Operational Safety Issues

Significant Events Review: Examples

S S Bajaj

Significant Events Review

- **Requirements for Reporting to AERB**
  - **Prompt Notification: Within 24 hrs**
  - **Detailed Report: Within 20 days**

- **Reviews**
  - **By Utility- Station Operations Review Committee**
    - **HQ Safety Review Committee**
  - **By AERB- Unit Safety Committee**
    - **Safety Review Committee for Operating Plants (SARCOP)**

Representative Significant Events

- **Un-intended power rise- KAPS 1 (March 2004)**
- **Fuel bundle damage during fuel handling - KGS 1 (Jan 2003)**
- **Heavy water leakage during ISI on coolant channel -MAPS 2 (March 1999)**

OVER POWER INCIDENT AT KAPS 1

KAKRAPAR ATOMIC POWER STATION (UNIT-1)	
Station	2 x 220 MWe PHWR Units
Occurrence	March 2004
Unit Status at the time of Incident	Operating at 160 MWe
Affected System	Reactor Regulating System
INES Rating	2

INCIDENT : UNINTENDED POWER RISE BY ~ 40%

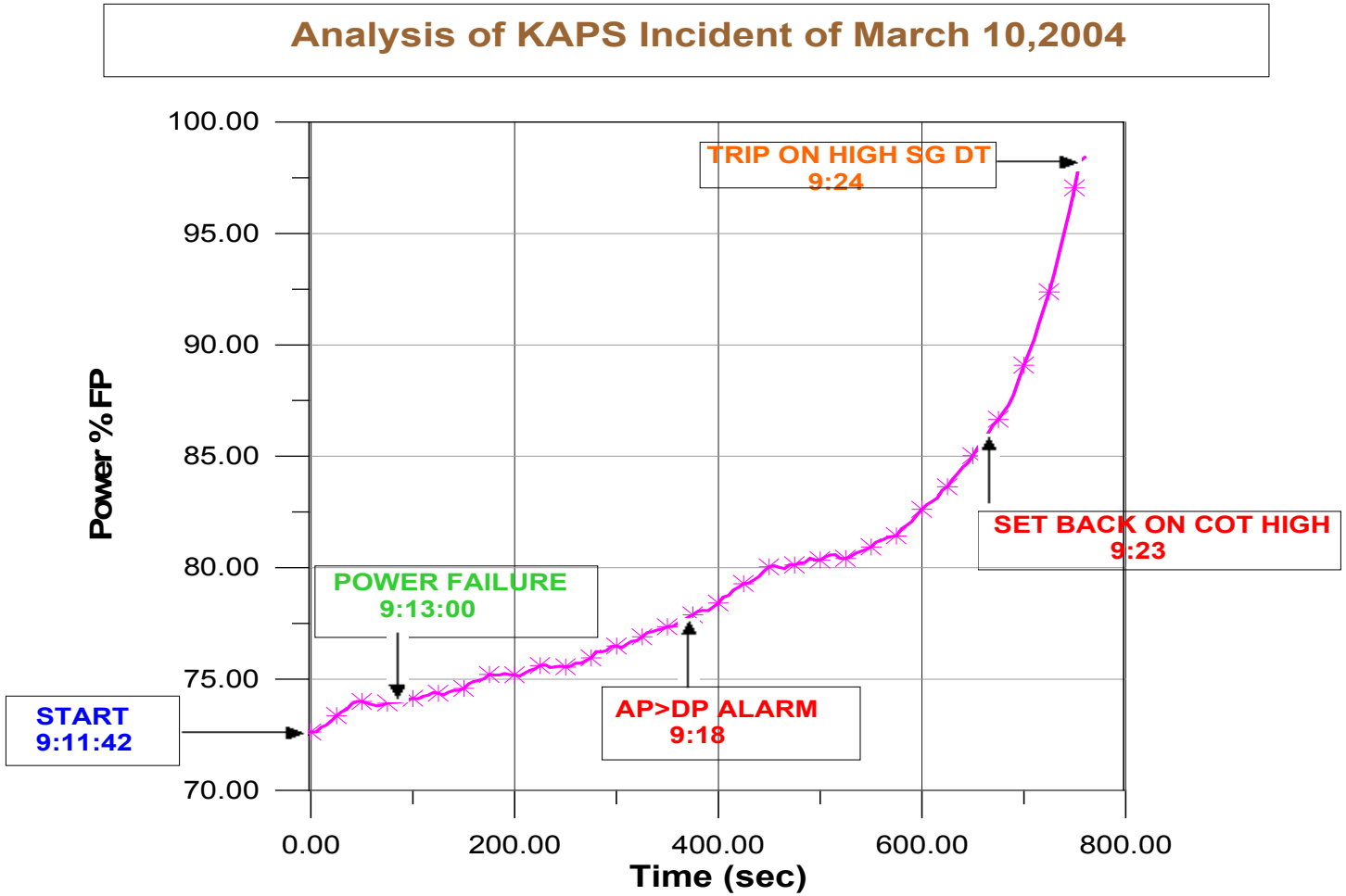


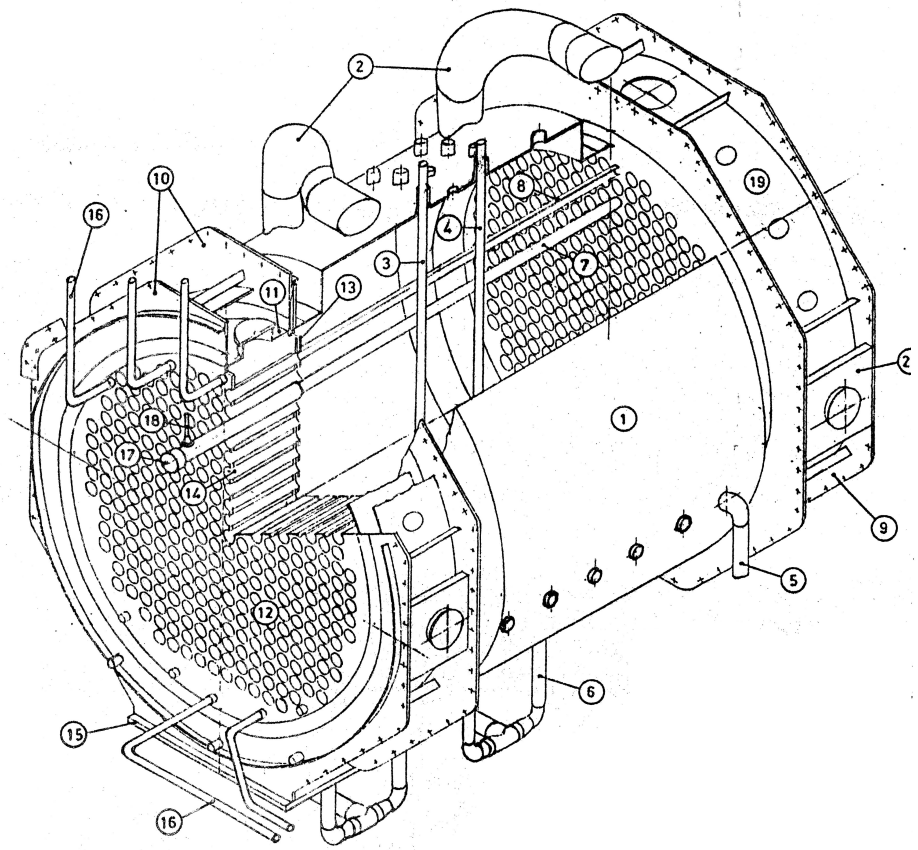
Fig-1 : Variation of Actual Reactor Power

Reactor Regulating System

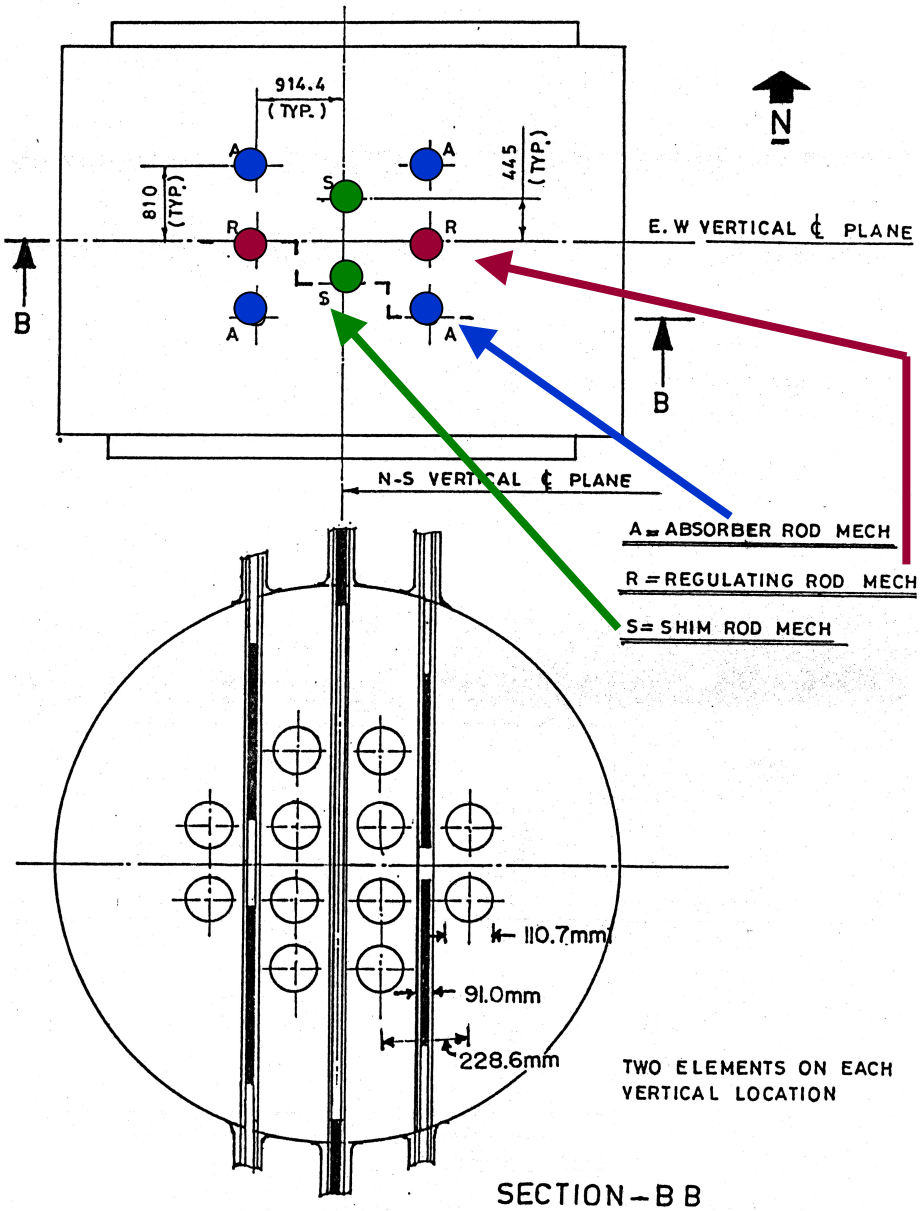
- **Regulating Rods**
- **Absorber Rods**
- **Shim Rods**
- **Automatic Liquid Poison Addition System(ALPAS) Control Addition Mode(CAM)**

