OPERATION AND MAINTENANCE AT SAFARI-1 RESEARCH REACTOR IN SOUTH AFRICA

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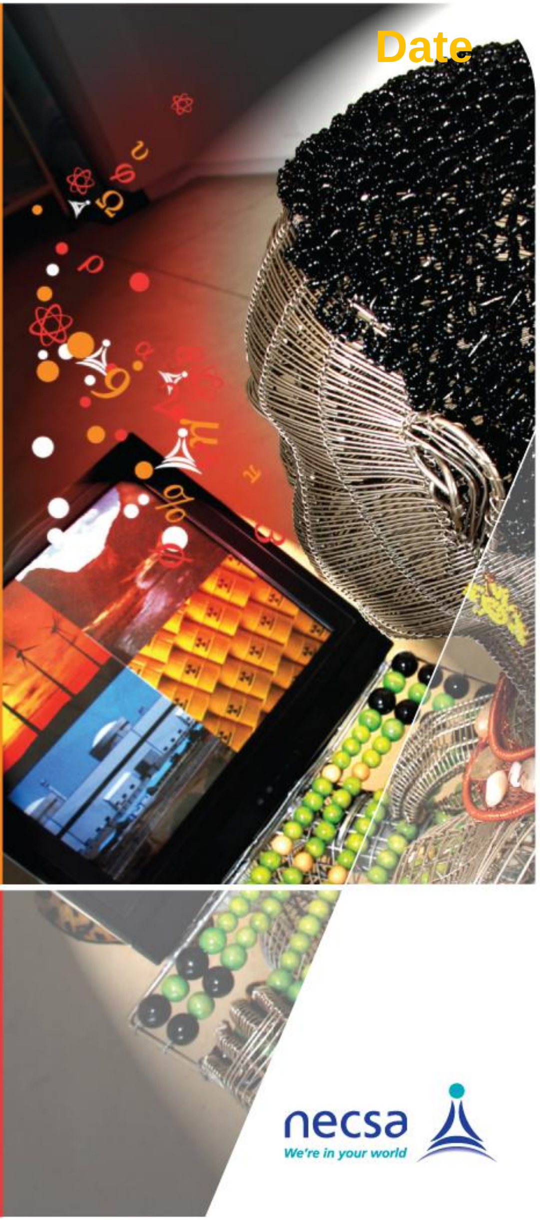

The Geographical Location of SAFARI-1, Necsa

Role of SAFARI-1

- 20 MW Research Reactor
- Operational since March 1965 (46 Years)
- 90% Funded by NTP commercial sales
- NTP also funds:
  - LEU fuel element final disposal, and
  - D&D of SAFARI-1 from April 2010
- 10% Funded by Necsa for historical liabilities
- Reactor needed until early 2020s for commercial production
- With operation of Dedicated Isotope Production Reactor (DIPR) in early 2020s SAFARI-1 will function as back up and focus on R&D
- HEU to LEU conversion of fuel completed and ^{99}Mo target plate licensed

