Role of Leadership and Safety Culture in Regulatory Decision Making Process of BAPETEN

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Agenda

• Introduction
  • BAPETEN & the Structure; Hierarchy of Law; Conventions; Licensees Profile.

• Decision Making Process
  • In General
  • BAPETEN Procedure

• Leadership
  • Role of leader

• Safety Culture
  • Practice in regulatory body

• Case study
  • Safety Reassessment Indonesian RRs after Fukushima.

• Remarks
Part 1: Introduction

- BAPETEN is an independent regulatory body, responsible for regulating the 3S:
  - safety and security of facilities and activities engaging nuclear energy and ionizing radiation – including emergency preparedness; and
  - safeguards of nuclear materials.
- Chairman of BAPETEN is directly report to the President of Indonesia. All regulatory decision is based only on technical issues, i.e. risk & threat review and assessment.
- BAPETEN was established in May 1998 based on Act No. 10/1997 on Nuclear Energy.
- Act No. 10/1997 on Nuclear Energy:
  - Separating executive-promotional function (BATAN) and regulatory function (BAPETEN)
  - Regulation are carried out through rulemaking, licensing (authorization) and inspection (law enforcement).
• Act No. 10/1997 on Nuclear Energy.
• GR No. 2/2014 on the Licensing of Nuclear Installation and the Utilization of Nuclear Materials
• GR No. 61/2013 on Radioactive Waste Management;
• GR No. 54/2012 on the Safety and Security on Nuclear Installations;
• GR No. 46/2009 on the Liability of Nuclear Damages;
• GR No. 29/2008 on the Licensing of Ionizing Radiation Sources and Nuclear Materials.
• GR No. 33/2007 on the Safety of Ionizing Radiation and Security of Radioactive Sources. (adapting the IAEA BSS-115).
• GR No. 26/2002 on the Transport Safety of Radioactive Materials (tba.);
• BCR No. 4/2009 on Nuclear Reactor Decommissioning; BCRs ...
Some International Conventions

- Nuclear Non-Proliferation Treaty (NPT). Ratified with Act No 8/1978;
- The Southeast Asia Nuclear Weapon Free Zone Treaty (SEANFZ). Ratified with PR No. 9/1997;
- **Nuclear Safety Convention.** Ratified with PR 106/2001
- **Joint convention** on the safety of Spent Fuel Management and on the Safety of Radioactive Waste management. Ratified with PR 84/2010
- Convention on **Early Notification** of a Nuclear Accident. Ratified with PR No. 81/1993; and Convention on **Assistance** in the Case of a Nuclear Accident or Radiological Emergency. Ratified with PR No. 82/1993;
- Comprehensive Nuclear Test Ban Treaty (**CTBT**). Signed 24 September 1996. Ratified with Act No. 01/2012
Licensee profiles

Nuclear Facility
- Research Reactor, 3
- Nuclear Fuel Cycle, 4
- Nuclear Materials
- NPP & Experimental Power Reactor
- Uranium Recovery

Health Facility
- Radiotherapy
- Radiodiagnostic
- Nuclear Medicine

Industrial Facility
- Irradiator
- Radiography
- Gauging
- Analysis
- Well logging
- Etc.

Research & Education Facility
- Research
- Education

TENORM
Nuclear Installations

Three research reactors operated by BATAN (National Nuclear Energy Agency)

• MPR-30 (RSG-GAS) Reactor, Serpong (suburb of Jakarta)
  – 30 MWt maximum power; Uranium Silicide 19.75%
  – Pool type with H₂O; Beryllium reflector.
  – **Production:** Mo-99 & Ir-192

• TRIGA-2000 Reactor, Bandung, West Java
  – 2000 kWt maximum power; U-ZrH 19.75 %
  – Pool type with H₂O; Graphite reflector.

• Kartini Reactor, Yogyakarta, Center of Java
  – 100 kWt maximum power; U-ZrH 19.75 %
  – Pool type with H₂O; Graphite reflector.
Part 2: Decision Making Process

Criteria for Safety

• “No unreasonable risk”.
• “Adequate protection of public health and safety”.
• “Risk as low as reasonably practicable”.
• “Safety as high as reasonably achievable”.
• “Limit risk by use of best technologies at acceptable economic costs”.