Reactor Protection System

- **Primary Shut Down System**
- **Secondary Shut Down System**

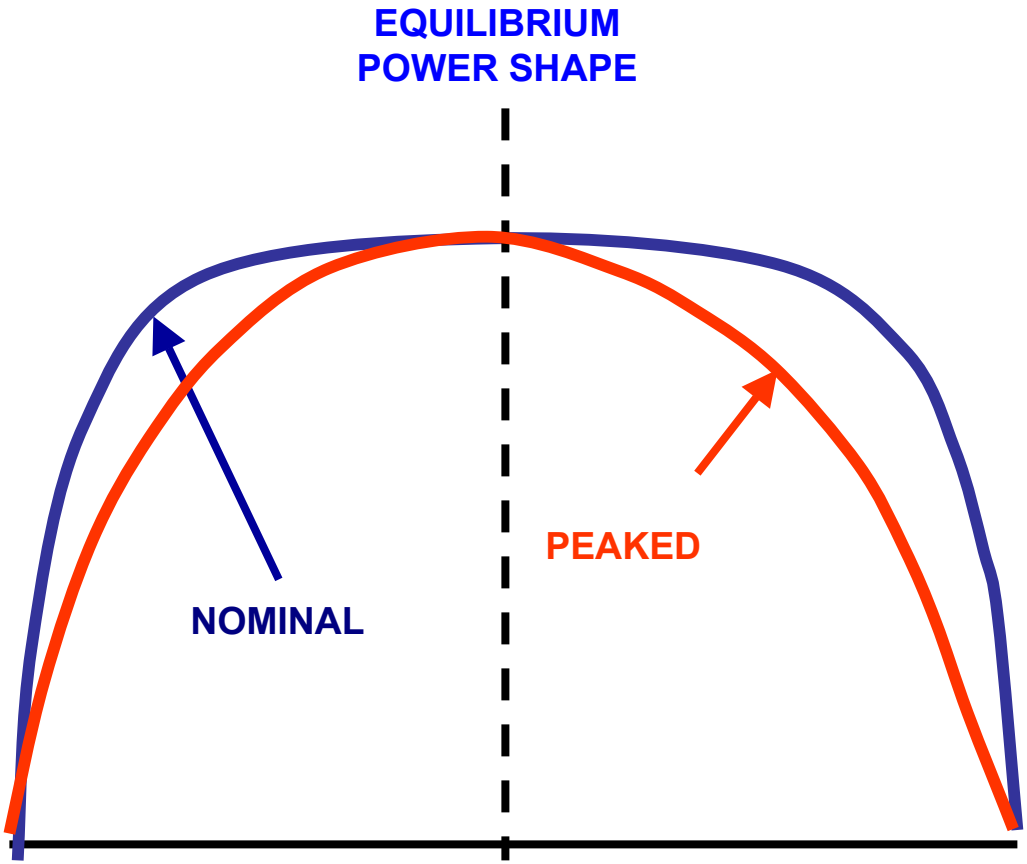


1	CALANDRIA SHELL	11	MAIN SHELL ASSY.
2	OVER PRESSURE RELIEF DEVICE	12	TUBE SHEET F/M SIDE
3	PRIMARY SHUTDOWN SYSTEM RODS	13	TUBE SHEET CAL. SIDE
4	SECONDARY SHUTDOWN SYSTEM TUBES	14	LATTICE TUBE
5	MODERATOR INLET	15	END SHIELD SUPPORT PLATE
6	MODERATOR OUTLET	16	END SHIELD COOLING PIPES
7	CALANDRIA TUBE	17	END FITTING ASSY.
8	COOLANT TUBE	18	FEEDER PIPES
9	END SHIELD	19	OUTER SHELL
10	C.S. OCTAGONAL STRUCTURE ASSY.	20	SUPPORT LUG



Regulating Rods (4 Nos.)	**Reactivity Adjustments** **•Changes in Demand Power** **•Fuel Depletion** **•Refueling** **•Flux Tilts**
Absorber Rods (8 Nos.)	**Xenon Over ride**
Shim Rods (4 Nos.)	**Coarse Reactivity Adjustments** **•Large Changes in Demand Power** **•Reactor Set Back**
ALPAS- CAM	**• To Extend Shim Rod Capability** **• Acts on:** **- Shim Rods Leaving Parked Position** **- Actual Power-Demand Power > 4%**

REACTOR CONDITION PRIOR TO INCIDENT



REACTOR POWER 73% FP

PEAKED FLUX OPERATION

REGULATION BY CORNER ADJUSTERS

JUST BEFORE INCIDENT

- CHANNEL G-05 REFUELLING PLANNED
- POWER UPS-1 PREVENTIVE MAINTENANCE PLANNED

EVENT	CONTROL RM ACTION
0913 : POWER TO RODS LOST - EMTR - ADJ ROD BLOWERS FAILED	ASK ELECT.MAINT. TO ATTEND
0918 : AP-DP>4%	BLOCK ALPAS-CAM
0923 : COT V. HIGH (SETBACK SIGNAL)	
0924 : RX TRIP ON SG ΔT	

COT – Channel Outlet Temperature

Analysis of KAPS Incident of March 10,2004

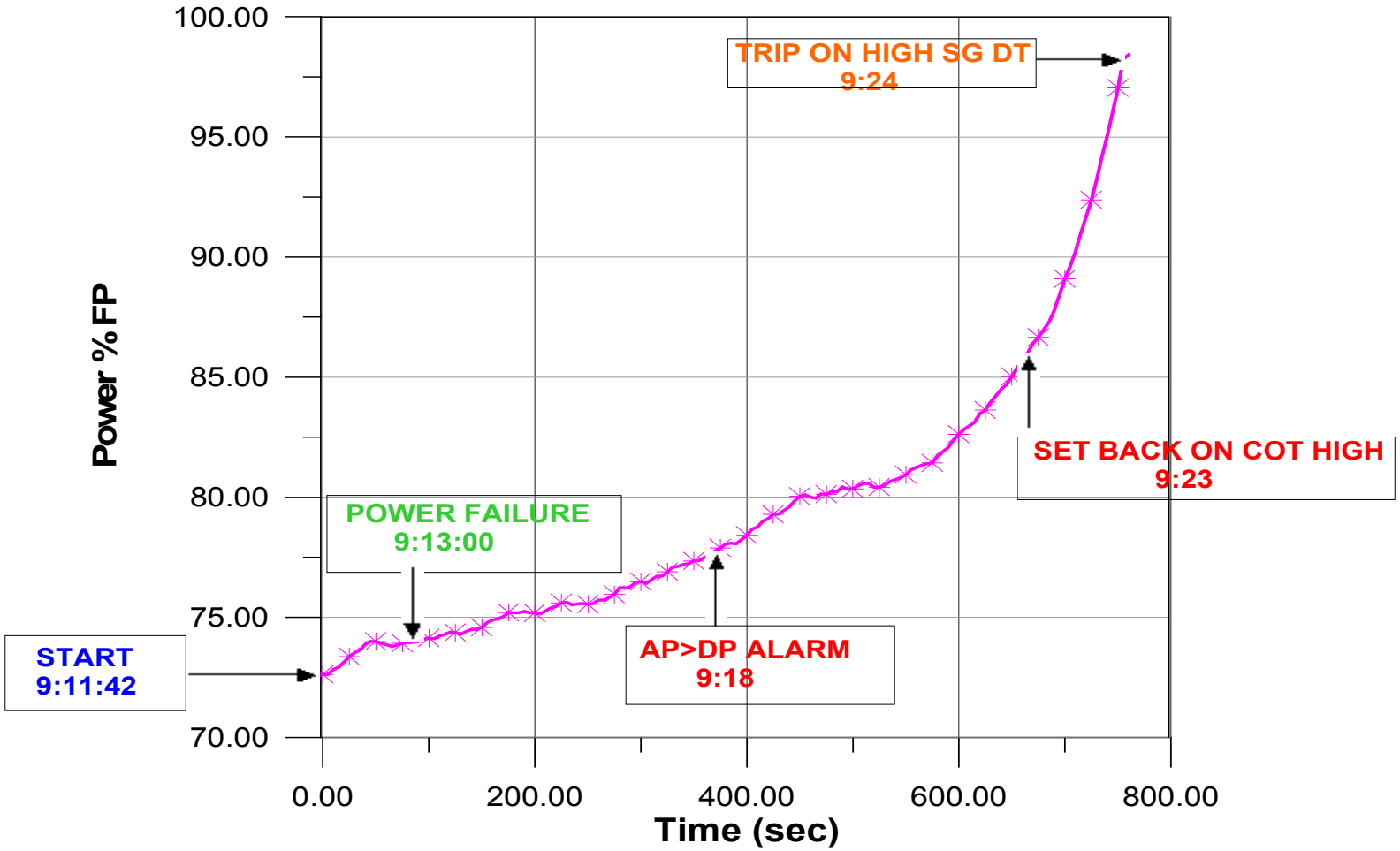
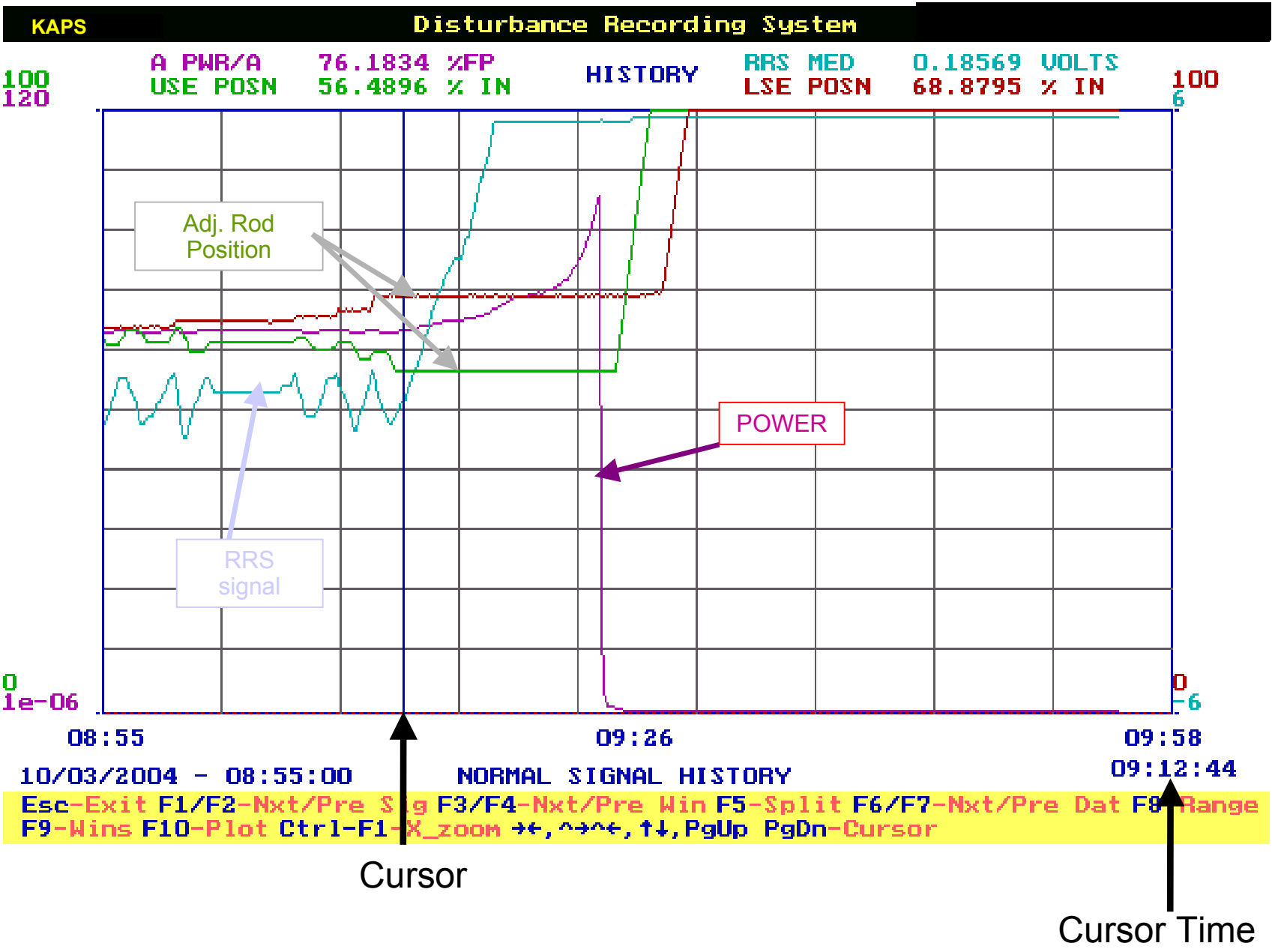
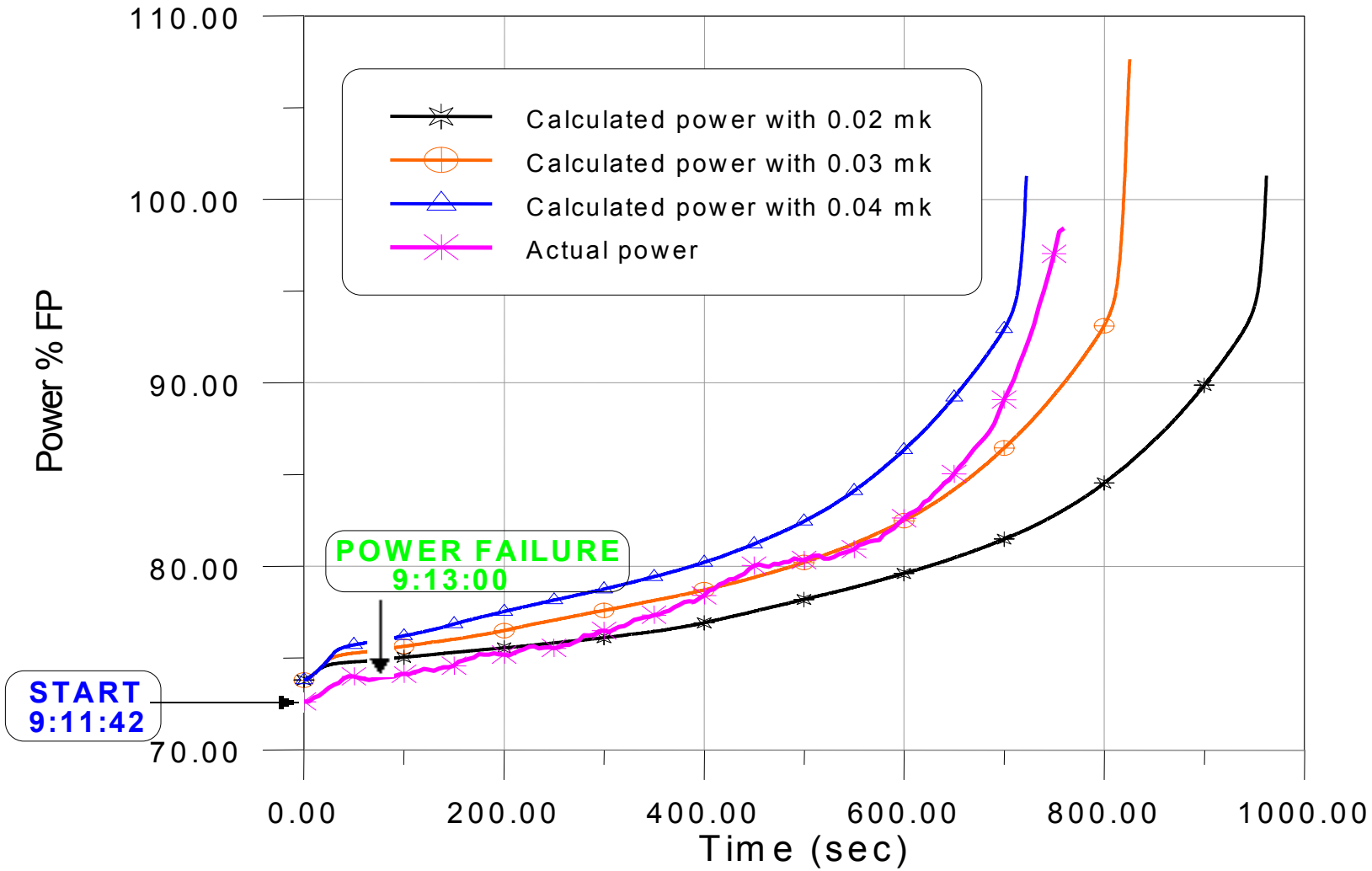