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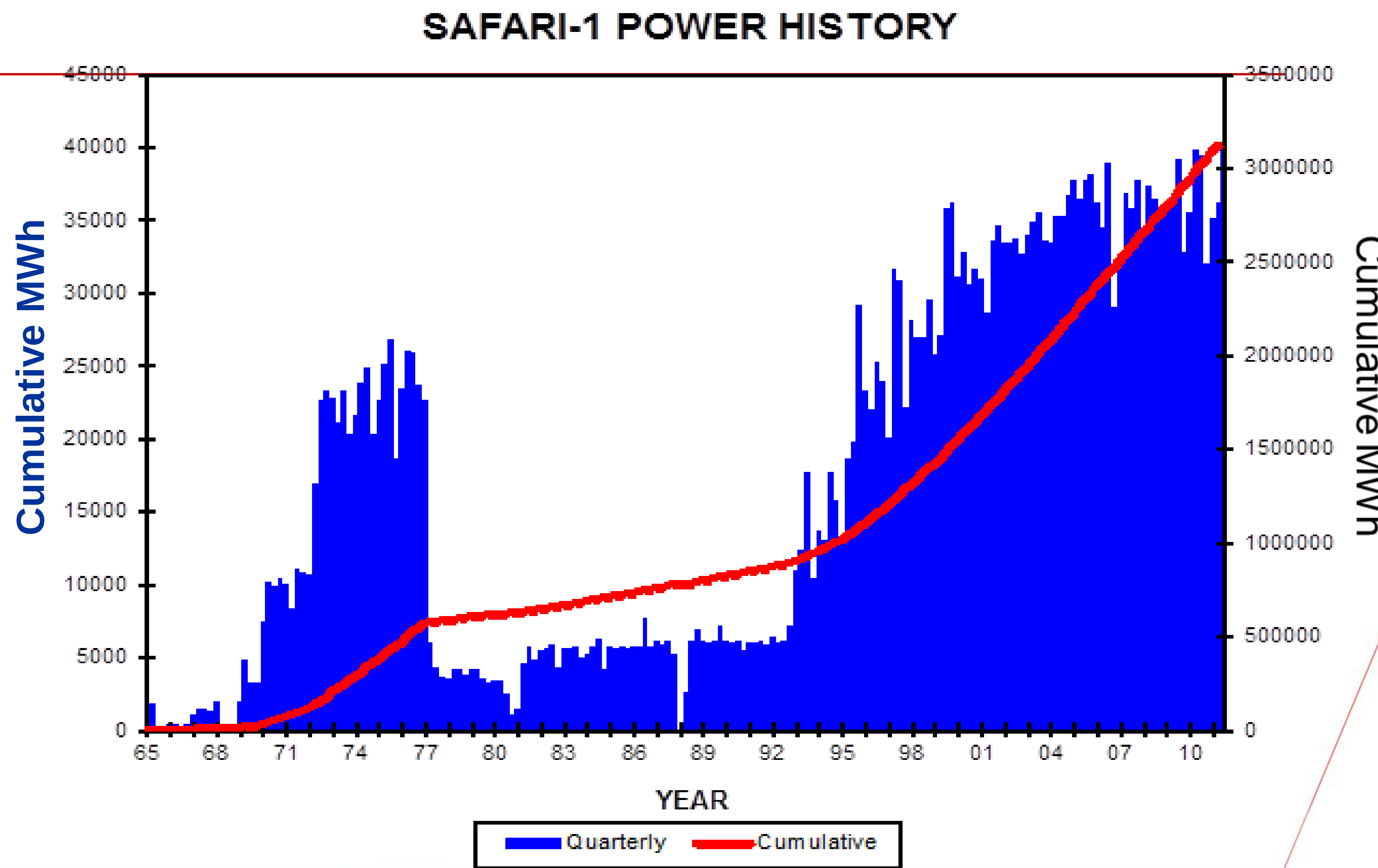

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SAFARI-1 Operation

- The era of production in the reactor is reflected in the increased usage below:

Thermal Power	Years
1st 1000 GWh	30
2nd 1000 GWh	8.8
3rd 1000 GWh	7.0

- Reactor maintenance scheduled down time per annum is currently:
  - Ten 5 day shutdowns with 21 to 35 days operating cycle
  - One 12 day shutdown
  - Total scheduled shutdown time is ~62 days with 303 days operation at full power