Initiators:
- Petition for rulemaking
- Application for license/approval
- Findings for enforcement

DMP:
- Risk assessment
- Threat assessment
- Regulatory impact analysis

Regulatory Decision:
- New Regulation & Guides
- Rejection, License & Approval
- Enforcement: Suspension, Revocation, Penal provision

Decision Making Process
Decision Support System

Management Information System (MIS)
BAPETEN: B@LIS and EVADOSE

Computer Codes. BAPETEN: PARET/ANL, MCNP
RELAP-5, MVP, SRAC, and SCALE

Regulation, guides, standards, best practices

Procedures, Working Instructions [including acceptance criteria]
Decision Making Process

DMP for Enforcement Process of BAPETEN

Evaluator & Inspector: Finding Report

Project Manager: Petition for Regulatory Decision addressed to Director of Licensing

Director order to develop RIA Draft

Director and Staff presents to the Deputy Chairman & the Chairman for approval to initiate enforcement plan

RIA Finalization: Request for additional information; TSO/Expert presentation (Technical & legal aspects)

Presentations to the Chairman for decision making
SF-1 Principle 3: ... “Effective leadership and management for safety must be established and sustained.”

- Leadership in safety matters has to be demonstrated at the highest levels;
- To ensure the promotion of a safety culture, the regular assessment of safety performance and the application of lessons learned from experience.

SSG-16: Action 78. The senior management of all the relevant organizations should provide effective leadership and effective management for safety to ensure a sustainable high level of safety and a strong safety culture.

But, what is leadership? What are the roles of Leader?
Roles of Leader

Sooo many interesting roles of Leader:

Elaine B Greaves Esq., President and CEO of Season to Success Inc.:
- Communicator,
- Thinker,
- Decision maker,
- Team builder, and
- Image builder.

Leadership Roles & Responsibilities:
- Directing,
- Coaching,
- Supporting and
- Delegating.

Patty Vogan, Entrepreneur.com's "Leadership" columnist and owner of Victory Coaching:
- Futurist,
- Historian,
- Ambassador,
- Analyst, and
- Contrarian.

“The art of leadership is saying no, not saying yes. It is very easy to say yes.”
[Tony Blair]

http://www.timcoburn.com/role-of-the-leader/
Roles of Leader

Role of Leader [Peter M. Senge, 1990]
Leader as a Designer

What to design?

Shared vision: “To be a world-class nuclear regulatory body”.

An **IMS**: Regulatory business process, procedures, ...

An effective Regulatory DMP. Incl. the DSS

Steps to adopt Safety Culture within the RB

Knowledge management

... ... ... ... ...

17
1. You cannot teach without learn → Promote learning attitude
   - The world has change very fast. If you don’t change you die!
   - To change is to learn and to unlearn.
   - Helping everyone in the organization, oneself included, to gain more insightful views of current reality.

2. Promoter for management system and role model for safety culture:
   - Accountable: Be a role model for effective decision making
   - Questioning attitude
   - Discourage complacency with regard to safety
   - Not just good looking paper or certificate, but in the real day to day life in demonstrating commitment to safety: Do we do what we said we do?
1. Helping everyone in the organization, oneself included, to gain more insightful views of current reality (in regard of safety).
2. Fostering safety culture for all the licensee;
3. Promoting service excellence, without sacrificing safety;
• The ultimate goal of leadership and management for safety is Safety Culture: “The assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance”

• SF-1, Principle 3 LMS, 3.13: A safety culture that governs the attitudes and behaviour in relation to safety of all organizations and individuals concerned must be integrated in the management system. Safety culture includes:
  – Individual and collective commitment to safety on the part of the leadership, the management and personnel at all levels;
  – Accountability of organizations and of individuals at all levels for safety;
  – Measures to encourage a questioning and learning attitude and to discourage complacency with regard to safety.
Safety Culture, Leader & Regulator

- Strong regulator should aim to create strong operator in safety culture.
- Leader ensures strong (effective) regulator.
- Effective regulator: [http://www.ictregulationtoolkit.org/6.5]
  - Providing the regulator with a distinct legal mandate, free of ministerial control.
  - Prescribing professional criteria for appointment.
  - Involving both the executive and the legislative branches in the appointment process.
  - Appointing regulators for fixed terms and protecting them from arbitrary removal.
  - For a board or commission, staggering the terms of the members to ensure continuity within the top ranks of the agency.
  - Exempting the agency from civil service salary and employment rules that make it difficult to attract and retain well-qualified staff, as well as to terminate poorly performing staff, as necessary where the civil service system and salaries do not seem to work.
  - Providing the agency with a reliable and adequate source of funding.
Part 4: Case Study

- May 2011: Director of Licensing requested the Deputy Chairman and the Chairman of BAPETEN an approval to initiate safety reassessment to all the three research reactor. Permission granted for assessing worst case analysis, seismic and geo-technical, volcanic, and emergency preparedness.

