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TITLE: BACKFITTING AND SAFETY UPGRADING OF OLD
OPERATING NUCLEAR POWER PLANTS
THE BELGIAN EXPERIENCE

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1. **INTRODUCTION**

Belgian utilities operate 7 PWR units distributed over 2 sites, Doel and Tihange.

- The first-generation plants (Doel 1 and 2, Tihange 1) are in operation for about 19 years:
  - Doel 1 and 2 are twin units of 400 MWe each, with a common turbine hall and control room, common nuclear auxiliaries and safeguards; it was built by ACECOWEN, a consortium formed by WESTINGHOUSE and the Belgian companies ACEC and COCKERILL. The architect-engineer was BELGATOM.
  - Tihange 1 is an 870 MWe unit, the first 3 loop-PWR of Westinghouse design in Europe. It was built by the consortium ACECOWEN - CREUSOT LOIRE - FRAMATOME; the architect-engineer was BELGATOM and EDF.

These three units were connected to the grid between August 1974 and August 1975.

- The second-generation plants (Doel 3 and 4, Tihange 2 and 3) were commissioned from 1982 to 1985:
  - Doel 3 and Tihange 2 are 900 MWe units, with 3 loops, a threefold safeguard system, a double-wall containment, and an additional protection system, especially designed to cope with external accidents (gas explosion, aircraft crashes, ...). The NSSS was supplied by FRAMACECO, a joint venture formed by FRAMATOME, ACEC and COCKERILL.
  - Tihange 3 and Doel 4 are 1000 MWe plants, very similar to Tihange 2 and Doel 3 concerning layout and design. The NSSS was supplied by ACECOWEN.

BELGATOM was the architect-engineer of these four units.

2. **THE BELGIAN APPROACH FOR BACKFITTING AND SAFETY UPGRADE**

2.1. **Regulatory context**

During the 10th, 20th and 30th years of operation of a Belgian nuclear power station, both the Utility and the Safety Authorities have to proceed to a comparative examination of the design, construction and operating rules of the existing plants and the applicable regulations in force at that time in the U.S. and the European Community countries.

The conclusions of the examination have to be summarized in a joint report that:

- identifies the differences;
- evaluates whether they are acceptable or not;
- suggests the appropriate improvements;
- gives a schedule for their implementation.
2.2. Methodology for backfitting and safety upgrading

First-generation plants (Tihange 1 and Doel 1/2)

A systematic comparison between applicable rules and existing plants could lead to very long and expensive studies (most of the regulations were published in the 70's. At that time the design of DOEL 1/2 and TIHANGE 1 was almost completed).

Since BELGATOM (A/E) and VINCOTTE (Safety Authorities) follow the evolution of regulations year by year and have been deeply involved in the design, the erection and the start up of the plants, they were able to identify without a complete investigation the rules which, taken into account, could make significant differences to the plants.

Previous experiences abroad and particularly in the U.S. had given the same conclusions (a team of Belgian experts met U.S. utilities and the NRC in 1984).

It was therefore decided not to proceed to such a systematic comparison. Instead of that, a practical approach was preferred.

It was agreed that BELGATOM and the utilities on the one hand, the Safety Authorities on the other, would both list the safety subjects to be considered and compare them to achieve a common list.

Topics to be considered essentially concern:

- operation problems occurred during the 10-year period after the start-up;
- safety problems identified during the same period but for which no immediate action was required;
- safety concerns discussed during the licensing of the last four Belgian NPP's;
- feedback from foreign nuclear plants operation;
- safety topics identified within the safety re-evaluation programs of other NPP's.

The main topics finally retained are notably:

- Protection of the plants against external hazards
  - natural: earthquakes, tornadoes, flood, lightning
  - man-induced: airplane crash, explosion, toxic gases

- Protection of the plants against internal accidents (design basis accidents, beyond design basis accidents)
  - Fire
  - Pipe breaks (HELB study)
  - Missiles
• Verification of the system’s adequacy to cope with normal operation and emergency situations:
  * safety systems (safety injection, spray, emergency feedwater, shutdown cooling, containment isolation, ...)
  * supporting systems (electrical supplies, instrument air, cooling, ...)

☐ Second-generation plants (Tihange 2 and 3, Doel 3 and 4)

The same methodology is being applied; however, the Safety Authorities did require to proceed to a Probabilistic Risk Assessment of the Doel 3 and Tihange 2 units in order to use both deterministic and probabilistic approaches for the safety reevaluation of the plants.