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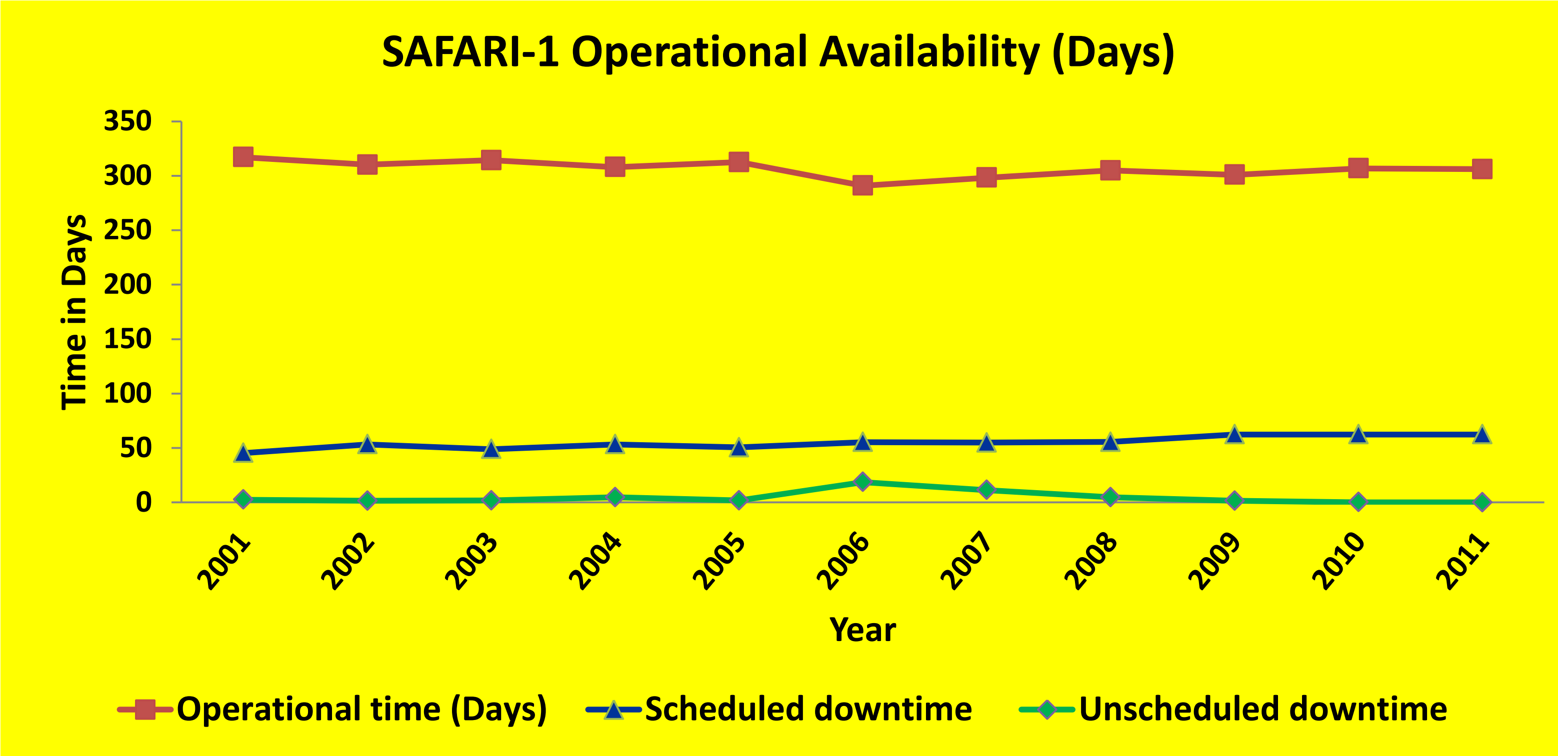
SAFARI-1 Operational Performance



Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Operational time (Days)	317.0	310.1	314.2	308.0	312.5	290.9	298.2	304.8	300.9	306.7	~306
Scheduled downtime	45.4	53.3	49.0	53.3	50.6	55.4	55.0	55.5	62.5	62.5	62.5
Unscheduled downtime	2.6	1.5	1.8	4.7	1.8	18.7	11.3	4.8	1.5	0.2	0.1

Maintenance Programmes

- The maintenance programmes list:
  - Responsibilities for tasks
  - Frequency of maintenance i.e. daily, weekly, monthly, yearly and >1 year
  - Schedule of tasks
  - Criteria and controls for maintenance tasks
  - Systems which can be isolated when reactor is in operation
  - Applicable restrictions for on-line maintenance
  - Records to be kept
- The maintenance programmes cover the following:
  - Routine tasks ~1919 per annum
  - Shutdown tasks ~572 per annum
  - Ad hoc tasks ~434 per annum

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Maintenance Control

- Included in maintenance programmes are the following verification controls:
  - Operational checks
  - Functional tests
  - Periodic routine inspections
  - In-service inspections

- All maintenance instructions and tasks comply with the Operating Technical Specification (OTS) and requirements of the Safety Analysis Report.