- Directorate of Licensing organized an internal meeting engaging inspector, reviewer and assessor (internal TSO) to develop the plan; schedule; teams; general safety criteria; applicable law, regulation and guides, analysis methods and computer codes to be used; and the list of external experts that would be contacted.

- After some meetings, project managers agreed to prioritized the reassessment program to TRIGA-2000 reactor:
  - As the oldest RR reached it’s first criticality in 1965;
  - Recent development of national hazard map and a potency that the building code in 1960s is somewhat different with the current situation;
  - More detail research on Lembang Fault, 11km to the north of TRIGA-2000, are available; and
  - Massive bubbles in the core and fission product release were found after the upgrading program (from 1000 kW to be 2000 kW in the year of 2000), especially if the reactor power increased to be >1000kW.
Methodology

• Site re-evaluation:
  • Seismic aspect
  • Volcanic aspect

• Plant safety assessment:
  • Inherent safety assessment by BATAN → reviewed by BAPETEN
  • Review of the current status by BAPETEN.

• Emergency preparedness and response:
  • General requirements
  • Requirements for infrastructure
  • Functional requirements
Regulatory Action

• Early September 2011: Directorate of Licensing finalized all the three reassessment reports;

• Series of presentations to the Chairman and Deputy Chairman were made in early September 2011:
  • Brief report by Director of Licensing
  • Project manager and technical officers presentation for risk assessment
  • External experts presentation for seismic and geo-technical aspect
  • Internal lawyer for RIA (after consultation to external lawyer)

• The Chairman made the decision to suspend the license of TRIGA 2000 reactor for two years, ordered the Director of Licensing to finalize the decision;

• Top management of BAPETEN requested top management of the Operator for a meeting to
  • Inform the decision to be signed to suspend the license, with the basis of the decision;
  • Ask the operator to submit Decommissioning Plan document asap,
  • Inform the Operator to submit an application should the Operator ask for life extension, attached with a detail plan, otherwise the Operator would be required to perform decommissioning.

• 30 September 2011: The Chairman signed the license suspension document, with further instruction to remove all nuclear fuel from the reactor core and that the Operator shall remain be responsible for the security of the plant.
• The study case shows that leadership and safety culture plays very important role in regulatory decision making process of BAPETEN, which in some cases could be very tough situation;

• Understanding the roles of leader (as designer, teacher and steward) is very important to build a strong leadership, which at the end should be aimed to create strong Operator in safety;

• For a better regulatory decision making process, BAPETEN learned that improvement plan should be made to increase quality of risk/threat assessment, RIA, and the DSS, (and even to develop national TSO where possible, considering that Indonesia is an embarking country).

• Leadership and management for safety, the IMS of BAPETEN, is not only a paperwork. It helps BAPETEN develop Safety Culture in BAPETEN and fostering Safety Culture of the Operator. Many further works is indeed still need to be done to increase the maturity of documentation and the Culture.
Attachment: Case Study
Reassessment to the Three RRs in Indonesia
Requirements for infrastructure

Quality assurance programme

Logistical support and facilities

Plans and procedures

Mitigating the non-radiological consequences

Taking agricultural countermeasures

Keeping the public informed

Managing the medical response

Assessing the initial phase

Protecting emergency workers

Providing information and issuing instructions and warnings to the public

Basic responsibilities

Assessment of threats

General requirements

Establishing emergency management and operations

Identifying, notifying and activating

Functional requirements

Taking mitigatory actions

Taking urgent protective actions

Indonesia
14 Categories Chart (ISE per April 2012)

Indonesia

Functional Requirements

General Requirements

Series1
Epicentrum data, $M \geq 5$, 1900-2009
Tectonic map and active faults
MPR-30 Safety Reassessment

