Safety Provisions for the KLT-40S Reactor Plant Floating Power Unit

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KLT-40S REACTOR PLANT SAFETY CONCEPT

The KLT-40S reactor plant safety based on:
- Defense-in-depth concept
- Inherent safety features
- Engineered safety features and procedures including:
  - passive safety systems
  - self-actuating devices
  - proven engineering practices and up-to-date design experience

The KLT-40S reactor plant design is developed in compliance with the Russian laws, regulatory rules for marine nuclear propulsion plants; safety principles elaborated by the world's nuclear community and reflected in IAEA recommendations.

The safety analysis approach is using two complementary deterministic and probabilistic methods that provide comprehensiveness and completeness for the analysis.
KLT-40S REACTOR PLANT PHYSICAL SAFETY BARRIERS

1 – FUEL COMPOSITION
2 – FUEL CLADDING
3 – RCS PRESSURE BOUNDARY
4 – PLANT CONTAINMENT
5 – PROTECTIVE ENCLOSURE
KLT-40S REACTOR PLANT INHERENT SAFETY FEATURES

- Negative reactivity coefficients on fuel and coolant temperature and on steam density and integral power
- High thermal conductivity of the fuel composition defining its relatively low temperature
- Natural circulation in the reactor coolant system and EHRS passive channels
- Insertion of control rods into the core under the force of springs (scram rods) or gravity (shim rods) in case CRDMs are de-energized
- High thermal capacity of the reactor primary coolant system components and structures
- High mechanical stress margin on the reactor coolant system pressure
- Compact modular and leaktight design excluding long and large diameter RCS pipelines
EMERGENCY REACTOR SHUTDOWN SYSTEMS

1. Reactor
2. CRDMs
3. Soluble absorber injection system
4. Pressure-actuated electric circuit-breaker

Pressure-actuated electric circuit-breakers de-energizes CRDMs (shutdown the reactor) on:
- High reactor coolant pressure
- High containment pressure
EMERGENCY HEAT REMOVAL SYSTEMS

Two autonomous passive channels for emergency heat removal
Duration of operation without water makeup is
- for two channels, 24 h
- for one channel, 12 h

1. Reactor
2. Steam generator
3. Main circulation pump
4. Emergency heat exchangers
5. Purification and residual heat removal system
6. Auxiliary condenser

Hydraulically operated air distributors

Pneumatically-driven valves in the passive EHRS channels are opened on primary circuit overpressure
EMERGENCY CORE COOLING SYSTEM

1 Reactor
2 Steam generator
3 Main circulation pump
4 ECCS hydroaccumulator
5 ECCS water tank
6 Recirculation system

Combination of passive and active emergency core cooling subsystems in the case of a loss of coolant accident

The ECCS water storage tank capacity is 2×10 m³
The ECCS hydroaccumulator capacity is 2×4 m³
EMERGENCY CONTAINMENT PRESSURE REDUCTION SYSTEM

- Passive ECPRS consists of two channels
- The safety function is to protect the safety barrier (plant containment)
- The operation time is 24 hours
- In the case of LOCA, radioactive products are retained within the containment
The reactor plant is designed to withstand the following external hazards:

- Marine environmental conditions in accordance with the requirements of the Russian Maritime Register of Shipping
- Shock resistance of at least 3 g
- Unit submersion with the reactor shutdown and containment integrity ensured
- Crash of an aircraft with the mass of 10 t from the height of 50 m
SEVERE ACCIDENT ANALYSIS

Some results of the severe accident analysis:

- The inner surface of the reactor vessel doesn’t melt.
- Heat is reliably removed from the outer surface of the reactor vessel bottom.
- Despite the high temperature difference, the mechanical properties of the reactor vessel material are preserved at the level that is sufficient to ensure the load bearing capacity.

THE MOLTEN CORE IS RETAINED INSIDE THE REACTOR VESSEL
Under normal operation conditions and in design-basis accidents, the population radiation dose rate does not exceed 0.01% of the natural radiation background.

- No mandatory evacuation area
- Emergency planning zone doesn’t exceed 1 km
The objective of the stress analysis is to assess safety of the floating power unit and to perform a sustainability analysis of the power unit under the extreme external events that exceed the Russian regulatory requirements.

The following postulated events were adopted for the stress analysis of the floating power unit design:

- Earthquake, magnitude 10 on the MSK-64 scale
- Tsunami waves, casting the floating power unit ashore
- Total blackout with all off-site, auxiliary and emergency power sources unavailable
- Core meltdown in the floating power unit reactors
STRESS ANALYSIS RESULTS FOR THE KLT-40S FLOATING POWER UNIT

- **Seismic impact of magnitude 10**: no radiological consequences for public and environment
- **Tsunami waves, casting the floating power unit ashore**: no radiological consequences for public and environment
- **Total blackout with all off-site, auxiliary and emergency power sources unavailable**: no radiological consequences for public and environment
- **Total blackout and core meltdown in the floating power unit reactors**:
  - The reactor remains deeply subcritical
  - The leaking reactor coolant and non-condensing gases are localized within the containment
  - No melting through the reactor pressure vessel with heat being removed by the passive system of reactor vessel external heat removal
KLT-40S floating power unit PSA general goals:
- To estimate safety level of the power unit
- To develop recommendations on technical measures and operational procedures to increase the safety

In Level 1 PSA the design and operation of the unit are analysed in order to identify the sequences of events that lead to core damage and the core damage frequency is estimated

Status of KLT-40S floating power unit PSA:
Developed:
- PSA Level 1 for internal initiating events for full power operating conditions
- PSA Level 1 for low power and shutdown modes
- PSA Level 1 for internal hazards (fires and flooding)
- PSA Level 1 for external hazards
KLT-40S Floating Power Unit Probabilistic Safety Assessment (II)

**PSA Level 1 results**

<table>
<thead>
<tr>
<th>Scope of PSA</th>
<th>Core damage frequency (1/reactor*year)</th>
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<tbody>
<tr>
<td>PSA Level 1 for internal initiating events for full power</td>
<td>&lt;10^{-7}</td>
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<tr>
<td>PSA Level 1 for low power and shutdown modes</td>
<td>\sim 3 \cdot 10^{-9}</td>
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Recommendations to increase safety were developed based on PSA results

Interrelation between initiating events frequencies and conditional core damage probability

PROBABILISTIC SAFETY ASSESSMENT LEVEL 1 RESULTS INDICATED THAT KLT-40S FLOATING POWER UNIT DESIGN IS WELL-BALANCED AND ITS SAFETY LEVEL MEETS RUSSIAN REGULATORY REQUIREMENTS AND IAEA RECOMMENDATIONS FOR EXISTING AND FUTURE POWER PLANTS
THANK YOU FOR ATTENTION!