- System, Structures and Components (SSC) depending on safety classification are subject to the following controls prior to installation:
  - Design and procurement control
  - Manufacturing control in SAFARI-1 workshop and in Necsa ASME VIII and ASME III nuclear manufacturing facility
  - Approval and qualification of supplier, and QC release

Continues…

Maintenance Control Continued

- Prior to reactor shutdown a shutdown meeting is held and the Maintenance Shutdown Programme (MSP) agreed on
- The MSP is approved and forwarded to the National Nuclear Regulator who performs regular surveillances
- Maintenance tasks completed during the shutdown are reviewed w.r.t. records and in the post shutdown meeting to ensure compliance to MSP, OLC and OTS
- For in-service inspections procedures and plans are drawn up and most are performed as part of the MSP

Ageing Management System

The IAEA SSG-10 Guide provides guidance for ageing management system for Research Reactors (RR):

- Over the life of the of the RR
- Establishing an ageing management system
- Preventing ageing through appropriate preventative maintenance
- Detecting ageing through ISI
- Assessing and mitigating ageing effects by using an

  Ageing Management Programme (AMP)
- Promote safety culture through implementation

Ageing Management Programme

In SAFARI-1 the AMP was integrated with the existing Integrated Management System (IMS) but the following systems were strengthened:

- Design control
- Project management
- Configuration management
- Calculation control

Methodology for Selecting Ageing Management Projects

Use following methodology to select and prioritise ageing management projects:

1. Determine **Ageing** System, Structure and Components (**SSC**)
2. For each Ageing SSC define the applicable **Ageing Mechanisms** (AM)(1 - 13)
3. For AM identify a **Remedial Actions** (replace, refurbish, redesign or maintain)
4. Prioritise the Remedial Action (RA) as follows:
   - If RA is not performed select applicable **Impact Factors** (9) and rate each 0, 5 or 10 and sum for total Impact Factor
   - Multiply total Impact Factor by **Weighting Factor** (1-10) based on Remedial Action being controllable, implementable, viable, cost, urgency

$$\left[\textbf{RA Priority} = \sum_{i=1}^{9} \textbf{Impact Factor (0, 5 or 10) x Weighting Factor (1 to 10)}\right]$$

Grouping of Ageing Systems, Structures and Components

- Reactor block, fuel and internals
- Cooling systems
- Confinement and containment
- Instrumentation and controls
- Power supply
- Auxiliaries (e.g. fire protection, crane, hot cells and radioactive waste handling)
- Experimental facilities
- Non SSC:
  - Documentation (e.g. SAR, OTS and management systems)
  - Staff training

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Ageing Mechanisms

- Radiation resulting in changing of properties
- Temperature causing changes of properties
- Creep due to stress or pressure
- Mechanical displacement, fatigue or wear from vibration and cyclic loads
- Corrosion
- Material deposition (e.g. Crud)
- Flow induced erosion (e.g. orifice and concrete)
- Obsolescence through technology change
- Damage due to power excursions and operational events
- Flooding causing deposition and chemical contamination
- Fire resulting in effects of heat, smoke and reactive gases
- Changes in requirements such as legislation or acceptable standards
- Other time dependent phenomena

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Prioritisation of Be Reflector Elements

- For Be elements 4 Ageing Mechanisms: radiation change in properties, creep due to stress/pressure, mechanical displacement and damage due to operational events
- For priority assessment four Impact Factors were identified and rated:
  - Non-availability 10
  - Reportable nuclear event 0
  - Radiological exposure 0
  - Injury to anyone 0
  - Environmental releases 0
  - License complications 5
  - Lifetime limitations 10
  - Public non-acceptance 0
  - Stakeholder non-acceptance 5 (Sum of Impact Factor = **30**
- Weighting Factor given as **8** since Be replacement is easy, albeit at high cost
- Total priority for a Remedial action to replace Be elements is 30 x 8 = **240**

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Remedial Action Description	Priority
Safety Critical Ageing Management	
Upgrade safety-critical neutron and gamma detectors and instrumentation	400
Safety-critical instrumentation segregation and separation of routing	280
Periodic safety review (10 yearly) and possible INSARR by IAEA	200
Mission (Operation)- Critical Ageing Management	
Upgrade ventilation stack monitors and data transmission	400
Convert LEU targets	350
Replace Be reflector elements	**240**
Lifetime Extension Ageing Management	
Asses reactor vessel lifetime for recommendation of surveillance/replacement	400
Assess reactor building and stack integrity for lifetime extension of facility	350
Organisational (Management Control) Ageing Management	
Controlled storage areas for critical spares, handling tools, maintenance equip	300
Develop expertise by filling vacancies and training of personnel	240
IMS compliant to standards ISO, OHSAS, NNR, Necsa SHEQ and IAEA	150