- Site reevaluation:
  - Seismic aspect
  - Volcanic aspect

- Plant safety assessment:
  - Review of current status by BAPETEN.
  - Inherent safety assessment by BATAN: SBO and Scram failure scenario. → Reviewed by BAPETEN
Volcanic aspect

Mt. Salak view from Bogor
Explosions: 1668-1699, 1780, 1902-1903, 1935 & lastly in 1938 (freatic erruption only)
## Ciseeng hot springs

<table>
<thead>
<tr>
<th>Loc.</th>
<th>$T^\circ$</th>
<th>pH</th>
<th>K</th>
<th>Na</th>
<th>Ca</th>
<th>Mg</th>
<th>B</th>
<th>Li</th>
<th>SiO$_2$</th>
<th>HCO$_3$</th>
<th>SO$_4$</th>
<th>Cl</th>
<th>F</th>
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<td>275</td>
<td>79</td>
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<td>3.1</td>
<td>-</td>
<td>140</td>
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<td>3.5</td>
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<td>7</td>
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<td>20</td>
<td>0.3</td>
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<td>68</td>
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<tr>
<td>C-1</td>
<td>42</td>
<td>7.6</td>
<td>7</td>
<td>126</td>
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<td>13</td>
<td>2</td>
<td>-</td>
<td>28</td>
<td>500</td>
<td>82</td>
<td>15</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Source: Asnawir Nasution (2011)
Experts opinion & BAPETEN conclusion

• Expert-1: ITB (university) geothermal researcher
  • That Ciseeng hot springs might erupts from gap/fracture and the formation temperature below the surface is relatively low, < 150 °C;
  • The hazard to Serpong nuclear installation is very small.

• Expert-2: BATAN water resources expert
  • Hot springs temperature: 30-40 °C, as the enthapy from chemical reaction between limestone and groundwater;
  • It’s not from volcanic activities.

BAPETEN Conclusion:
• The hot spring is not part of volcanic activities.
• Volcanic hazard to Serpong nuclear facilities is very low and acceptable.
BATAN assessment paper to the MPR-30 reactor:

- For the RSG-GAS, the Fukushima accidents give an impact to perform a reanalysis due to accidents of SBO occurrence which occur sequentially, followed to fail scram on the RSG-GAS along with a cooling rate that is not protected by the RPS.

- Analyses were performed using the transient calculation program for research reactors (Paret-ANL), applied to the model of the hot and the average channel.

- The results shows that the rate of cooling is not protected by 50% and delay time control rods fall protection exceeds 0.5 seconds causes the temperature of the hot channel exceeds the safety limit, but this is not happen in the average channel. **The RSG-GAS inherent safety system has capability to decrease the reactor power as gradually although reactor does not scram.**

Source: Endiah Puji Hastuti, 2011
BAPETEN assessment paper to the MPR-30 reactor:

- After MPR-30 shutdown normally, the reactor power from fission reaction terminates and leaves decay heat. The primary coolant pump still operates for a few hours, until decay heat is sufficiently small and allows the core to be cooled by natural convection without leading to significant increase in fuel temperature.

- The second mode is natural convection cooling after LOFA, where primary coolant pumps stop before the reactor scram, therefore the decay heat is much higher than the natural circulation after normal shutdown. The reactor should operate safely by natural convection at any designated condition that might occur during its life time. The analyses are aimed at ensuring that at any condition for natural convection cooling, the reactor core can be adequately cooled.

Source: Azizul Khakim, 2011
• Seismic and volcanic risks to MPR-30 are very low and acceptable;

• Plant safety reassessment for extreme condition is acceptable, but could further be investigated for other high impact very-very low probability scenarios.

• Emergency preparedness and response plan is also acceptable, but can be improved in some points:
  – IAEA EM to review the existing national nuclear emergency preparedness infrastructure and recommend improvement plan (Nov 2012);
Kartini Reactor, Yogyakarta

- Site reevaluation: **Seismic and Geotechnic aspect**

- The earthquake: 27 May 2006
- No significant damages to the Kartini Reactor building.