The main topics of the Tihange 2 and Doel 3 reevaluation programs deal essentially with:

• the assessment of the status of structures, systems and components against design criteria (mainly mechanical and electrical qualification of components);
• the review of national and international operation feedback regarding:
  - inservice inspection
  - periodical testing
  - thermal ageing of components
  - stress corrosion cracking of Inconel 600 components
  - radiation protection
  - upgrading of technical specifications
• severe accidents analysis;
• the evolution of U.S. safety regulations.

General description of the first Belgian PRA:

• Level 1 PRA

The level 1 PRA, carried out to evaluate the overall probability of core damage, has the following features:

• all reactor conditions are taken into account, from power operation to cold shutdown. The time spent in each of these states is obtained from the operating experience for the unit.
• the list of initiating events, including those ascertained from operating experience, covers a wide range of situations, including:
  - primary and secondary system piping breaks,
  - steam generator tube ruptures (including SGTRs in combination with secondary system breaks)
- primary and secondary transients, particularly loss of heat sink or of component cooling systems, gradual or sudden dilution incidents, etc.,
- total or partial loss of electrical supplies,
- anticipated transients without scram (ATWS),
- loss of residual heat removal system during shutdown,
- transients resulting from accidental actuation of the emergency plant cooldown system.

So far, internal and external hazards have not been taken into consideration. However, the following should be noted:

• PSA of aircraft crash and gas explosion type events was carried out at the design stage.

• Post-fire or post-flood situations should not have any significant effect on the overall risk, because of the strict physical separation of system trains at the design stage, together with the powerful fire detection and protection systems installed.

• As far as earthquakes are concerned, the methodology currently recommended for establishing the probabilistic earthquake severity curve does not appear to be reliable, and can definitely not be used as a basis for unit modification decisions.

The following points should also be noted:

• Very detailed human reliability analysis is being carried out.

• Common mode failures are taken into account.

• Accident sequences are analyzed over a given time period, the end of which is characterized by safe, stable operation.

• Level 1+ PRA

It was decided in Belgium to extend the level 1 PRA, but without going on to carry out full level 2 PRA. This intermediate, "level 1+" PRA analyzes situations that could jeopardize containment integrity, and can be used to determine the most probable containment failure modes, thus providing the order of priority to be applied in the drafting of procedures for managing severe accidents.
3. **PROCESS OF SAFETY RE-EVALUATION STUDIES**

**Topic 1**

- Feasibility Studies for Upgrading
- Synthesis Report
- Decision
- Process (owner)
- Safety Authorities Acceptance
- Detailed Realization Studies
- No Action

It is important to stress that:

- The methodology proposed by the A.E. and the Owner for the evaluation of each safety concern had to be agreed by the Safety Authorities.

- The feasibility studies were carried out on:
  - a technical basis
  - a cost/benefit analysis basis

- The decision process took place after all majors topics have been evaluated in order:
  - to optimize the investment regarding the safety improvement of the plant
  - to try defining global solutions for solving numerous specific deficiencies (i.e. Emergency systems in DOEL 1/2 and TIHANGE 1, RHR5 replacement in TIHANGE 1)
4. EXAMPLE OF REALIZATION

The key data of the global safety reevaluation are given in appendix 1.

4.1. THE TIHANGE 1 SEISMIC REEVALUATION

INITIAL SEISMIC DESIGN

Two seismic levels were considered for the design:

- level S1, which corresponds to the actual definition of the operating basis earthquake (O.B.E.), with a horizontal ground acceleration of 0.05g;
- level S2, which corresponds to the safe shutdown earthquake (S.S.E.), with a horizontal ground acceleration of 0.1 g.

The design criteria of structures, systems and components were selected according to the state of the art at that time (late sixties).

SEISMIC REEVALUATION REQUIREMENTS

During the licensing process of the TIHANGE 2 and 3 units, experts appointed by the Commission of the European Communities recommended to consider an horizontal ground acceleration of 0.17 g for the Safe Shutdown Earthquake.

METHODOLOGY USED

In order to qualify the plant to the new requirements, innovative methods have been used or developed in conjunction with classical methods:

- a 3D-non linear analysis has been performed in order to qualify the electrical auxiliaries building;
- the piping network has been qualified, using a non linear calculation method;
- Active components and cable trays were analyzed with the so-called SQUIG methodology.

