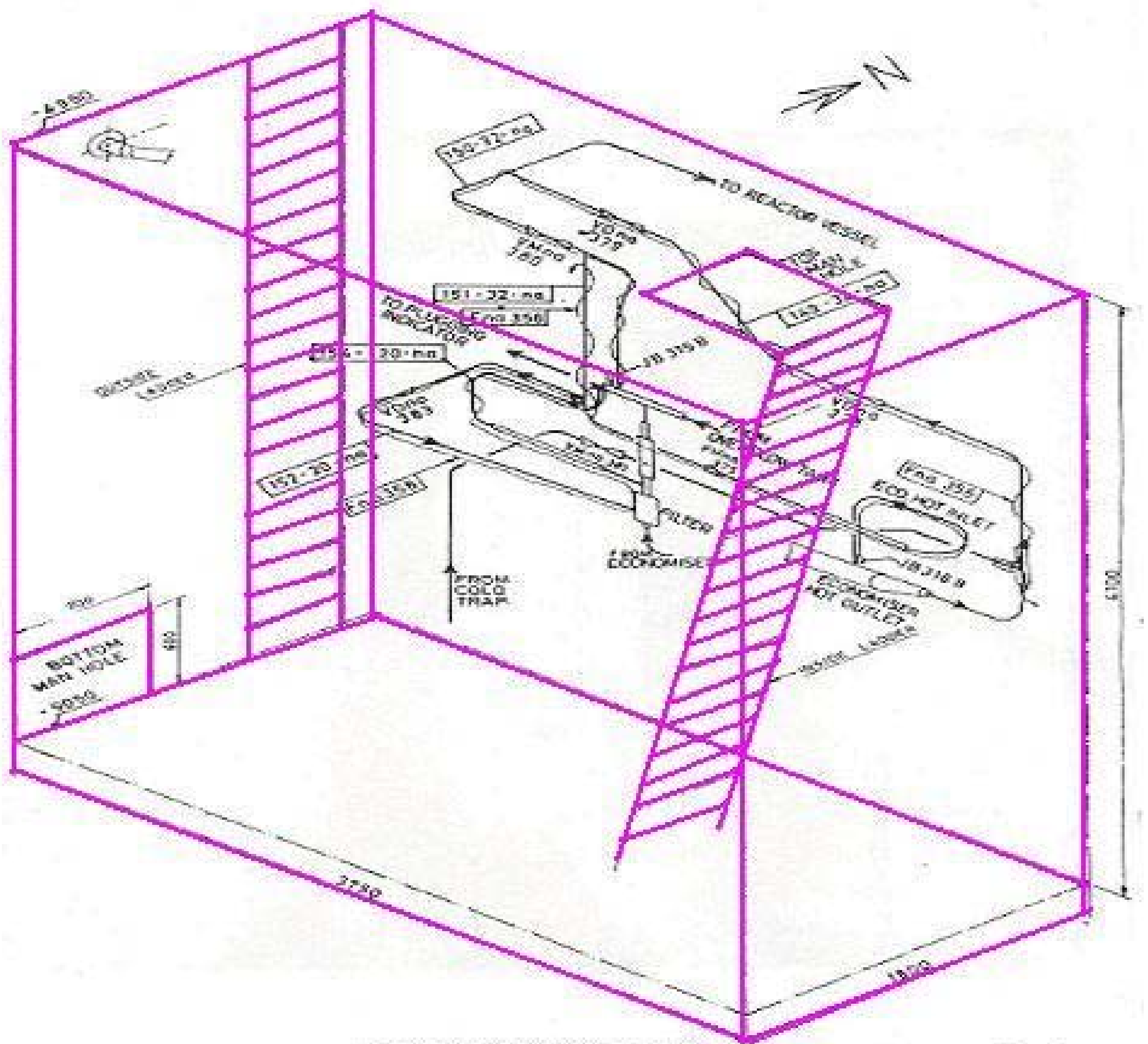
Fuel
Handling
Incident




ø6 WIRE ROPE
RADIAL FEED INDICATOR
AXIAL FEED ASSEMBLY
MOBILE PLATE
MAIN MOTOR
MAIN DRIVE ASSEMBLY
SPACER FLANGE
BORING BAR
GUIDE TUBE 22.6 mm Thk
TOOL HEAD
CUTTING TOOL
HOLDING & SEALING PLUG
JAW