<table>
<thead>
<tr>
<th>Institution</th>
<th>Time</th>
<th>Depth [km]</th>
<th>Magnitude</th>
<th>Epicenter</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Mb</td>
<td>Ms</td>
</tr>
<tr>
<td>BMG, Indonesia</td>
<td>5:54:01</td>
<td>11,87</td>
<td>5,9</td>
<td></td>
</tr>
<tr>
<td>ESDM, Indonesia</td>
<td>5:54:01</td>
<td>17</td>
<td></td>
<td>6,2</td>
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<tr>
<td>USGS, US</td>
<td>5:53:58</td>
<td>10</td>
<td></td>
<td>6,3</td>
</tr>
<tr>
<td>Harvard CMT, USA</td>
<td>5:54:05</td>
<td>21,7</td>
<td>6,0</td>
<td>6,3</td>
</tr>
<tr>
<td>ERI, Japan</td>
<td>5:53:59</td>
<td>10</td>
<td></td>
<td>6,4</td>
</tr>
<tr>
<td>NIED, Japan</td>
<td>5:53:58</td>
<td>10</td>
<td></td>
<td>6,3</td>
</tr>
<tr>
<td>EMSC, Europe</td>
<td>5:53:58</td>
<td>10</td>
<td></td>
<td>6,4</td>
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<tr>
<td>GEOFON, Germany</td>
<td>5:54:02</td>
<td>N/A</td>
<td>5,8</td>
<td></td>
</tr>
</tbody>
</table>

Source: Djoko Wintolo (2011)
The 2006 Earthquake

- The seismogenic source is located at eastward of Opak river fault, around the intersect between Opak river and Oya river, with magnitude of 6.3 Mw and the focal depth is 10 km.
- Based on coseismic and post seismic investigation by GPS measurement, the fault displacement is about 0.3 – 9.1 cm.
- The calculated PGA value by UGM Team according to SNI-03-1726-2002 is 0.234 – 0.288 g and fall into risk level 3. Meanwhile, the results by MAEC team are: PGA is 0.5g (horizontal) and 0.47 (vertical).

Source: Djoko Wintolo (2011)
Geo-technical analysis

- Expert review on:
  - Probabilistic Seismic Hazard Analysis (PSHA) for Kartini RR Yogyakarta (Oct, 2005);
  - Seismic Risk Analysis for KARTINI RR (Dec, 2004);
  - Building Structure Analysis from Seismic Hazard for Kartini RR (Aug, 2005);
  - Kartini RR Retrofitting Documents (2004-2005): 9 Critical Items; and
  - New regulation and standards on seismic (next page).

- Expert inspection to the current reactor building and structure condition.
  (14 findings);
Geo-technical analysis

- Expert review on new regulation and standards on seismic.
  - Maximum Considered Earthquake (MCE) is based on 2% in 50 year or 2475 repetition period [NEHRP 2003 – FEMA 273];
  - Seismic Design Category (SDC): D.

- **Expert conclusion**: Kartini RR building is highly likely need some improvements to fulfill the new regulation and standards.

**CORRELATION BETWEEN SEISMIC-RELATED TERMINOLOGY IN MODEL CODE**

<table>
<thead>
<tr>
<th>Code, standard, or resource document and edition</th>
<th>Level seismic risk or assigned seismic performance or design category as defined in the Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACI 318-05 and previous editions</td>
<td>Low seismic risk, Moderate/intermediate seismic risk, High Seismic risk</td>
</tr>
<tr>
<td>Uniform Building Code 1991, 1994, 1997</td>
<td>Seismic Zone 0,1, Seismic Zone 2, Seismic Zone 3,4</td>
</tr>
</tbody>
</table>

SDC = Seismic design category as defined in code standard or resource document
SPC = Seismic performance category as defined in code standard or resource document.

Design Response Spectrum for Yogyakarta area based on SNI 03-1726-2010* and Seismic Zonation Map for Indonesia 2% 50 years for 0,2 second and 1 second: Hard, Medium and Soft Soil

* Source: Ashar Saputra (2011)
Expert Recommendation:

- To recheck thoroughly the retrofitting measures that have been done in order to understand the retrofitting methods and performance target after it;

- To change the wall components of reactor building structure with stronger materials;

- Even though the 2006 Yogyakarta earthquake was insignificantly affecting Kartini reactor, it is suggested to study the PGA and NGA in this area to anticipate the long term situation.

Note: Kartini RR operating license will be end in 2019.
TRIGA 2000, Bandung

Bandung

(6°53′15.82″S; 107°36′25.66″E)
• The TRIGA MARK II RR was designed and built for 250 kW power in an agreement cooperation between Indonesia and the IAEA.