SAFARI-1 Integrated Management System

- The Integrated Management System (IMS) integrates Quality, Health, Safety and Environmental (QHSE), Security and Safeguards management systems and has evolved as follows:
  - From ANSI NQA-1 used in the PWR fuel manufacturing plant
  - Number of PWR staff appointed by SAFARI-1 implemented system since 1994
  - NNR, IAEA and Necsa SHEQ system evolved and requirements incorporated
  - ISO-9001 certified in 1998
  - ISO-14001 certified in 2003
  - OHSAS 18001 certified in 2011
- Compliance through audits show a decreasing number of findings and observations:
  - Audits by NNR, Necsa SHEQ department (compliance increased by 10% to 91.8% in 2010) and Necsa Internal Audit function
  - SAFARI-1 management team of 6 performed self assessment audit

Safety Management System Performance

- Nuclear safety performance - reactor scrams halved to ~10 from previous year

Nuclear Occurrences	2009 FY	2010 FY	2011 FY
Level 2	5	1	2
Level 3	26	10	11

- Excellent occupational and health record improved by means of a Behaviour Based Safety (BBS) programme:
  - Every person is trained for safety observations (~ 10 min once per month)
  - One page check list used
  - Personnel observed notified at start and given feedback of safe and unsafe behaviour
  - "no-name and no-blame"
  - Total injury rate (annual average monthly injuries x 200 000/ possible annual man hours) dropped to zero