CRANE HOOK
CHAIN PULLEY BLOCK
LIFTING FRAME
LOAD CELL
UPPER PART OF
CUT GUIDE TUBE
OUTER SHEATH
TURN BUCKLE
EL(+)1000
EL 0.0
WIRE ROPE
EL(–)1100
SRP
EL(–)3600
LOWER PART OF
CUT GUIDE TUBE

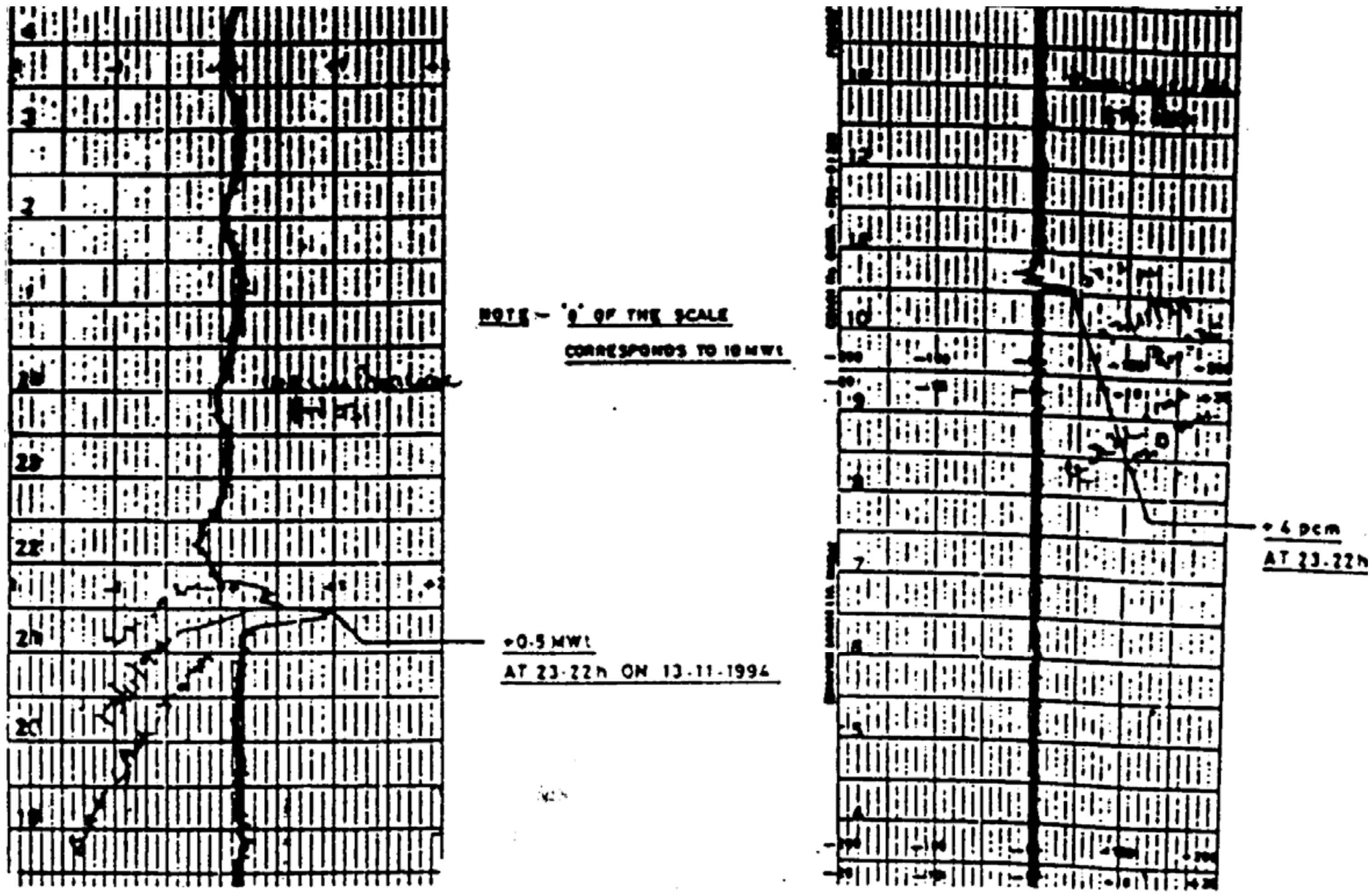


PURIFICATION CABIN

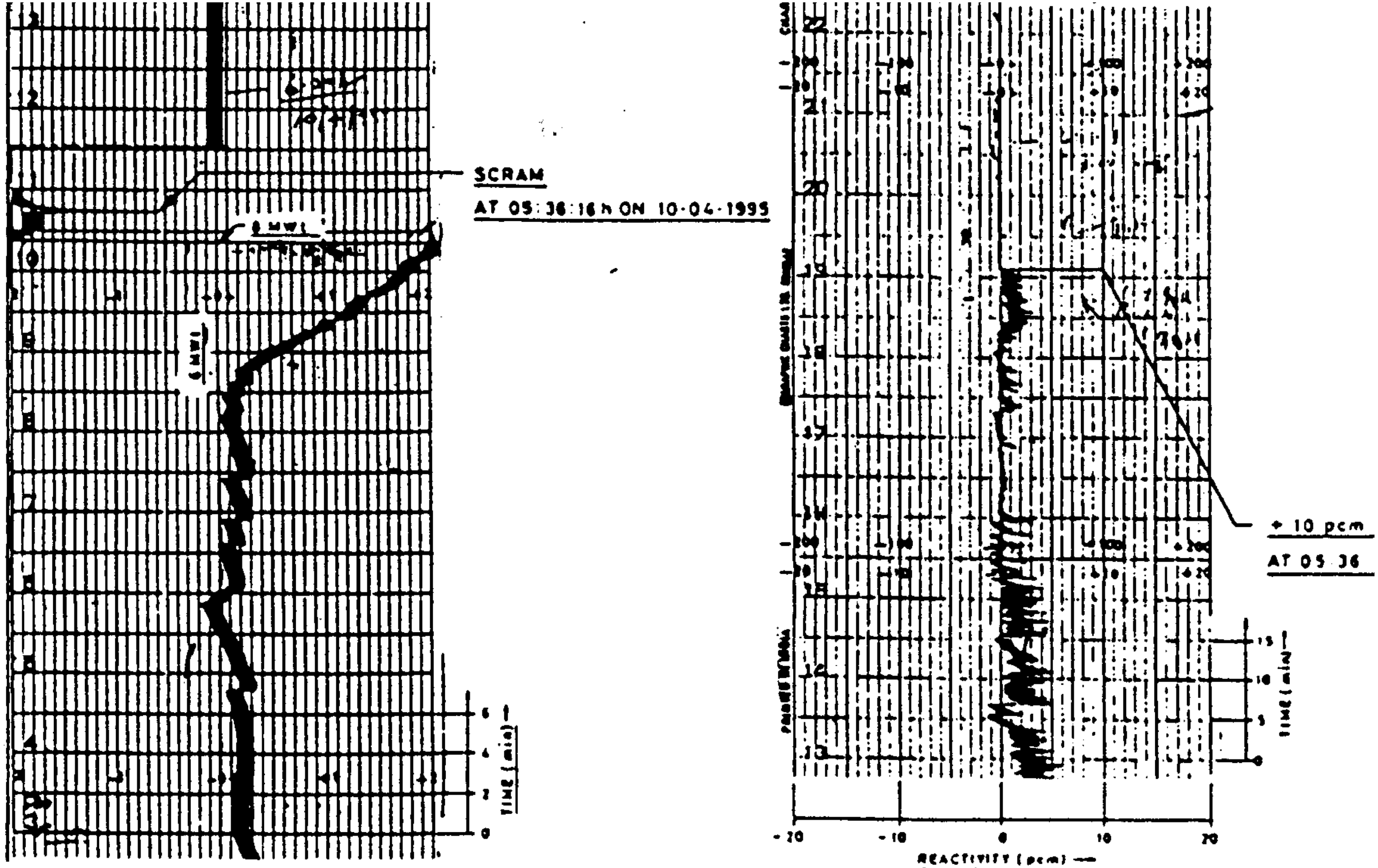
Fig 1

Sodium Leak Incident


NA380

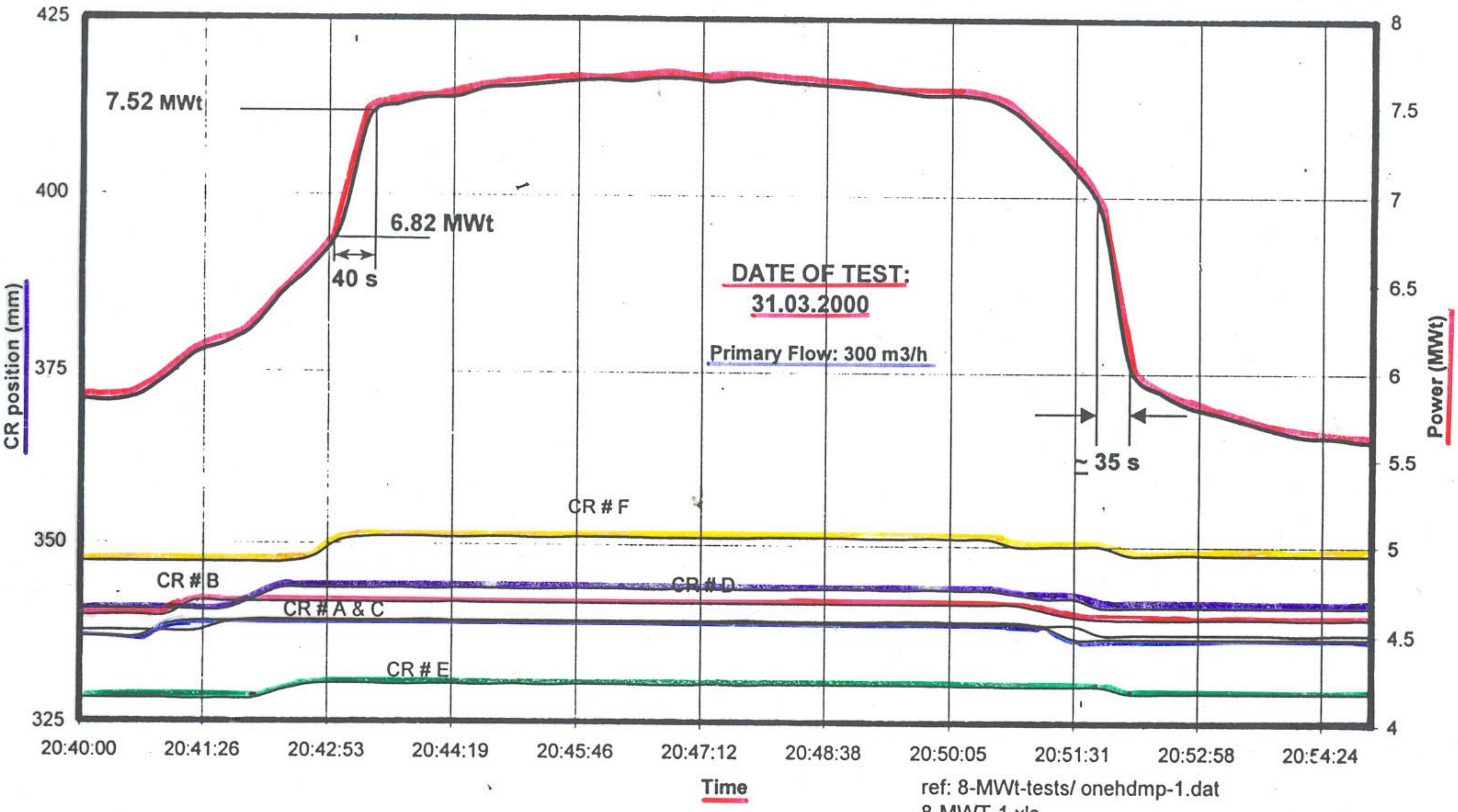


REACTIVITY TRANSIENT OF 13-11-94

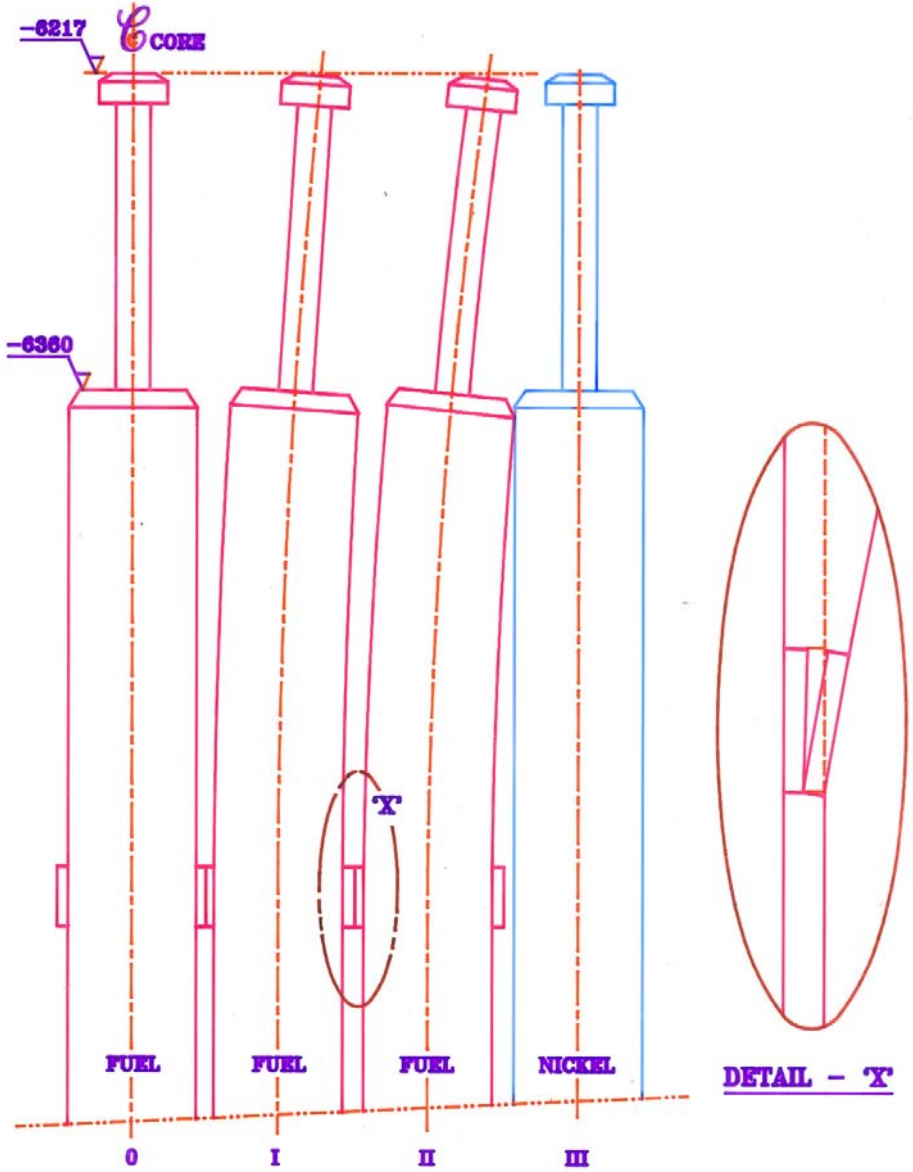


REACTIVITY TRANSIENT OF 10.04.95

NORMAL RAISING FROM 6 TO 8 MWT



ref: 8-MWt-tests/ onehdmp-1.dat