Fig-1 : Variation of Actual Reactor Power

POWER CURVE


KAPS
Disturbance Recording System
A PWR/A 76.1834 %FP
USE POSN 56.4896 % IN
HISTORY
RRS MED 0.18569 VOLTS
LSE POSN 68.8795 % IN
100
120
100
6
Adj. Rod Position
POWER
RRS signal
0
1e-06
0
6
08:55
09:26
09:58
10/03/2004 - 08:55:00
NORMAL SIGNAL HISTORY
09:12:44
Esc-Exit F1/F2-Nxt/Pre Sig F3/F4-Nxt/Pre Win F5-Split F6/F7-Nxt/Pre Dat F8-Range
F9-Wins F10-Plot Ctrl-F1-X_zoom →←,^→^←,↑↓,PgUp PgDn-Cursor
Cursor
Cursor Time

Analysis of KAPS Incident of March 10,2004
Initial Reactivity Addition of 0.02,0.03 & 0.04 mk



Variation of Actual and Calculated Reactor Power

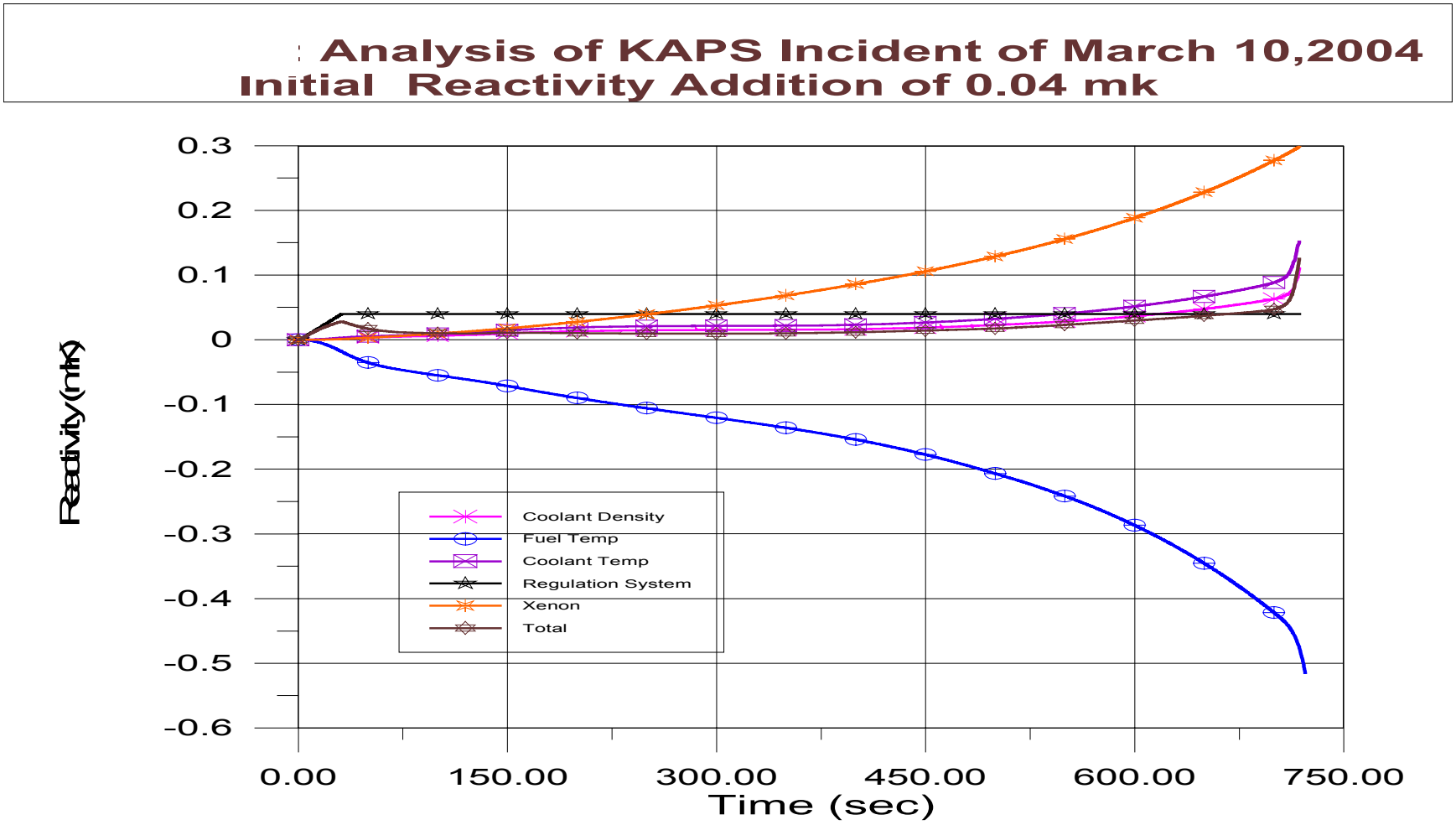
REACTIVITY CONTRIBUTIONS

XENON KILLING +

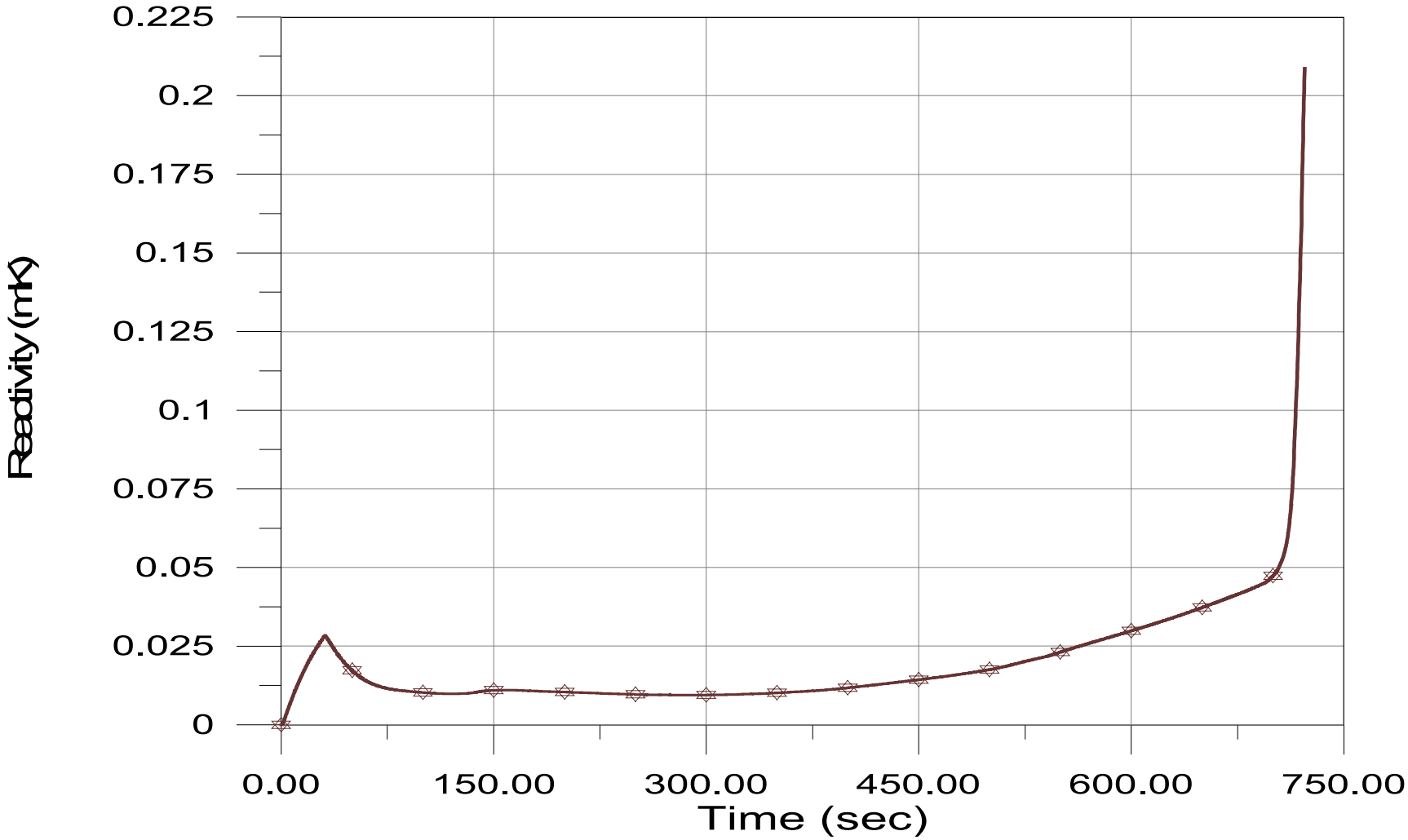
FUEL TEMPERATURE RISE -

COOLANT DENSITY FALL +

COOLANT TEMPERATURE RISE +



ATMIKA-T : Analysis of KAPS Incident of March 10,2004
Initial Reactivity Addition of 0.04 mk



Net Reactivity

FUEL CONDITION

- NO INCREASE IN COOLANT IODINE ACTIVITY
- ALL THE FUEL REMAINED WITHIN NUCLEATE BOILING
- MAXIMUM CLAD TEMPERATURE 322^0C

FUEL BUNDLE OVERPOWER

PEAK POWER : 615 KW

THERMO MECHANICAL ANALYSIS RESULTS

- FUEL CENTRE TEMPERATURE
- FISSION GAS PRESSURE
- SHEATH STRAIN

} WITHIN LIMITS

INCIDENT CAUSES

- FAILURE OF POWER SUPPLIES TO ADJUSTER RODS CONTROL UNIT (ARCUs)
  - VOLTAGE SPIKING LEADING TO FUSE FAILURES
  - FUSE LOCATION IN CIRCUIT – VULNERABILITY TO CCF
  - NORMAL SUPPLY TO ALL ARCUS FROM SAME SOURCE (MCC-M)
- INADEQUATE INDICATIONS IN CONTROL ROOM
  - ALL ADJUSTER RODS INCAPACITATED INDICATION
  - POWER RISE TREND