• First foundation stone was laid down by the first President, Ir. Soekarno, in April 9, 1961; and the building erection was done in 1963.

• First criticality: 16 October 1964. Uprated firstly to 1000 kW in 1971, and uprated again (upgraded) to 2000 kW in the year of 2000.


• In 11-15 April 2005, the IAEA mission found massive bubbling in the core and fission product release, especially for power > 1000kW.

• The reactor building never been upgraded/retrofitted, except a minor retrofitting measure was done in 2005.

• In 21 February 2006, BAPETEN modify the license to be “can be operated only for the purpose of fixing the problems of the bubbling and the fission product release.” The license will be ended in 2016.

• In July 2010, Ministry of Public Works released “Indonesia Seismic Hazard Map 2010”.
Methods:

• External experts*: Seismic and geotechnic analysis:
  – Analysis of Lembang Fault;
  – Analysis of the wave propagation and reactor building and structure.
• Core safety analysis by internal TSO.
• Field inspection to Lembang fault area and to the reactor building.

* Team for Revising of Seismic Hazar Map of Indonesia 2010 (Established by the Ministry of Public Works in December 2009; Research Center for Disaster Management, Institut Teknologi Bandung (ITB University).
Zonation Map, 2% in 50 years

Source: Masyhur Irsyam (2011)
Lembang Fault

(1968) H.D. Tjia: Lembang Fault has slip component.


(2008) Eko Yulianto: Paleoseismology study proves there was earthquake by the Fault previously.

(2010) Irwan Meilano: With GPS proves that the slip rate is 2 mm/year.

(2011) Danny H. Natawijaya: Satellite research shows the existence of slip around Lembang area.

(2011) Irwan Meilano: With GPS proves that the slip rate is 2 mm/year.

Source: Irwan Meilano (2011)
The Fault is about 11 km from the TRIGA-2000 RR with a length of 22 km spreading to the East-West direction.

Maximum magnitude Earthquake generated by the Fault is 6.4 RS and the PBA is 0.35 g for 200 years recurrence period.

In the last 500 years there was 2 Earthquakes generated by the Fault.

Source: Irwan Meilano (2011)
Lembang Fault

Experts study conclusion:

- Lembang Fault is an active Fault and it’s formation was related to volcanic activity.
- Lembang Fault has both strike slip and dip slip components; and
- The slip rate of Lembang Fault is 2mm/year.

Source: Irwan Meilano (2011)
Experts recommendation:

- Considering earthquake with PGA of 0.35g, improvement should be done in some critical elements of TRIGA-2000 (10 items);
- With the application of response spectra analysis drawn from the new standards, more components should be improved;
- The fact that SDC falls into “D” category, then a high level detaining requirements should be implemented;
- Further detail investigation on the building & structure is highly recommended.
• Fission products were detected;
• From reshuffling of the fuel and sipping tests performed by BATAN, there are some significant notion that the source of the fission products problem is from the FFCR with burnup of >50%;
• In fact, burnup of 3/5 FFCR are: 54,65%; 54,0% dan 47,45%;
• NUREG 1282: Burnup > 50% could cause 4,6% swelling at maximum;
• NUREG 1537: FFCR of TRIGA reactor can not be > 50%;
• In 21 February 2006, BAPETEN modify the license to be “can be operated only for the purpose of fixing the problems of the bubbling and the fission product release.”
• In August 6, 2009: BAPETEN stated that FFCR problem should be solved by BATAN in order to remodify the license back to normal operation;
• Following the F-D accident, in the mid 2011 BAPETEN perform separate calculations and study: Operation parameter analysis with RELAP5; TH Parameter Analysis with PARET/ANL; Analysis of cladding internal pressure; and desk study on the effects of burnup and neutron irradiation to the fuel matrix.
### Void fractions for various power level in hot channel using RELAP5