8-MWT-1.xls



TENTATIVE POSTULATE

Summary of Experiences

- The performance of sodium systems has been excellent
- Sodium & Cover gas purity well maintained for over two decades
- Pumps and Steam generators have operated very well
- Performance of Carbide fuel far beyond our original expectations
- Man-rem expenditure for 22 years of operation is only 78 person-mSv (7.8 man-rem)
- Cumulative activity discharged through stack is 14.3 TBq (460 Curies) of Ar^{41}

Future Plans

- Two major improvements carried out in recent years to avoid spurious trips
  - Reheaters in steam water system changed from contact type to non-contact type
  - Steam Generator Leak Detection System triplicated in each loop
- Planning to modify the steam generators to achieve the rated steam & sodium temperatures at 20 MWt itself, as against the design power of 40 MWt.

Future Plans

- Residual Life of plant governed by dose on the Core Support Structure
- Residual Life Assessment & Plant Life Extension are in progress. It is expected that FBTR will be operable at least till 2027.
- Carbide fuel will be retained as driver fuel at least till 2014
- It is planned to test metallic fuels on a large scale starting from 2014

Conclusions

- Very good operational experience feedback in operating a fast reactor and large scale handling of sodium
- Experience has vindicated the international perception that sodium cooled fast reactors are ecologically very clean
- FBTR operation has provided sufficient confidence for the design and launch of construction of the 500 MWe Prototype Fast Breeder Reactor at Kalpakkam


THANK YOU