- BLOCKING OF ALPAS CAM BY OPERATOR
- SETTING OF OVERPOWER TRIPS AT INAPPROPRIATE HIGH LEVELS
  - COMMUNICATION PROBLEM

DESIGN MODIFICATIONS

POWER SUPPLIES TO ARCUs

- SEGREGATION OF POWER SUPPLIES TO 4 ARCUs
- DELETION OF FUSES

ALPAS CAM

- ELIMINATE MANUAL BLOCKING FEATURE
- RATIONALISE LOGIC OF ACTUATION ESP. WRT SHIM ROD POSITION

CR INDICATIONS

WINDOW ANNUNCIATION ON FAILURE OF POWER TO ADJUSTERS

OVERPOWER PROTECTION – (AP-DP) TRIP

- TRIP SETTING DISPLAY
- AP/AUTHORISED POWER DISPLAY

SAFETY CULTURE/ TRAINING

ACTIONS TO PREVENT RECURRENCES / LESSONS LEARNT

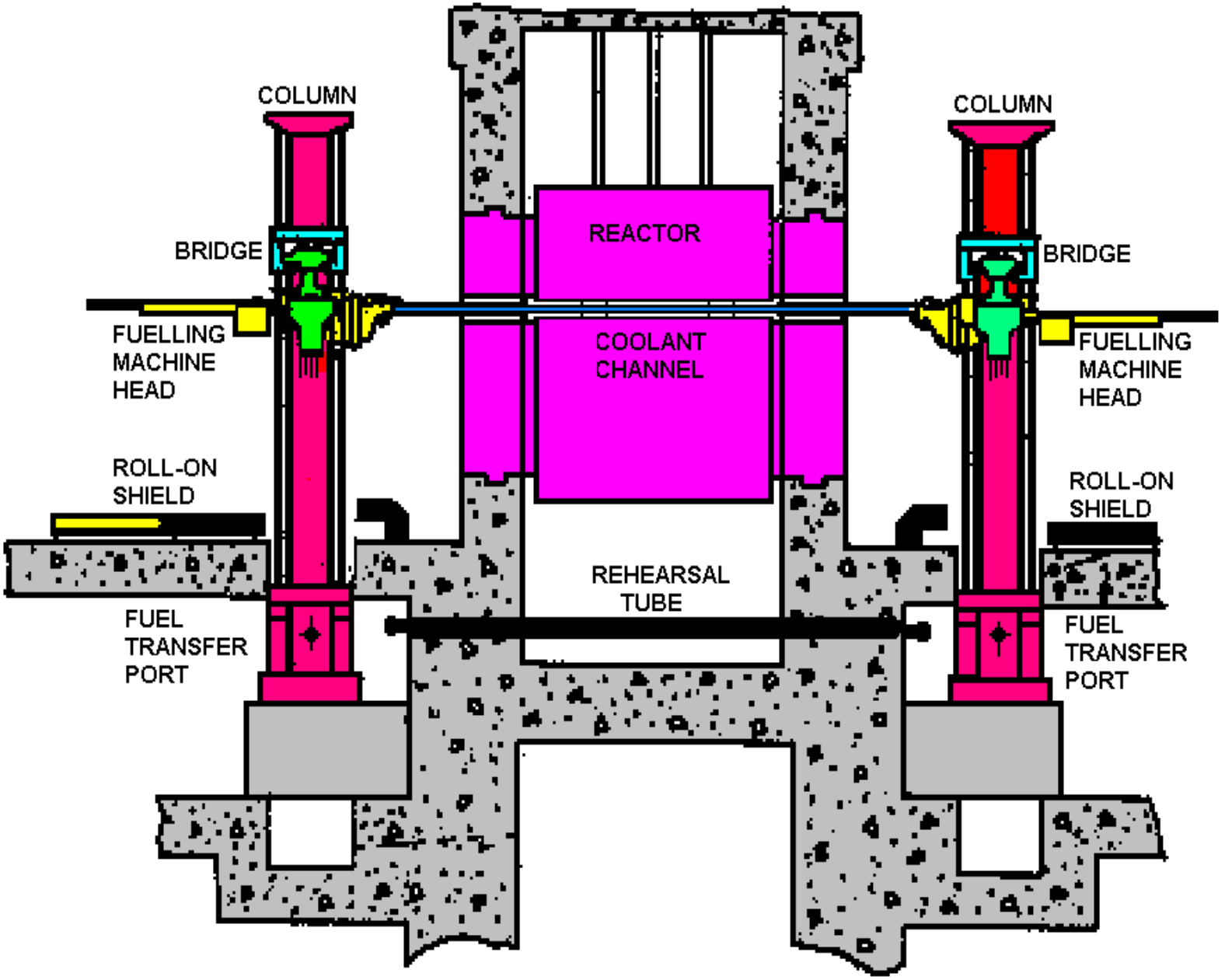
- **EXPLICIT COMMUNICATION TO OPERATING STAFF PARTICULARLY FOR NON-NOMINAL MODES OF OPERATION**
- **BACK- FITTING OF IDENTIFIED DESIGN IMPROVEMENTS IN OLDER PLANTS**
- **ADEQUACY OF DESIGN QA CHECKS & COMMISSIONING TESTS**

REGULATORY ACTIONS/ STIPULATIONS

- MULTI TIER REVIEW OF INCIDENT
- UNIT SHUTDOWN TILL EVENT CAUSE CLEARLY ESTABLISHED AND REMEDIAL ACTIONS TAKEN
- SIMULATION OF INCIDENT TO EXPLAIN EVENT
- RETRAINING OF OPERATING STAFF AND STATION MANAGEMENT ORDERED
- REVIEW OF PROPOSED DESIGN MODIFICATIONS
- RESTART PERMITTED AFTER IMPLEMENTATION OF DESIGN MODNS. AND RETRAINING & REQUALIFICATION OF OPERATORS
- REVIEW OF OTHER OPERATING UNITS AND PLANTS UNDER CONSTRUCTION

FUEL BUNDLES DAMAGE DURING REFUELLING

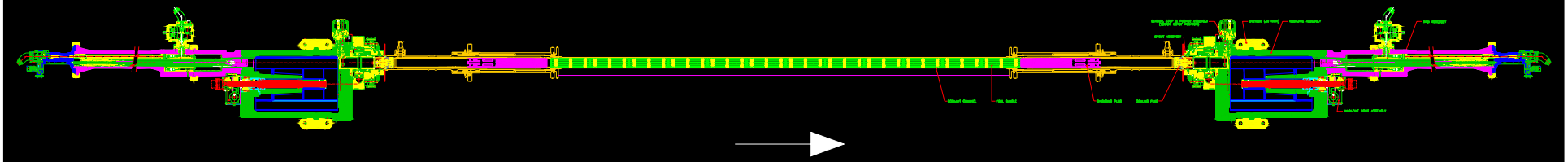
KAIGA GENERATING STATION (UNIT-1)	
Station	2 x 220 MWe PHWR Units
Occurrence	January 2003
Unit Status at the time of Incident	Operating at Full Power
Affected System	Fuel Handling System
INES Rating	1