<table>
<thead>
<tr>
<th>No</th>
<th>Power (kW)</th>
<th>Max centerline temp. (°C)</th>
<th>Max cladding temp (°C)</th>
<th>Temp. gap (°C)</th>
<th>Mass flow rate (kg/s)</th>
<th>Max coolant temp (°C)</th>
<th>Max void (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>359.89</td>
<td>133.23</td>
<td>147.35</td>
<td>0.43</td>
<td>91.73</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1050</td>
<td>372.14</td>
<td>134.16</td>
<td>148.97</td>
<td>0.45</td>
<td>93.44</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>1100</td>
<td>384.00</td>
<td>134.70</td>
<td>150.20</td>
<td>0.47</td>
<td>94.58</td>
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<tr>
<td>4</td>
<td>1200</td>
<td>407.67</td>
<td>135.72</td>
<td>152.61</td>
<td>0.50</td>
<td>95.96</td>
<td>1.21</td>
</tr>
</tbody>
</table>
### RELAP5 Calculation Results for Various Power with $k=0.199$ dan $k=0.99$ W/mK

<table>
<thead>
<tr>
<th>Power Level</th>
<th>$k_{\text{gap}}=0.199$ W/mK</th>
<th>$k_{\text{gap}}=0.99$ W/mK</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1050 kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100 kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1200 kW</td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$k_{\text{gap}}=0.199$ W/mK</th>
<th>$k_{\text{gap}}=0.99$ W/mK</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot channel max centerline temp (°C)</td>
<td>438.85</td>
<td>359.89</td>
<td>78.96</td>
</tr>
<tr>
<td>Hot channel max cladding temp (°C)</td>
<td>133.23</td>
<td>133.23</td>
<td>0.00</td>
</tr>
<tr>
<td>Temperature gap in hot rod (°C)</td>
<td>147.35</td>
<td>147.35</td>
<td>0.00</td>
</tr>
<tr>
<td>Mass flow rate di hot channel (kg/s)</td>
<td>0.43</td>
<td>0.43</td>
<td>-</td>
</tr>
<tr>
<td>Hot channel max coolant temp (°C)</td>
<td>91.73</td>
<td>91.73</td>
<td>0.00</td>
</tr>
<tr>
<td>Max void (%)</td>
<td>0.00%</td>
<td>0.00%</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$k_{\text{gap}}=0.199$ W/mK</th>
<th>$k_{\text{gap}}=0.99$ W/mK</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot channel max centerline temp (°C)</td>
<td>455.05</td>
<td>372.14</td>
<td>82.91</td>
</tr>
<tr>
<td>Hot channel max cladding temp (°C)</td>
<td>134.16</td>
<td>134.16</td>
<td>0.00</td>
</tr>
<tr>
<td>Temperature gap in hot rod (°C)</td>
<td>148.97</td>
<td>148.97</td>
<td>0.00</td>
</tr>
<tr>
<td>Mass flow rate di hot channel (kg/s)</td>
<td>0.45</td>
<td>0.45</td>
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<tr>
<td>Hot channel max coolant temp (°C)</td>
<td>93.44</td>
<td>93.44</td>
<td>0.00</td>
</tr>
<tr>
<td>Max void (%)</td>
<td>0.03%</td>
<td>0.03%</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$k_{\text{gap}}=0.199$ W/mK</th>
<th>$k_{\text{gap}}=0.99$ W/mK</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot channel max centerline temp (°C)</td>
<td>470.85</td>
<td>384.00</td>
<td>86.85</td>
</tr>
<tr>
<td>Hot channel max cladding temp (°C)</td>
<td>134.70</td>
<td>134.70</td>
<td>0.00</td>
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<tr>
<td>Temperature gap in hot rod (°C)</td>
<td>150.20</td>
<td>150.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Mass flow rate di hot channel (kg/s)</td>
<td>0.47</td>
<td>0.47</td>
<td>-</td>
</tr>
<tr>
<td>Hot channel max coolant temp (°C)</td>
<td>94.58</td>
<td>94.58</td>
<td>0.00</td>
</tr>
<tr>
<td>Max void (%)</td>
<td>0.31%</td>
<td>0.31%</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$k_{\text{gap}}=0.199$ W/mK</th>
<th>$k_{\text{gap}}=0.99$ W/mK</th>
<th>$\Delta T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot channel max centerline temp (°C)</td>
<td>502.41</td>
<td>407.67</td>
<td>94.75</td>
</tr>
<tr>
<td>Hot channel max cladding temp (°C)</td>
<td>135.72</td>
<td>135.72</td>
<td>0.00</td>
</tr>
<tr>
<td>Temperature gap in hot rod (°C)</td>
<td>152.61</td>
<td>152.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Mass flow rate di hot channel (kg/s)</td>
<td>0.50</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>Hot channel max coolant temp (°C)</td>
<td>95.96</td>
<td>95.96</td>
<td>0.00</td>
</tr>
<tr>
<td>Max void (%)</td>
<td>1.21%</td>
<td>1.21%</td>
<td>-</td>
</tr>
</tbody>
</table>
Results from RELAP5 Calculation:

- Voids are generated for Rx power >1000kW, and at 1200kW power, void fraction = 1.2%. This results is in accordance with inspection results.

