

Scottish CNDNews**Safety of HMS Tireless**

The safety case for nuclear submarines depends on the integrity of four boundaries which are designed to prevent the release of radioactive material into the atmosphere:

The first boundary is the cladding of the fuel rods;  
the second boundary is the pressure vessel and primary coolant circuit;  
the third boundary is containment provided by the reactor compartment;  
the fourth boundary is incomplete and comprises the rest of the submarine.

The Navy's claims that a release of radiation from HMS Tireless in Gibraltar is a very remote possibility is totally dependent on all of these barriers being proven to be sound. Because of the accident which happened in May the integrity of each of the first three boundaries is questionable. In addition it will not be possible in Gibraltar to conduct adequate inspections of these barriers.

**First Boundary - Fuel Core Cladding**

The reactor is fuelled by highly enriched uranium which is mixed with zirconium. The fuel rods are clad in a zirconium alloy. This cladding prevents the spread of radioactive products into the coolant and beyond.

The loss of coolant from HMS Tireless on 12th May may have had an impact on the integrity of the cladding of the fuel rods in the submarine's reactor. The exact events which took place within the first few seconds of the accident on HMS Tireless have not been made public and may not be fully understood by the Navy. Coolant will have started to escape rapidly from the primary circuit. It is possible that the reactor operator was able to bring the situation under control by closing valves and isolating the leaking part of the circuit. Nevertheless there may well have been a rapid change in temperature within reactor. This could have damaged the zirconium cladding on the fuel rods. In a more serious accident Navy manuals describe how the cladding can fail.

It will not be possible to thoroughly examine the state of all the cladding on the fuel rods in Gibraltar.

**Second Boundary - Primary Coolant Circuit**

By its nature the reactor on HMS Tireless is a pressurised water reactor. The primary coolant circuit contains water under very high pressure, around 170 bar (2460 psi). The circuit is complex with two loops each running from the pressure vessel through a steam generator. There are several coolant pumps on each of these loops. There are also pressurise, ion exchanger and emergency cooling loops and valves on most key sections. As a result there are a large number of welds in the primary circuit.

HMS Tireless was commissioned in 1985. After 11 years in service the submarine was in refit at Devonport dockyard from April 1996 to June 1999. During the refit the reactor was refuelled. There will also have been a substantial amount of work

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During the refit the primary circuit will have been inspected. This will have included the examination of welds using ultrasound and other methods. This system of inspecting for weaknesses in the coolant circuit is an essential part of the safety case for nuclear submarines. It is clear that in this case the inspection process did not detect a weakness which resulted in a crack several millimetres across appearing only 11 months after the end of the refit. It is not known whether the failure was in the conduct of the inspection itself or in the analysis of the large volume of data produced during a refit.

This inspection failure has implications for the safety of all British nuclear powered submarines, but it has particular effect with regard to HMS Tireless. If the system failed with regard to one weld during this refit, there must be a higher than average chance that the inspection process will have failed with regard to other welds within the coolant circuit on HMS Tireless.

The situation is further complicated by the fact that the Navy themselves do not know what caused the crack in the weld and may not know for many months. The Chair of the Nuclear Regulatory Panel, Captain Hurford has said in Gibraltar that they did not know the cause.

In January 1990 hairline fractures in the coolant circuit of one submarine resulted in all British nuclear submarines being kept in port, except the Polaris submarine on nuclear patrol. Over a year later the MoD's adviser Reg Farmer was interviewed about the problem and it was clear that the Navy were still speculating about exactly what the cause of the hairline fractures was. The water chemistry of the coolant and particularly its Ph was given as the most likely explanation. The scrapping of five hunter killer submarines was related to this defect. At least three of the four Polaris submarines were also affected.

There are two issues with regard to reactor circuits which make cracks more likely. One is that radiation makes the pipework and pressure vessel more brittle and so more liable to cracking. Secondly different alloys are used in various parts of the circuit. The problem discovered in 1990 was in a weld joining two different alloys. Reg Farmer said that this was where the coolant circuit enters the steam generator.

A detailed inspection of the state of the primary circuit on HMS Tireless's reactor could only be carried out during a major refit in a dockyard.