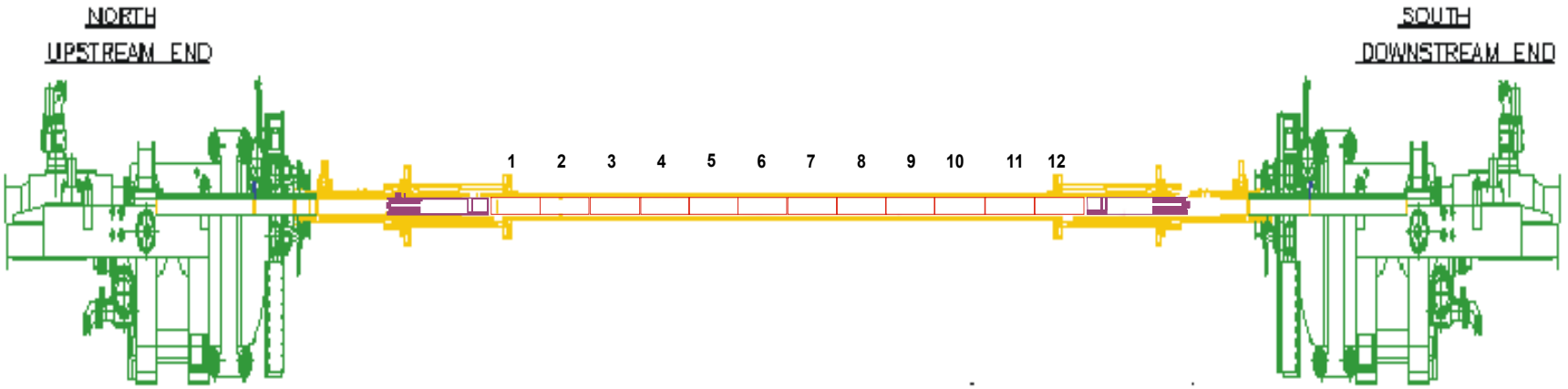
ON-POWER FUELLING MACHINES

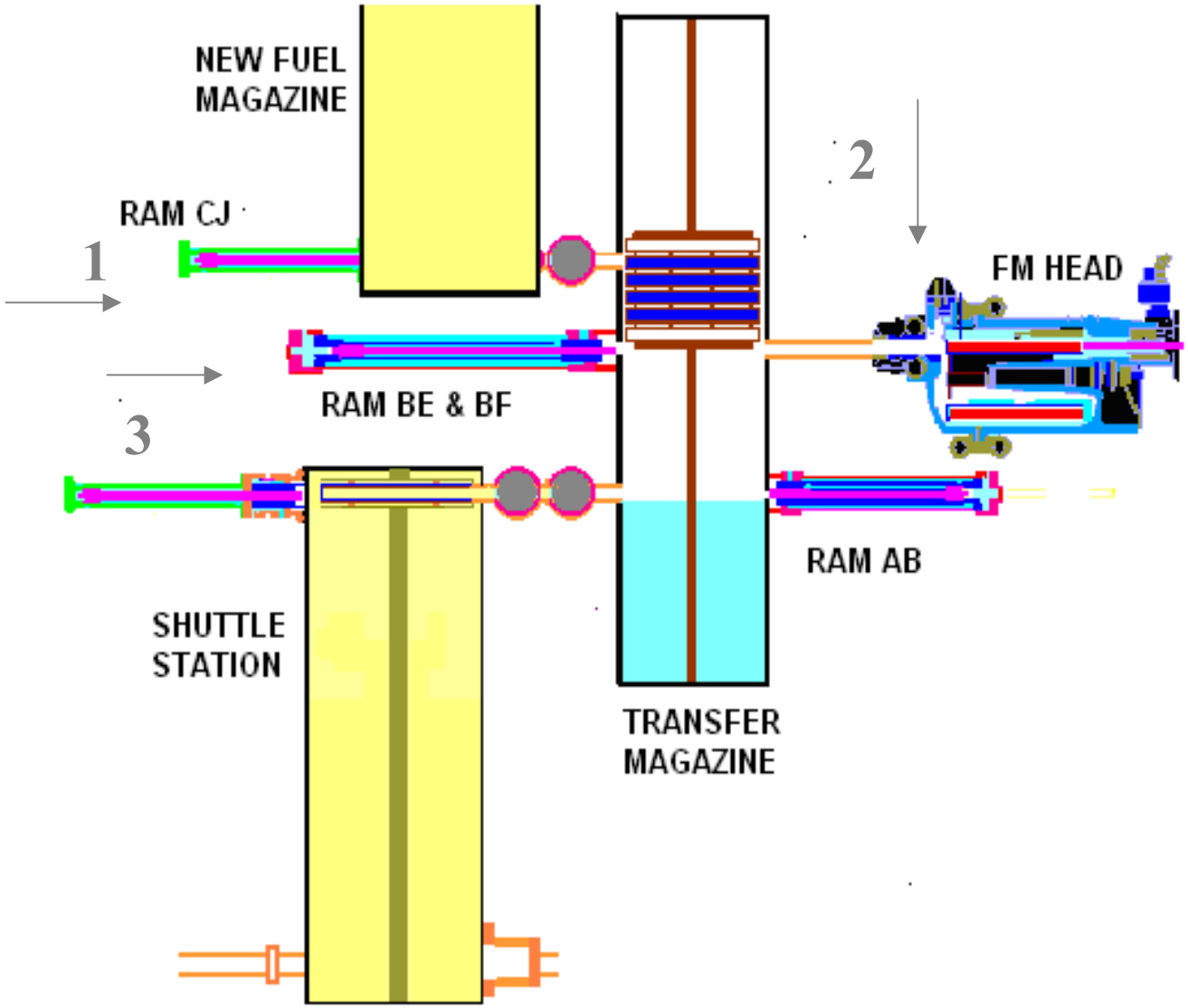
UPSTREAM END

DOWNSTREAM END

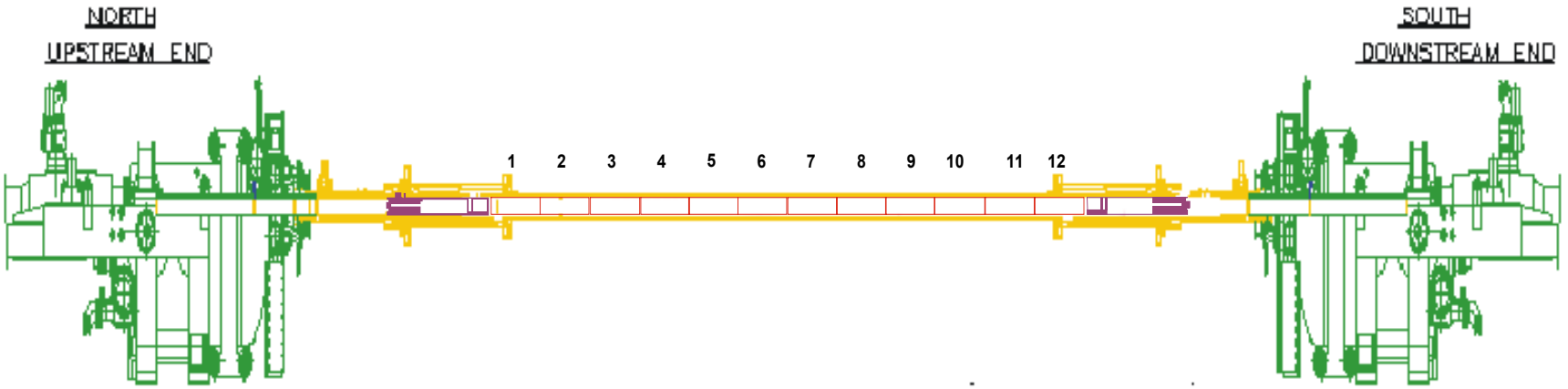


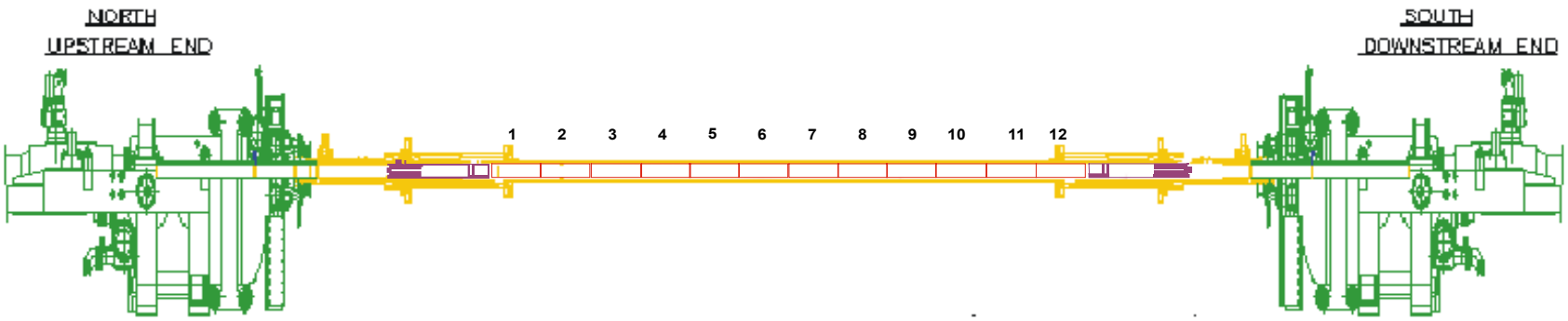
FUELING MACHINES CLAMPED ON TO THE CHANNEL


NORTH
UPSTREAM END
SOUTH
DOWNSTREAM END
1
2
3
4
5
6
7
8
9
10
11
12



FUEL TRANSFER SYSTEM

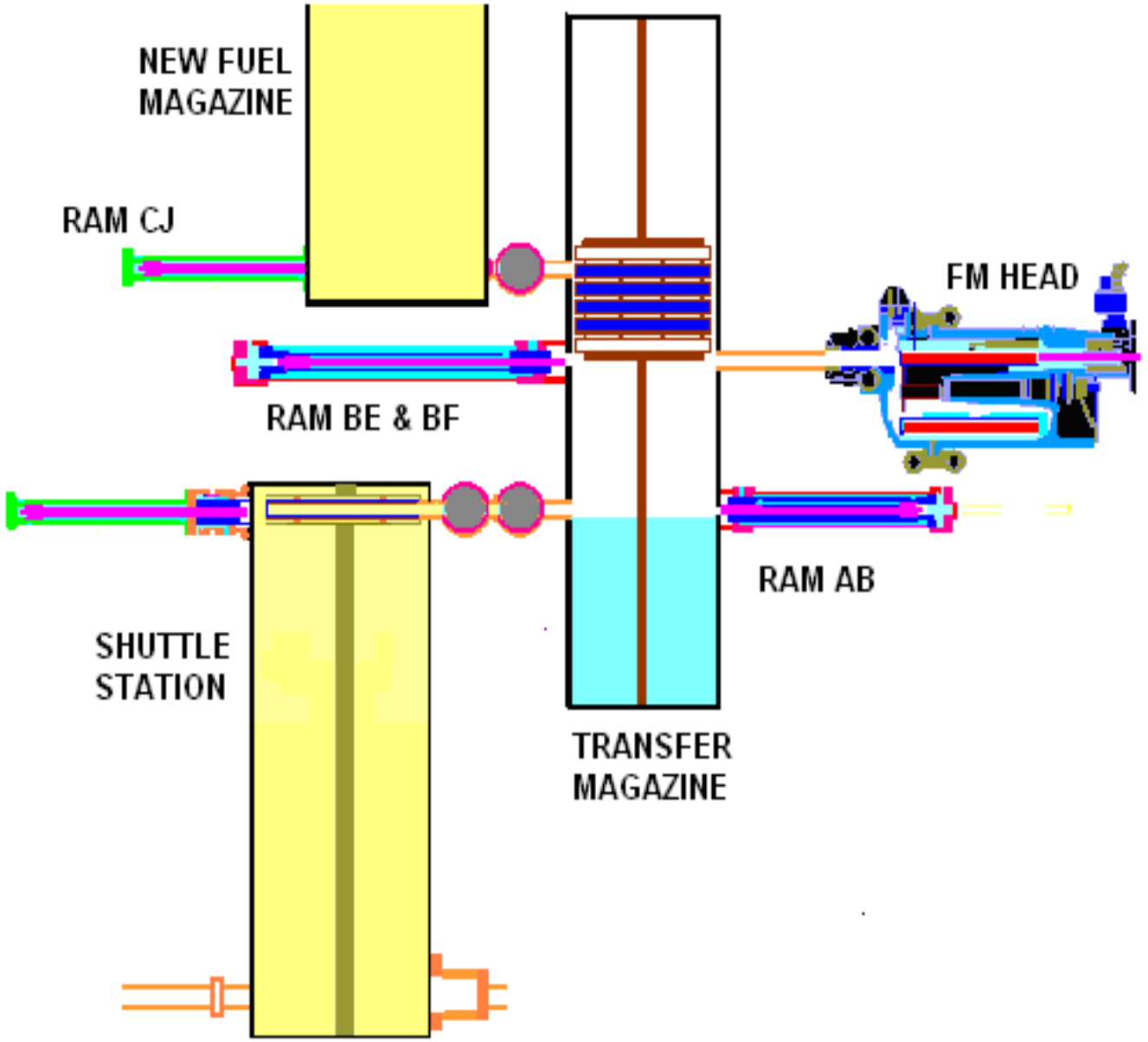

NORTH
UPSTREAM END
SOUTH
DOWNSTREAM END
1
2
3
4
5
6
7
8
9
10
11
12



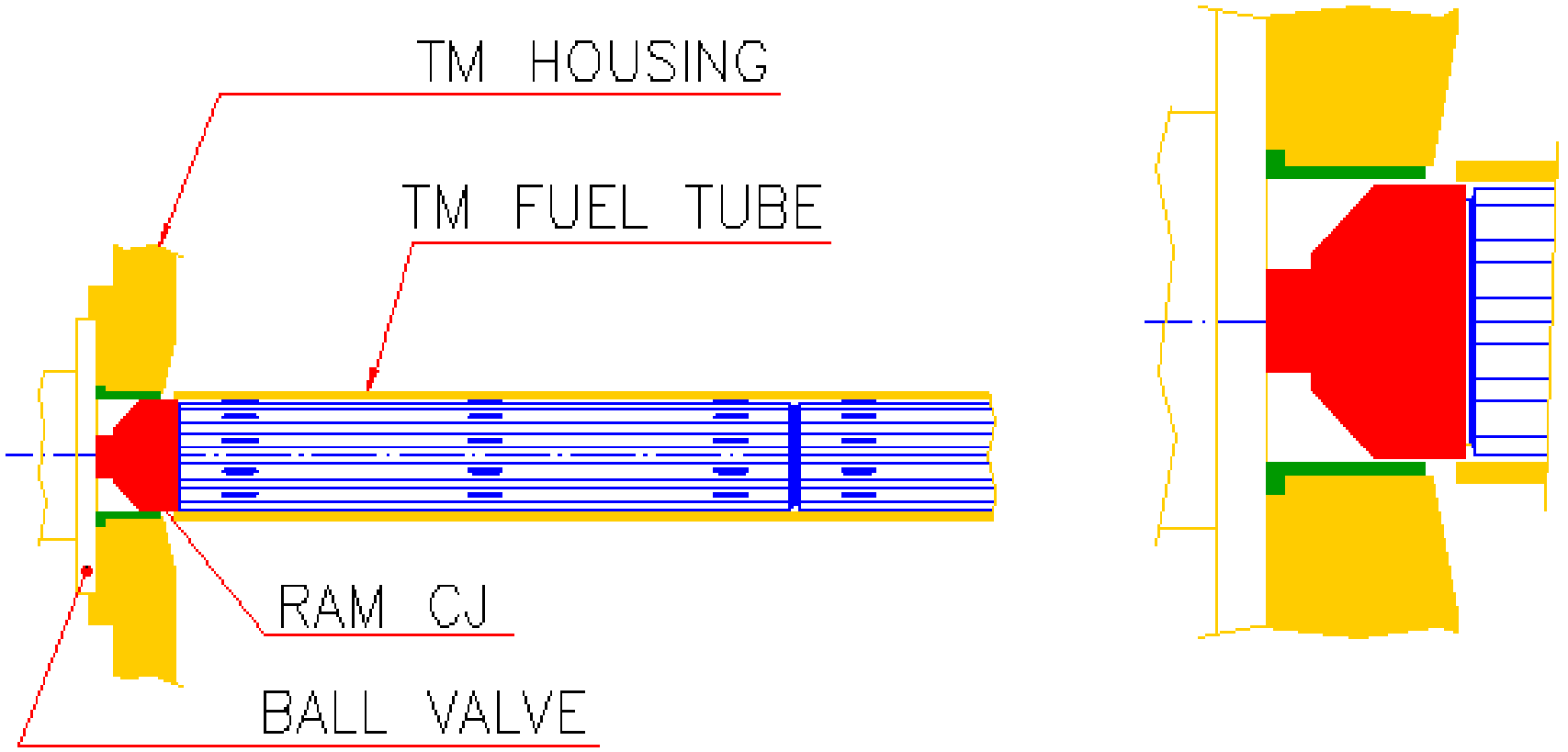
- ON AFTERNOON OF 25-JAN-03, AFTER COMPLETION OF LOADING THE NEW FUEL AND UNLOADING THE SPENT FUEL BUNDLES FROM K-11 CHANNEL, THE DOWNSTREAM SHIELD PLUG COULD NOT BE INSTALLED. UPSTREAM SHIELD PLUG WAS IN POSITION.