- Maximum fuel temperature for the following power levels does not exceed SCRAM and LCO limits:
  - 1100 kW (110%): 384 °C
  - 1050 kW (105%): 372,14 °C

- Mass flowrate increases with the increase of power and temperature due to natural circulation effect.
Operational parameter analysis

Center Fuel Temperature at the power of 1000kW

![Graph showing Center Fuel Temperature at the power of 1000kW]
The Results

Calculation results for various power in hot channel

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Core Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Max. Temp. of fuel center, °C</td>
<td>380.25</td>
</tr>
<tr>
<td>Max. Temp. of the cladding surface, °C</td>
<td>130.48</td>
</tr>
<tr>
<td>Maximum void fraction, %</td>
<td>0.14</td>
</tr>
<tr>
<td>Coolat outlet Temp., °C</td>
<td>63.27</td>
</tr>
<tr>
<td>Minimum burnout ratio</td>
<td>6.96</td>
</tr>
</tbody>
</table>

- Steady state condition were calculated with PARET/ANL in natural convection mode. The LCO for maximum temperature of the fuel, i.e. 550 kW, is not be exceeded for the core power of 1200kW.
Stress and Swelling

• For cylinder with a thin wall (wall diameter < R/12)
  \[ S = \frac{r_i}{t} P = 83,705 \text{ atm} = 1230,462 \text{ psi} \]

• Tensile strength of SS-304 for T(clad.) 133,23°C is ± 65.000 psi

• Hence, stress in the clad wall < clad strength.

\[ S = E \frac{\Delta r}{r} \]

• E = Elastic modulus of SS-304 pada for T(clad. 133,23°C = ± 26 Mpsi

\[ \text{Diameter increase: } \Delta r = 86 \, \mu m \]

\[ S_t = E \frac{\Delta l}{l} \]

\[ S_t = \frac{r}{2t} P \]

\[ \text{Axial length increase } \Delta l = 0,017 \, \text{mm} \]

• Note: LCO according to NUREG-1537 is 0,318 cm.
Burnup Analysis and In-Core Fuel Management Study of the 3 MW TRIGA MARK II RR
(M.Q. Huda, S.I. Bhuiyan, T. Obara)
TheU-ZRH x Alloy: Its properties and use in TRIGA fuel (M.T. SIMNAD)
Results

Safety Evaluation Report on High-Uranium Content, Low-Enriched Uranium-Zirconium Hydride Fuels for TRIGA Reactors (NUREG-1282)

• The irradiation performance of 20-, 30-, and 45-w% uranium fuels was evaluated by irradiation testing to high burnups (>50% of the U-235) in the ORR and subsequent post irradiation examination.

• Fuel swelling was determined by measuring rod diametrical growth following the ORR irradiation and was compared with predictions based on a correlation developed for 8- to 10-w% uranium-zirconium hydride fuels during the Systems for Nuclear Auxiliary Power (SNAP) reactor program in-the 1960s. Diametrical growth was measured on nine 45-, one 30-, and one 20-W% uranium fuel rods. The maximum swelling predicted was 0.025 in (0.010 cm) (about a 4.6% increase in diameter).

  – Outer fuel diameter = 36.4 mm \(\rightarrow\) increase to 36.4 x 1,046 = 38.1 mm

  – This greater than the outer clad diameter = 37.5 mm
TRIGA-2000 Reassessment Results

- TRIGA-2000 management has to update its seismic study with the national new regulation and standards;
- Full retrofitting and detail engineering design of the reactor building and structure is mandatory;
- FFCRs with burnup of >50% shall be removed from the core;
- The reactor cannot be operated for >1000 kW core power;
- Note: The Liner of reactor tank shall not be used beyond 2016;
- On September 30, 2011, BAPETEN suspended the license of TRIGA-2000 for two years period;