4.2. THE DOEL 1 & 2 EMERGENCY SYSTEMS ADDITION

Designed to deal with new design criteria (major external explosion, earthquake, high energy line break outside containment, complete loss of on-site electrical supplies, major fire in the electrical auxiliary building or in other areas of the plant housing safety-related components that could not be physically separated), the new emergency safety systems (one per unit) are installed in a new building.

The new emergency system is able to stabilize the plant at hot shutdown conditions and to bring it to cold shutdown.

The safety functions of the emergency system are:

- safe shutdown of the reactor and residual heat removal;
- primary system integrity;
- radioactivity confinement and effluents control within authorized limits.
5. LESSONS LEARNED FROM THE REEVALUATION OF THE
TIHANGE 1, DOEL 1 & 2 NPPs

Safety re-evaluation organization
- Need for a very close co-operation between the owner and his consultant engineers;
- Need for a frequent and constructive dialogue with the safety authorities;
- Need for a dedicated organization of the owner;
- Need for an unambiguous decision process after all major topics have been evaluated.

Engineering studies
- Highly reliable overall plant review before involvement of design analyses;
- Early check of existing documentation and onsite collection of the information necessary so as to carry out engineering studies;
- Perfect control and monitoring of the contractors, including their ability to correctly manage and carry out onsite work;
- Highly reliable surveillance of the schedule necessitating a systematic risk evaluation with regards to implementation delays and the setting up of alternative means so as to limit their consequences, if any;
- Effective personnel management to handle unplanned contingencies;
- Efficient organization and decision making processes enabling minimal time loss, particularly with regard to the choice of contractors and the monitoring of contractual requirements;
- Need for utility's people dedicated training organization to be able to operate and maintain the new systems as soon as they are transferred for operation.

Works on site
- Take care in time of:
  - Equipment supply (try to foresee alternative solution)
  - Requalification testing (time consuming!) (25 - 30 people during 1986 shutdown at TIHANGE 1)
  - Logistic problems such as:
    - cloakroom capacity
    - washing-place capacity
    - number of scaffoldings
    - decontamination capability
- Need for an exhaustive and detailed planning of the works during the plant shutdown = critical path must be known before;
- Need for a comprehensive requalification testing program before re-starting the plant;
- Need for a first-class site construction management.
6. CONCLUSION

Safety reassessment of operating plants is a major concern in all nuclear countries in order to allow Nuclear to be "A High Technology Without Border".
Belgium has gained a valuable experience in this particular field during the reevaluation of their three oldest nuclear power plants and will still increase its know-how through the present Belgian programme along with similar activities abroad (see Appendix 2).

In particular, this experience has proven:

- the feasibility of safety upgrading of operating nuclear power plants without injury to their excellent availability, even by implementation of major modifications;
- the benefit of a very close cooperation between Owner, Engineering Company and Safety Authorities throughout the project;
- the benefit of a global approach for solving numerous specific deficiencies along with the optimization of the investment regarding the safety improvement of the plant;
- to be suitable for application to any kind of nuclear installation.
APPENDIX 1

SAFETY UPGRADING
OF THE
FIRST GENERATION BELGIAN NPP'S

KEY DATA

<table>
<thead>
<tr>
<th></th>
<th>Tihange 1</th>
<th>Doel 1 &amp; 2</th>
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<td>Engineering Effort</td>
<td>650,000 H</td>
<td>1,260,000 H</td>
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<tr>
<td>Implementation</td>
<td>75 M USD</td>
<td>155.79 M USD</td>
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1. WESTERN EUROPE

1.1. NETHERLANDS

BELGATOM was asked by E.P.Z. (Dutch owner) to define the safety reevaluation program of the BORSELE Nuclear Power Plant (PWR 450 MWe - commercial operation 1974).

The expertise started in March 1989 and the synthesis report was presented to the owner in February 1990.

The BELGATOM report has been approved by E.P.Z. and presented to the Dutch Safety Authorities. As a result of this evaluation, E.P.Z. decided to launch a detailed modification program aiming at solving the detected weaknesses, based upon our recommendations.

Among others, the following topics are analyzed:

- replacement of main steam and feedwater lines within the reactor building, using the superpipe concept;
- upgrading of the existing reactor protection system;
- upgrading of the safety-related electrical supplies;
- upgrading of the component cooling and service water systems;
- provision of an ultimate heat sink;
- upgrading of the protection of the plant against external hazards.