- DOWNSTREAM SHIELD PLUG WAS INSTALLED IN THE CHANNEL AFTER REMOVING THE UPSTREAM SHIELD PLUG. RE-INSTALLATION OF UPSTREAM SHIELD PLUG COULD NOT BE DONE. THE LENGTH OF FUEL COLUMN WAS 300 mm LONGER.
- CHANNEL WAS BOXED-UP WITHOUT UPSTREAM SHIELD PLUG AND THE REACTOR WAS MANUALLY TRIPPED AT 0000 HRS. ON 26-JAN-2003

•TO CHECK THE HEALTHINESS OF FUEL TRANSFER SYSTEM, TWO PAIRS OF NON-REACTOR GRADE BUNDLES WERE LOADED IN NEW FUEL MAGAZINE AND TAKEN OUT THROUGH FUEL TRANSFER PORT.

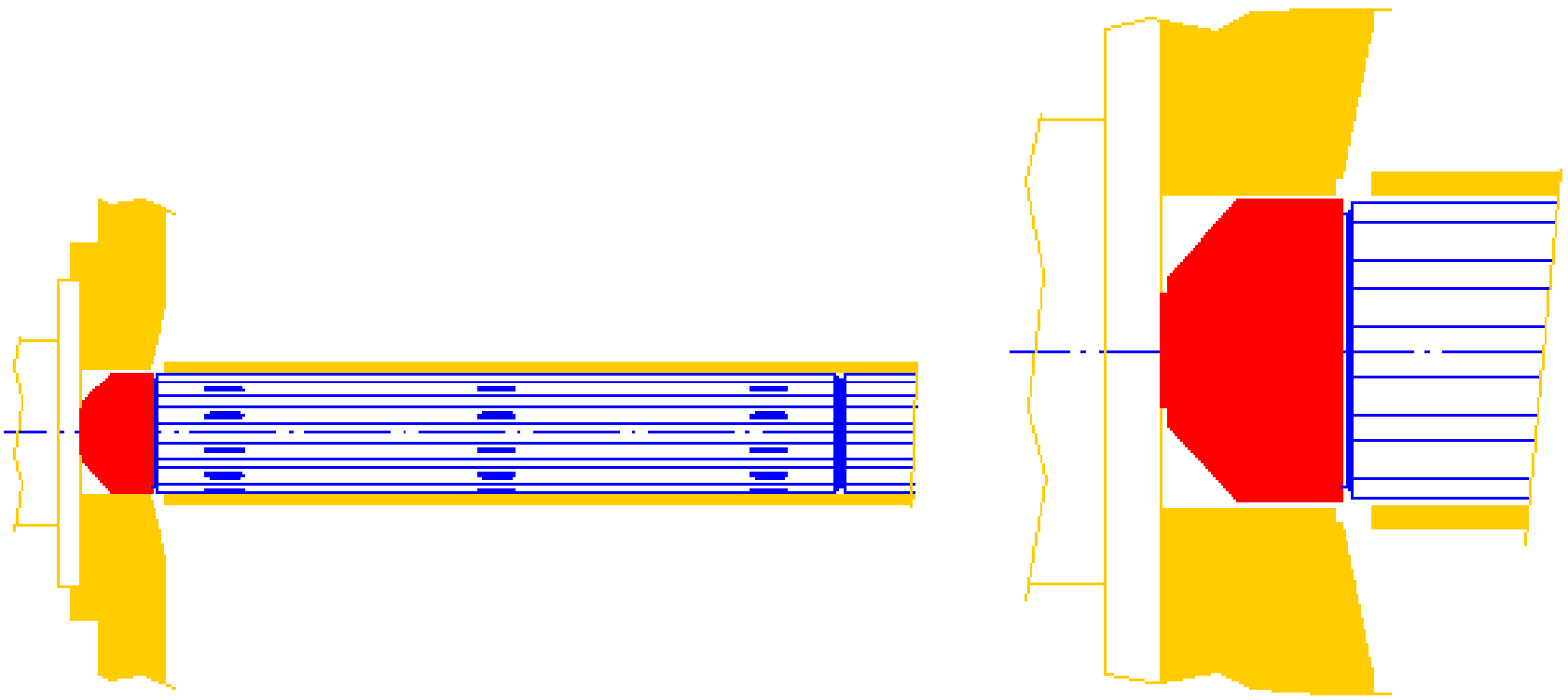
•VISUAL INSPECTION REVEALED THAT THE END PLATE OF THESE BUNDLES TOWARDS RAM CJ WAS FOUND DEFORMED.