### **Third Boundary - Reactor Compartment Containment**

#### *Comparison with land based reactors*

HMS Tireless is powered by a pressurised water reactor which is situated within the space available in the submarine, as a result the containment system is not as effective as on land based reactors. If there is a leak of coolant from the reactor then there will be a sudden jump in the pressure within the reactor compartment. On land based reactors this pressure surge can be contained by having a large space around the reactor. This is not possible within the dimensions of a submarine hull.

John Harrhy is a professional naval architect who works in New Zealand. In the

John Harrhy is a professional naval architect who works in New Zealand. In the past he worked for the Polaris Technical Director in the MoD. He was responsible for the structural analysis of secondary containment systems. He was employed by the UK Cabinet Committee on nuclear weapons safety to evaluate the effect of a fire on a nuclear armed submarine. He was project manager for the design and specification of simulators for four classes of nuclear submarine. He was the initial contact between the French and British governments on nuclear submarine safety.

In March 1992 Mr Harrhy wrote a submission to the New Zealand government arguing that nuclear powered submarines should not be allowed to visit New Zealand on safety grounds. He said:

"I worked alongside structural engineers from the UKAEA Safety and Reliability Directorate who were auditing the safety of the RN's Dounreay reactor establishment following penetration of the secondary containment structure which was necessary for the refuelling of the reactor.

"I learnt that the philosophy behind these domes was that the containment volume was large to reduce the rise in pressure caused by failure of the primary system. It is possible for all coolant to vaporise and spread contaminating material.

"The design of the dome prevented a pressure rise greater than one atmosphere. The regular nature of the dome also permits simple structural analysis to predict stress levels in the structure which are kept by design to be low. The lower the stress levels the more tolerant is the structure against imperfections in materials or construction methods.

"Quite frankly the UKAEA engineers were out of their depth with warship structures. Firstly the pressure rise due to a failure of the primary circuit is extremely high because of the small secondary containment volume. The pressures experienced by the structure is between twenty and thirty atmospheres.

"The structures whether for a surface ship or submarine are complex in comparison with a spherical dome ... For example an acceptable imperfection in the shell of a dome of a land based reactor may be an interlaminar zone measuring 100 mm square, or a void in a weld 50 mm long and 3 mm diameter. Each type of imperfection is relatively straightforward to detect, particularly as the structural materials are thin. However in a warship structure the acceptable imperfection will be an interlaminar zone 8 mm square or a weld void of 6 mm long and 2 mm diameter.

"Finding the needle in the haystack is therefore much more difficult for the containment structure of a warship than a land based reactor ..."

#### *Reactor Compartment Containment on HMS Tireless*

On the 12th May 2000 the primary coolant circuit in the reactor on HMS Tireless was probably at a pressure of around 170 bar ( 2,460 psi). When the crack several millimetres across developed there would be a rapid rise in pressure within the reactor compartment. This rise in pressure may have damaged weakpoints in the bulkheads and the hull itself.

A Navy training manual says that " the bulkheads are penetrated in a number of places (steam pipes, electrical supplies etc) and small leaks are likely. At start of life the compartment is pressure tested and the leak rates should not be more than

life the compartment is pressure tested and the leak rates should not be more than 1 per cent per day."

Given the existing weaknesses and the pressure surge at the time of the accident there is a substantial risk that the bulkheads and hull cannot provide the degree of containment which is assumed in the Navy's safety case. Furthermore Mr Harthy indicates that it could be very difficult to thoroughly examine the state of these bulkheads and the hull itself, because even minute cracks could undermine the safety case. While a full inspection might be done during a refit in a dockyard it could not be done properly in Gibraltar.

## Notes

### *Core Damage*

In the Navy's standard Loss of Coolant Accident (LOCA) scenario there is a sudden loss of coolant from a breach in the primary coolant circuit. The remaining coolant is then flashed off into steam. Even though it is assumed that the reactor has shut down the fuel core would still be damaged. Navy manuals say: "By this time the reactor will have been shut down, but because of the disappearance of coolant, the large amounts of decay heat being generated in the core will raise fuel temperatures rapidly. When fuel temperature reaches 900 C a chemical reaction takes place, the zirconium oxidising, taking oxygen from the surrounding steam and releasing large quantities of heat in the process."

While it does not appear that this happened on HMS Tireless, they were only a few steps away from it.