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SAFARI-1 BBS Performance

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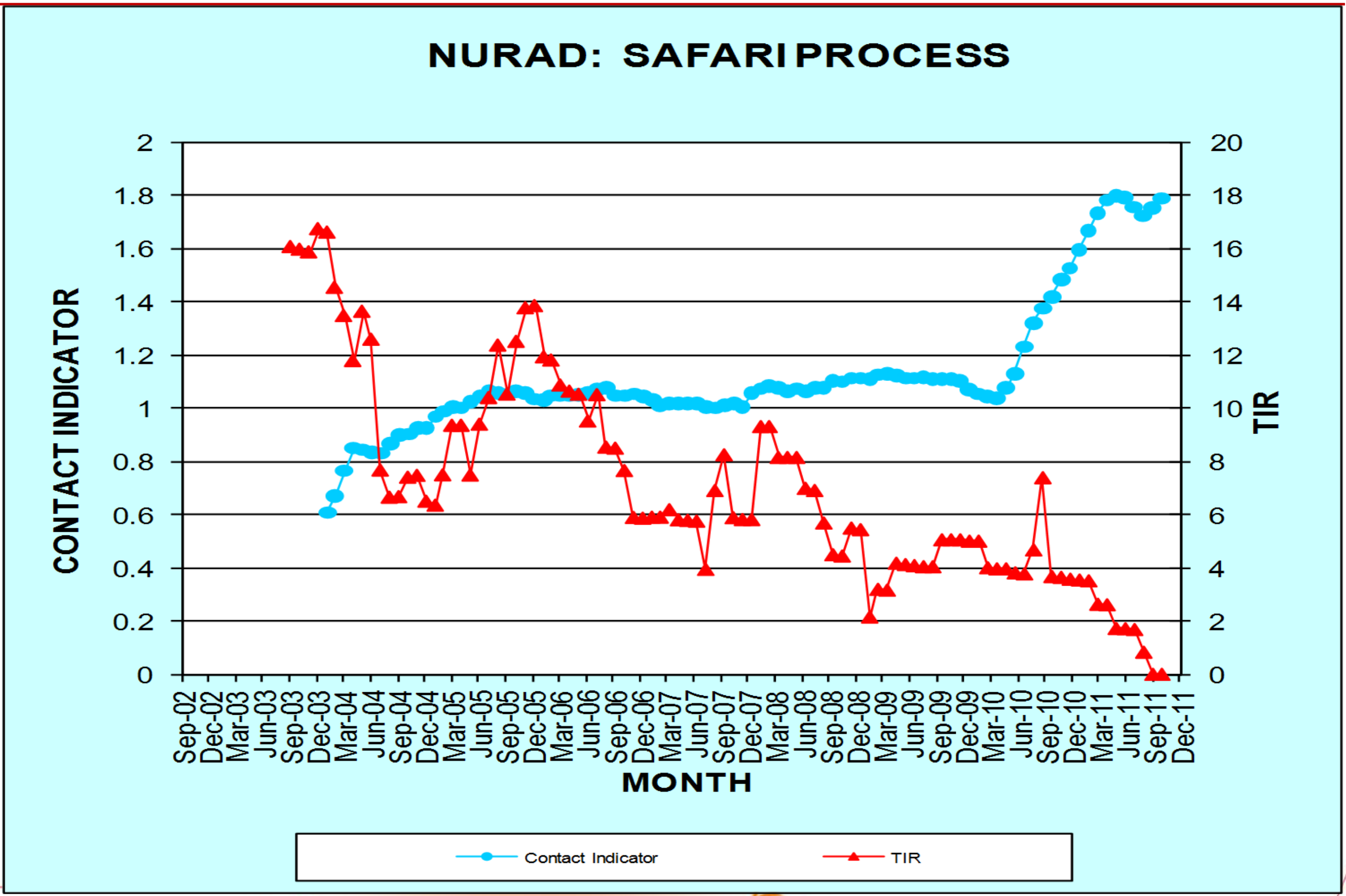
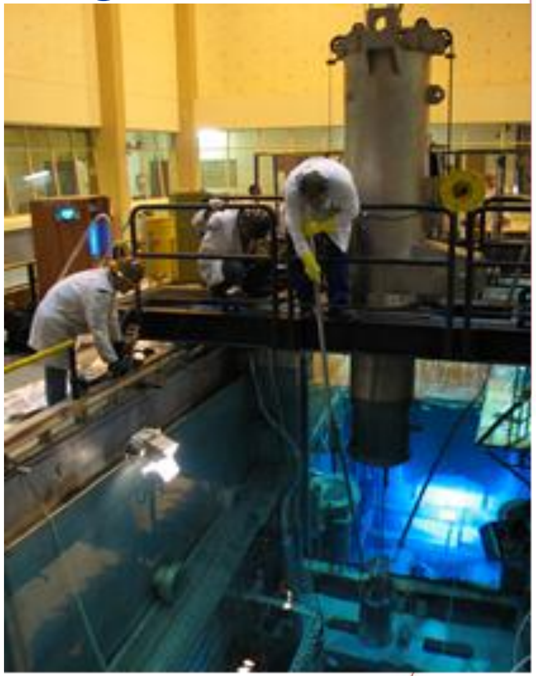


Security Upgrades

- SAFARI-1 is located within the Necsa security arrangement
- Separate security fence was installed
- Hardening of perimeter doors
- Installation of building camera system
- Biometric (throughout building) and parcel scanner
- Further hardening of building inner protection areas for conformance to INFCIRC/225/Rev.5

Safeguards Performance

- SAFARI-1 complied with and promotes international safeguards
- Initially had IAEA INFCIRC/66/Rev.2. type safeguards agreement
- SA signed NPT and CSA in 1991 and AP in 2002
- In 2011 SA received the IAEA broader conclusion
- Integrated Safeguards (IS) approach being developed
- IS will use power monitor and new spent fuel storage
- SAFARI-1 fuel converted from HEU to LEU in 2009
- ^{99}Mo production from LEU target licensed in 2010
- HEU spent fuel of US origin returned to US



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Conclusion

- SAFARI-1 has shown reliable operation in particular during the ^{99}Mo supply crises in 2010 when two major producers were off line for repairs
- The operational performance can be ascribed to the well developed and implemented maintenance programme and in service inspection
- For lifetime extension SAFARI-1 is actively implementing an ageing management programme to extend its life to 2030
- Nuclear safety and occupational health and safety have shown marked improvements through BBS, active management involvement and promotion of safety culture
- The basis for the excellent performance has been a well developed IMS which is continually being improved
- SAFARI-1 which is supporting R&D activities in Necsa and SA, has become a strategic supplier of irradiation services to NTP who technically fully funds it from commercial sales.

Thank You