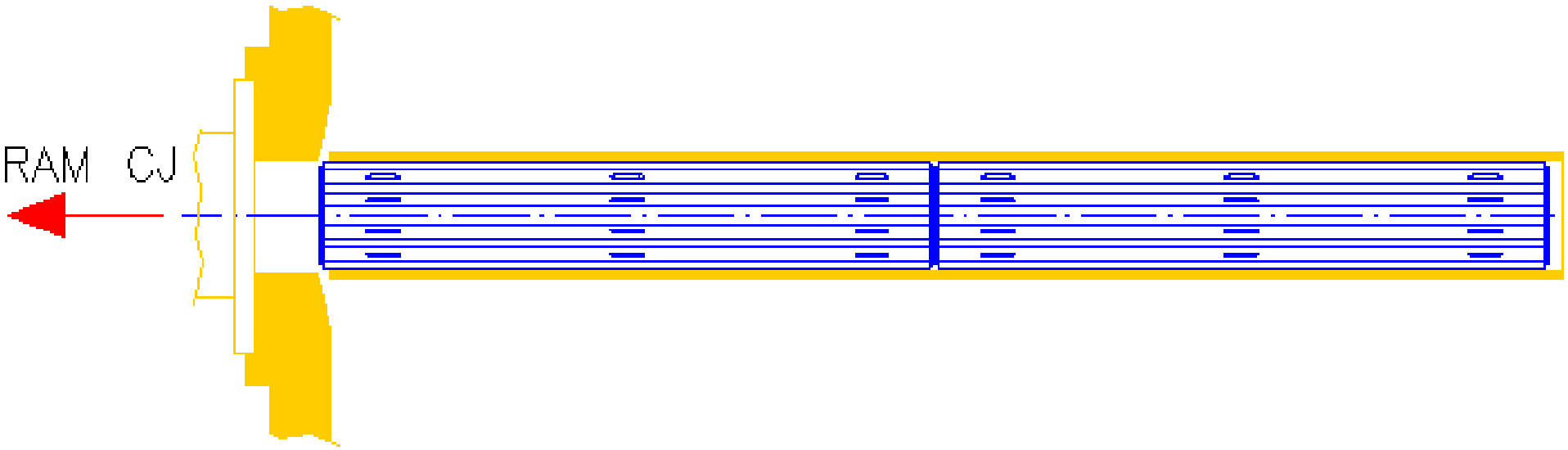
FUEL TRANSFER SYSTEM



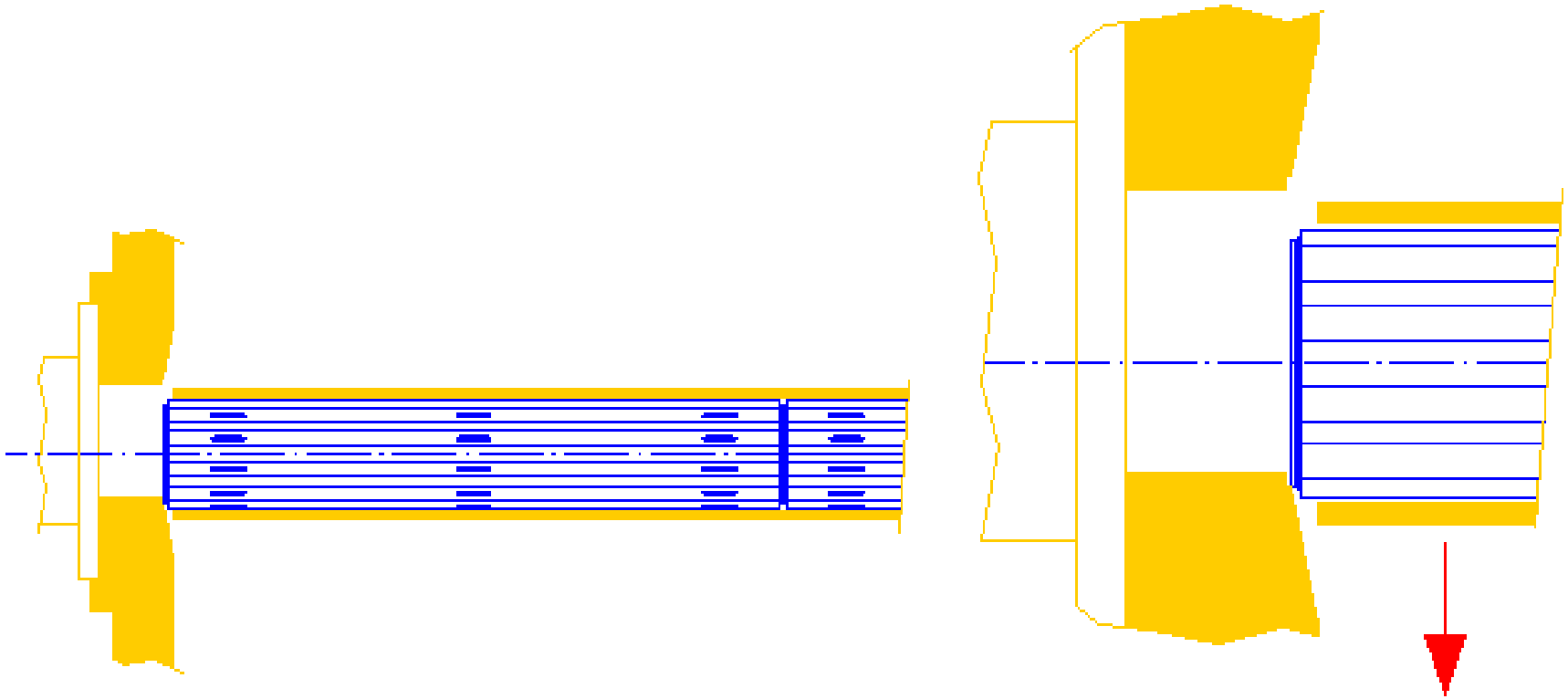
POSITION OF NEW BUNDLES IN TM AFTER NORMAL LOADING



POSITION OF K-11 CHANNEL NEW BUNDLES IN TM AFTER LOADING BY RAM CJ



RAM CJ RETRACTED

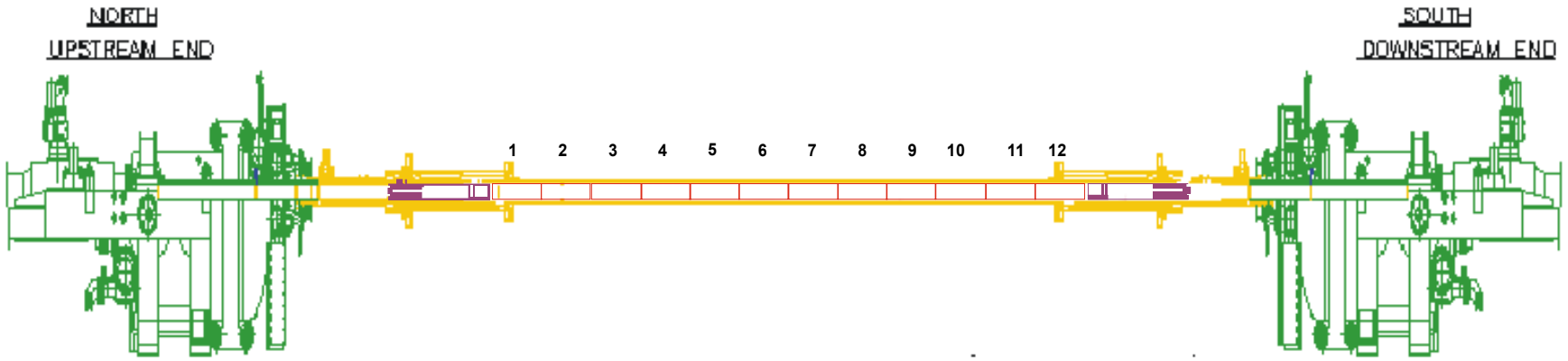


THE END PLATE OF REAR BUNDLE HITS THE EDGE OF TM FUEL GUIDE AS TM CARRIAGE MOVES DOWN


0684
ERG


NRG
0684

- **Based on this information it was concluded that end plates of four freshly loaded bundles in position 2,4,6 & 8 in channel K-11 were deformed.**
- **Four pencils in each of these damaged bundles were detached from the end plate towards the downstream end.**
- **It was conjectured that one of the damaged bundle could have become longer thereby inhibiting the installation of shield plug.**



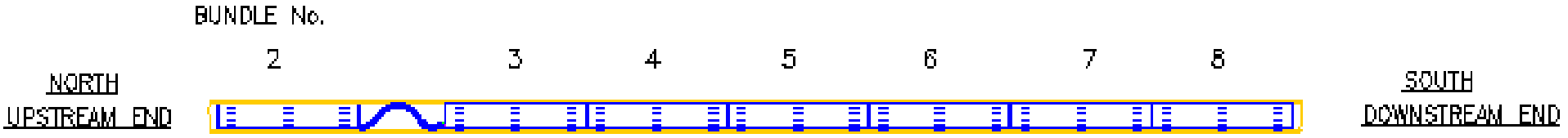
- Fuel bundles from channel K-11 at positions 12,11,10,9 were taken into south down stream fuelling machine by special grappling operation and discharged to the bay. Inspection of these bundles carried out and found to be intact.
- Bundle from position no. 1 was grappled into north upstream fuelling machine and discharged to the bay and inspection of this bundle also revealed no defect.
- Attempts to grapple bundle from position no. 2 failed.

- The decay heat calculations for the remaining 7 bundles present in the K-11 channel indicated that the maximum sheath temperature of the fuel pin within enclosed air environment of channel would be 165 degrees celsius after two days of reactor shutdown.
- Channel K-11 feeders were ice plugged and blanked at both ends on 30.01.2003.

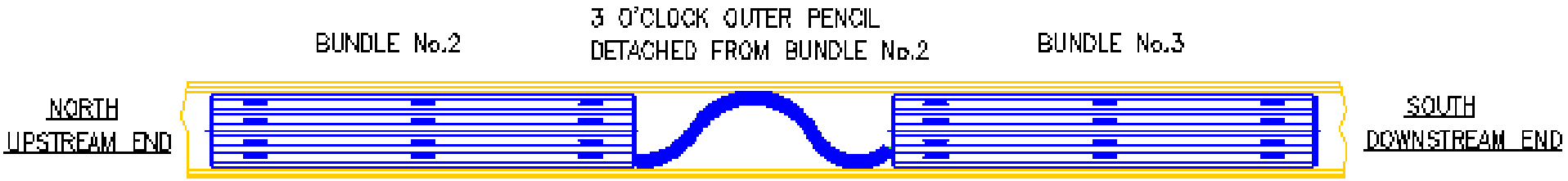
- After draining the channel, fuel bundles at positions 2 to 8 remaining in the channel were retrieved into shielding flasks by specially designed puller tools

- The loose bent pencil was retrieved using a scoop tool into a shielding flask

- All flasks along with retrieved fuel were shifted to SFSB

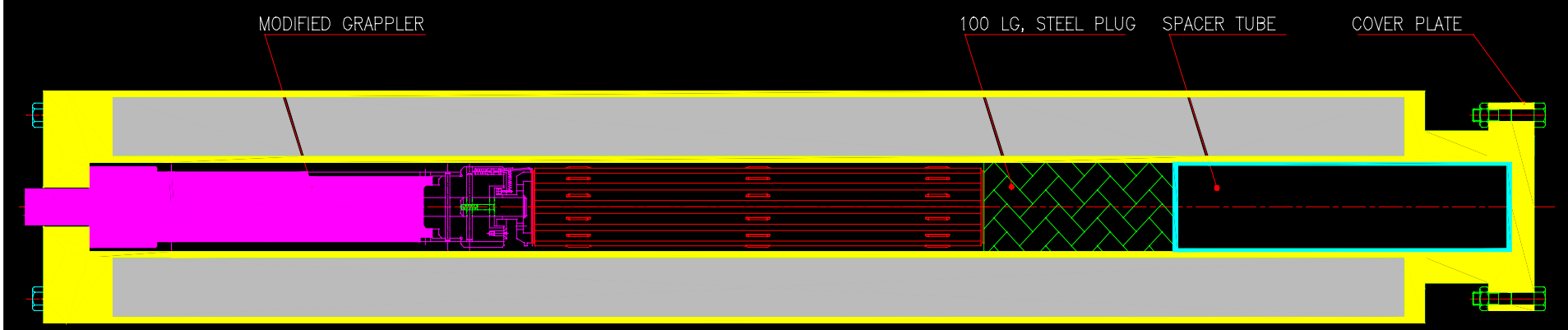


3 O'CLOCK OUTER PENCIL DETACHED FROM BUNDLE No.2 SANDWICHED BETWEEN BUNDLE No.3 & BUNDLE No.2



PENCIL BENT DUE TO APPLICTION OF B RAM FORCE 3

(SHAPE OF PENCIL CONSTRUCTED BASED ON SITE FEED BACK)



LEAD SHIELDED FLASK AFTER RETREIVAL OF SINGLE BUNDLE USING GRAPPLER

- **The root cause analysis of the event brought out that following were the contributing causes :**
  - **➨Wrong adjustment of fully advanced position of ram CJ after it was replaced (the stroke fell short by 4mm).**
  - **➨Verification trials of bundle movement were not carried out after the replacement of ram CJ**

Recovery from the event took 13 days

Regulatory Actions/ Stipulations

- Clearance for draining of the channel with 7 nos. of fuel bundles in it.
- Review of scheme of retrieval, with objective of safety of fuel and personnel.
- Inspection to establish the healthiness of the coolant channel before normalisation.

