Safety Assessment of the NET Predesign

W. Gulden, J. Raeder, E. Ebert, and H.-W. Bartels

Work carried out by European Associations on Safety and Environment inside the EC Fusion Technology Programme and by NET has been concentrated on safety-related guidance and on safety assessment of the NET Predesign. Emphasis has been put on analysis of accident sequences of regulatory concern up to worst case accidents, including quantification of consequences to components, systems, and plant, and of doses to the public. Probabilistic safety studies for the most important systems and broadly for the entire plant have been performed to supplement the calculated accidental doses by expectation values for their occurrence rate, and to check the relevance of the reference accident sequences selected initially by judgment. Waste masses per year of operation and for decommissioning have been quantified. For two countries and according to the practices and regulations of these countries, volumes of radioactive waste packaged for final disposal have been determined.

KEY WORDS: NET; fusion safety; accident analysis; environmental impact; doses.

1. INTRODUCTION

In the European strategy to develop a fusion reactor, the Next European Torus (NET) aims at demonstrating the scientific and technological feasibility of fusion power based on the tokamak principle. The NET activity proceeded from a conceptual design phase (1983–1986) into the predesign phase documented in Ref. 1. Results reported in this paper summarize work on safety-related guidance and on safety assessment carried out during NET Predesign by NET and by European Associations inside the EC Fusion Technology Programme.

2. SAFETY RELEVANT FEATURES OF THE NET DEVICE

The NET operation will be subdivided into two phases:

1. A Basic Performance Phase (BPP), which would require about 2500 hours of integral burn time over about 10 years of calendar time. The device will adopt the simplest and most robust configuration (e.g., no breeding blanket but only a shielding blanket).

2. An Extended Performance Phase (EPP) with a breeding blanket, which would last about 10 years. A neutron fluence of about 1 MWa/m² could be reached at the first wall.

The main parameters of NET are listed in Table I. Figure 1 shows the reactor hall schematically. Three confinement barriers are foreseen during machine operation. These barriers largely coincide with the vacuum vessel and its extensions (1), the cryostat, primary cooling system rooms, pumping rooms and part of the heating system rooms (2), and the reactor building (3). The interior of the reactor building is kept slightly depressurized, to ensure that there is no leakage to the environment, and the exhaust from the reactor building is filtered and monitored. Secondary confinement volumes are filled with inert gas where necessary to exclude ingress of oxygen into the torus in case of accident.

The shielding blanket and driver blanket use water as coolant up to 140°C and 256°C, respectively. The first wall (FW) structure consists of water cooled stainless
Table I. NET Basic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion power</td>
<td>1.2 GW</td>
</tr>
<tr>
<td>Plasma major radius</td>
<td>7.3 m</td>
</tr>
<tr>
<td>Plasma minor radius</td>
<td>2.43 m</td>
</tr>
<tr>
<td>Plasma current</td>
<td>25.0 MA</td>
</tr>
<tr>
<td>Magnetic field on axis</td>
<td>5.2 T</td>
</tr>
<tr>
<td>Average neutron wall load</td>
<td>0.8 MW/m²</td>
</tr>
<tr>
<td>Peak divertor heat flux</td>
<td>15.0 MW/m²</td>
</tr>
</tbody>
</table>

It can be integrated with or separated from the blanket box. Two basic design concepts have been studied which differ in the low Z protective armour. The first concept uses water-cooled carbon based local limiters. In the second concept, which has been analyzed in detail from the safety point of view, carbon fiber composite (CFC) tiles fully cover the first wall and are mechanically attached to the steel heat sink. They are cooled via radiation or conduction.

The divertor is made of CFC armour, 1-cm thick, of high thermal conductivity, brazed in “monobloc” geometry around water cooled tubes in Mo-alloy or Cu. The divertor plates are designed to operate at a static peak divertor heat flux of up to 15 MW/m².

3. DOSE LIMITS FOR OFF-NORMAL EVENTS AND IMPLICATION OF DOSE RECOMMENDATIONS FOR TRITIUM INVENTORIES

The dose recommendations for off-normal events are:

(1) Doses due to all operational in-plant transients and accidents and doses due to the conceivable ex-plant initiators should be limited by passive features and confinement barriers and should stay below about 1 mSv, i.e., about the annual dose from exposure to natural background radiation.

(2) Doses due to non-anticipated ex-plant initiators should be limited by passive safety features to a level that avoids disruption of community life. This entails target figures below 100 mSv.

To meet these recommendations, adequate emphasis has to be put on minimizing tritium and energy inventories, and on confinement strategy and containment design.

Based on the second recommendation, and using a specific dose of 0.5 mSv/g-T (for the most exposed individual of the public at 1 km from the release point) 100 mSv could be caused by a release of 200 g-T. To also account for releases other than tritium during an accident, a target of 150 g has been proposed for NET as the upper limit for tritium inventories vulnerable during any accident.

4. PLANT SAFETY ASSESSMENT

4.1. Radioactivity Inventories and Source Terms

The radioactivity inventories inside the plant and their mobilization by accidents during normal operation and maintenance have been quantified.

Tritium inventories deserve most attention. Optional design solutions exist for most tritium systems. However, in some cases, values given by the experts differ considerably. Therefore, the total plant tritium inventories of about 2000 g during the BPP and 3000 g during the EPP have to be considered as uncertain by about 30%.

To calculate doses to the public, realistic environmental source terms (EST) need to be used. Containment by design features, confinement strategy, radioactive decay, gravitational settling, diffusion to surfaces, chemical reactions at surfaces and mobility fractions following specific accident scenarios have to be considered.

In the frame of the ITER Conceptual Design Activity (ITER-CDA) safety analysis, a confinement release fraction (CRF) of 2% has been estimated for all accidents resulting in possible tritium releases to the environment. First analyses for the “torus plant area,” “isotope separation area,” and “driver blanket area” of NET show that a CRF value of about 0.5% has to be achieved to meet the more stringent dose recommendation of 1 mSv, if the effective dose equivalent (EDE) due to short-term release is the basis. In case dose due to ingestion has to be included, a confinement release fraction of down to 0.1% has to be achieved. Detailed analyses, however, of accident sequences are required to substantiate the CRF values used up to now, taking into account containment response and detritiation.

4.2. Identification and First Analysis of Important Accident Sequences

Based on engineering judgment, the “reference accident sequences” listed in Table II have been defined and analyzed.

In parallel, probabilistic safety studies for the most relevant systems and broadly for the entire plant have been performed to substantiate and supplement the