IMPROVEMENTS MADE IN FUEL HANDLING SYSTEM TO AVOID RECURRENCE

- **Procedure and checklist for replacement of rams were prepared.**

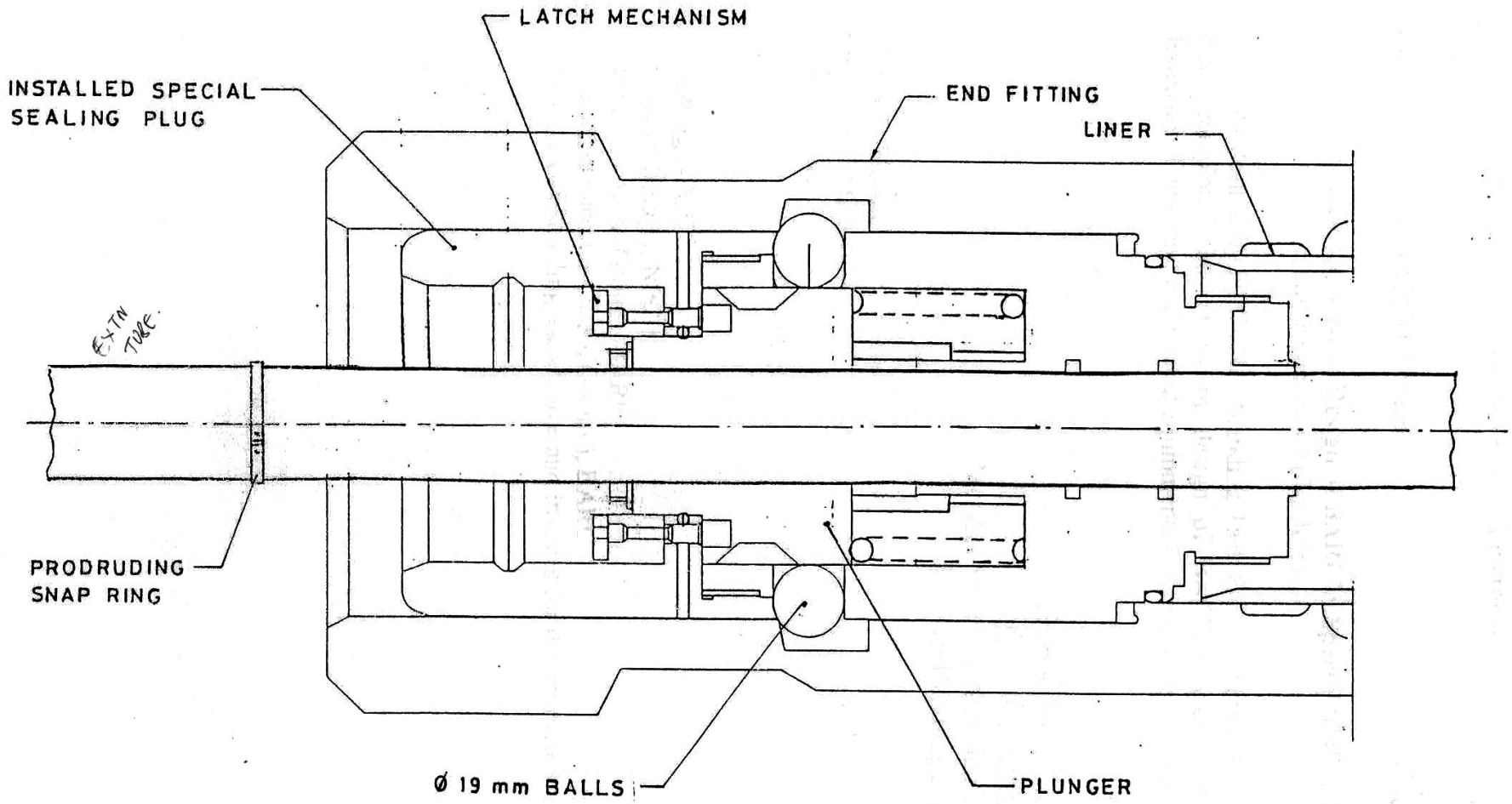
- **Measurement of the length of fuel string inside the channel before installation of shielding plug.**

HEAVY WATER ESCAPE INCIDENT

MADRAS ATOMIC POWER STATION (UNIT-2)	
Station	2 x 170 MWe PHWR Units
Occurrence	March 1999
Unit Status at the time of Incident	Shutdown
Affected System	Primary Heat Transport
INES Rating	Below Scale

PRIOR TO INCIDENT

- **UNIT UNDER SHUTDOWN (41 DAYS)**
- **MODERATOR CIRCULATION UNDER SHUTDOWN**
- **CORE COOLING MAINTAINED BY SHUT DOWN COOLING CIRCUIT WITH ONE SHUT DOWN COOLING PUMP OPERATING**
- **CHANNELS ISI WAS BEING CARRIED OUT USING INSPECTION TOOL 'BARCIS'.**
- **AFTER COMPLETING ISI ON 25 CHANNELS, CHANNEL K-5 WAS TAKEN UP. CHANNEL DE-FUELED AND SPECIAL SEALING PLUG INSTALLED, WHICH HAS PROVISION FOR CONNECTING EXTENSION TUBE FOR MOVING PROBE THRU CHANNEL**



INTERACTION OF PROTRUDING SNAP RING WITH SPECIAL SEALING PLUG

Elapsed Time	Event	Operator Action
00:00 Hrs.		Special Seal Plug Installed for ISI of Channel K-5
01:05 Hrs.	While Manipulating Extension Rod of Inspection System, D_2O Leak Started Through Special Seal Plug	Leak Detected
01:10 Hrs.	PHT Storage Tank Level Dropping	-Shutdown Cooling Pump Stopped Manually to Minimize Leakages (Reliance on Thermosyphoning Cooling) -Fire Water Addition Poised.
01:27 Hrs.		-Plant Emergency Alert Declared -Attempt to Reposition Special Seal Plug
01:35 Hrs.	Leak Stopped Due to Repositioning of Special Seal Plug.	

Elapsed Time	Event	Operator Action
01:50 Hrs.	PHT Storage Tank Level Low	Fire water Addition to Storage Tank (PHT D_2O Downgraded)
01:50 Hrs. To 03:35 Hrs.	Leak Restarted	-Attempts to Push Extension Tube Inwards and Install Blank- Failed -Attempt to Remove Special Seal Plug and Install Normal Plug-Failed
03:43 Hrs.	PHT Storage Tank Level Low	Fire Water Addition to Storage Tank
03:45 Hrs.		Shut Down Cooling Pump Started
04:27 Hrs	High Tritium Activity in Reactor Building Atmosphere	Plant Emergency Declared
04:55Hrs		Fire Water Added to Maintain Storage Tank Level

Elapsed Time	Event	Operator Action
08:39 Hrs.		After Organizing Additional Handling Tools, Normal Seal Plug Installed, Leak Stopped
09:10 Hrs.		Plant Emergency Called Off

During Shutdown Cooling Pump Stopped Condition

-Core Cooling by Thermosyphoning

PHT Temperature Rise

	Average Channel	High Power Channel
Initial	42.5^0C	
Maximum	58.8^0C	67.5^0C

Event Identification:

- **Storage Tank Level Fall**
- **FM Vault Beetle Indicated Leak in North FM Vault**
- **Leak Confirmed From CCTV**

Event Mitigation:

- **Shutdown Cooling pump stopped to reduce leakage**
- **Fire Water addition to PHT Storage Tank**
- **Plug re-positioned at intended position manually**
- **Normal Seal Plug installed using improvised handling tools**

After Leak Arrest

- Spilled Water collected through Vault Collection System and RB Sump
- During and After Incident No Iodine or Fission Product Activity Noticed in PHT System or RB
- Tritium Release Through Stack within Technical Specification Limits
- No Tritium Discharge Through Liquid Route
- PHT IP Decreased to 83% Due to Fire Water Addition to PHT Storage Tank

- **Total of 16 tons of heavy water leaked from PHT system during incident**
- **Recovered through**
  - **-Vault leakage collection system**
  - **-Vapor recovery system**
  - **-Vacuum mopping**
- **Heavy water escape through stack: 500 kg.**

SAFETY ASSESSMENT

-THOUGH SHUTDOWN COOLING WAS STOPPED TO REDUCE LEAKAGE, IT WAS LATER ESTABLISHED THAT PUMP AWAY FROM BREAK LOCATION CAN BE KEPT OPERATING DURING SUCH SITUATIONS

- LAYOUT PERMITS THERMOSYPHONING

-FOR CORE DECAY HEAT REMOVAL

- MODERATOR COOLING
- END SHIELDS COOLING
- FEEDER CABINETS COOLING
  - FM VAULT FANS
  - CABINET DOORS OPEN
  - CABINET VENTING DAMPERS OPEN
  - FM VAULT LINER FANS OPERATING

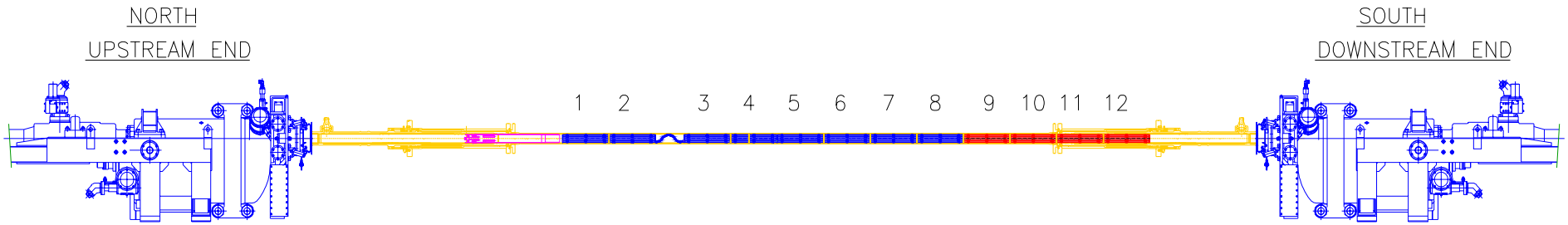
Regulatory Action/ Stipulations

- Restart of unit permitted only after full review of incident
- BARCIS tool prohibited from use till its design review and necessary modifications
- Strengthening of formal system of qualification of components/ tools developed for use in reactor
- Revised requirements for re-maintenance/ testing of BARCIS between uses
- Unavailability of moderator circulation during work on PHT System was deviation from normal practice necessitated addition of light water to PHT D2O during incident,with consequent downgrading

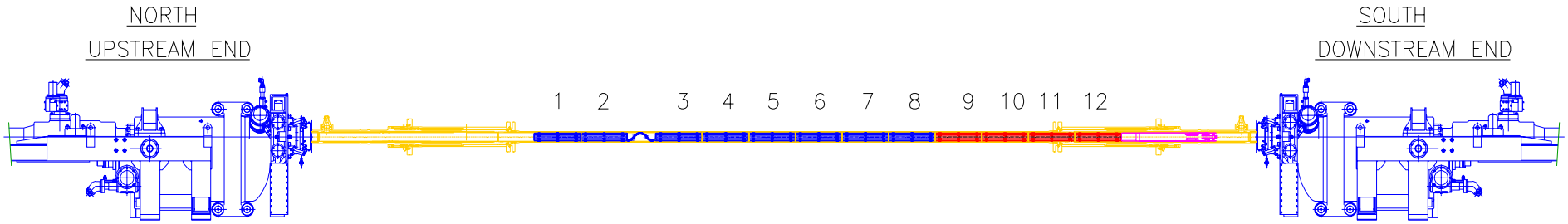
Significant Events - Closure

- **Three Significant Events presented are among the more prominent ones from Indian PHWR operating history, and illustrate the way they are handled by the utility and AERB**
- **All above events involved:**
  - Vigorous review by AERB with stipulations for remedial actions/improvements in affected and other similar plants
  - Clearance to restart after meeting minimum specified requirements
  - Lesson-learning resulting in improvements in design and operation

Thank You



DOWN STREAM FM FAILS TO INSTALL SHIELD PLUG



UPSTREAM SHIELD PLUG REMOVED & DOWN STREAM PLUG INSTALLED