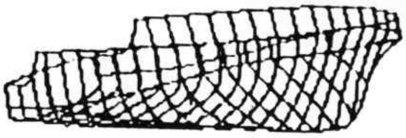
Ref No 23-57, Price $1.00

John Harrhy RCNC MRINA MIPENZ R Eng
Winner Gold Award for Excellence in Engineering-1990
Consulting Naval Architect &
Structural Engineer
A Member of ACENZ
262 Wakefield Quay
PO Box 445, Nelson
New Zealand
telephone 64-3-5468439
facsimile 64-3-5468571



John,

Best wishes,

Nuclear Powered Warship Safety

6 March 1992

The Author

John Harrhy is a professional Naval Architect with his own practice in Nelson.

He was trained by the Royal Corps of Naval Constructors in the United Kingdom as a warship designer.

Working for the Polaris Technical Director in the MoD(PE) he undertook many safety studies involving the manoeuvring performance and nuclear reactor safety of nuclear powered vessels operated by the Royal Navy.

He was responsible for the structural analysis of secondary containment structures and for the hydrodynamic prediction of safe manoeuvring envelopes.

Specifically he was responsible for the structural analysis of the secondary containment structure of the RN's land based reactor at Dounreay and was a member of the team established to quality assure the Dounreay Reactor containment system following refuelling.

He was employed by the U.K. Cabinet Committee on Nuclear Weapons Safety to evaluate and project manage an investigation into the safety of nuclear armed missiles subjected to a fire hazard aboard an SSBN.

He was responsible as project manager for the design and specification of submarine simulators for four classes of nuclear submarines.

He was the initial contact between the French and British Governments on issues of nuclear submarine safety.

He attended the Demonstration and Shakedown Operation of a British SSBN at Cape Kennedy in Florida where he came into contact with USN design engineers.

He spent many weeks on operational nuclear submarines as a trials and development officer.

In 1990 he was awarded the Gold Medal for Outstanding Engineering achievement by the Association of Consulting Engineers New Zealand

He objects strongly to any suggestion of visits to New Zealand of

REPRINTED BY:
N.Z. NUCLEAR-FREE

Aspects of Nuclear Warship Safety

Use of seaborne nuclear propulsion

Much of the impetus for nuclear propulsion was toward the development of submarine propulsion. At the close of the Second World War the UK opted for the use of hydrogen peroxide fuelled diesel engines, the Americans for nuclear fuelled steam systems.

In the late 50's the special relationship between the UK and USA permitted the transfer of nuclear propulsion technology from a successful USN development programme to the RN. At the beginning of the RN's involvement in nuclear propulsion the early reactor systems were supplied by the USA, and later Rolls Royce was permitted to undertake construction and development of reactor systems specifically for the RN.

The special relationship ended with the Kennedy administration and from the early sixties the development of nuclear propulsion systems diverged.

The British committed nuclear propulsion to submarines while the Americans diversified into surface ships and increased the range of propulsion systems to suit a variety of requirements for their submarine fleet- particularly non SSBN submarines.

The French, being shut out of NATO and under complete prohibition of technology transfer from the US, decided to develop their own systems in the late sixties to supply a platform for the 'Frappe de Force'.

Today there is little exchange of technical information between the Western Navies even though there has been considerable divergence of systems.

The use of civilian nuclear powered vessels has been brief in the Western world. The Savannah was proclaimed as the ship of the future way back in the sixties, however the problems of risk were never resolved. The International Maritime Organisation (IMO) presented a design standard which permitted the use of nuclear power for merchant ships, however none have been built. The risk was much too great for the commercial insurance market to endorse.

Nuclear Reactor Types

The reactor in use by RN submarines is colloquially known as the 'kettle'. The name derives from the relatively low pressure, low temperature steam (known as 'hot fog') developed in relation to oil fired boilers.

Power developed is between 40,000kW to 80,000kW and is small in relation to land based reactors used for electrical power generation.

The heat generated is transferred by forced convection of water to heat exchangers, which transfer the heat to a secondary water circuit creating steam to drive the turbines that propel the ship.

The cooling water for the condensers of the secondary circuit is

Aspects of Nuclear Warship Safety

Use of seaborne nuclear propulsion

Much of the impetus for nuclear propulsion was toward the development of submarine propulsion. At the close of the Second World War the UK opted for the use of hydrogen peroxide fuelled diesel engines, the Americans for nuclear fuelled steam systems.

In the late 50's the special relationship between the UK and USA permitted the transfer of nuclear propulsion technology from a successful USN development programme to the RN. At the beginning of the RN's involvement in nuclear propulsion the early reactor systems were supplied by the USA, and later Rolls Royce was permitted to undertake construction and development of reactor systems specifically for the RN.

The special relationship ended with the Kennedy administration and from the early sixties the development of nuclear propulsion systems diverged.

The British committed nuclear propulsion to submarines while the Americans diversified into surface ships and increased the range of propulsion systems to suit a variety of requirements for their submarine fleet- particularly non SSBN submarines.

The French, being shut out of NATO and under complete prohibition of technology transfer from the US, decided to develop their own systems in the late sixties to supply a platform for the 'Frappe de Force'.

Today there is little exchange of technical information between the Western Navies even though there has been considerable divergence of systems.

The use of civilian nuclear powered vessels has been brief in the Western world. The Savannah was proclaimed as the ship of the future way back in the sixties, however the problems of risk were never resolved. The International Maritime Organisation (IMO) presented a design standard which permitted the use of nuclear power for merchant ships, however none have been built. The risk was much too great for the commercial insurance market to endorse.

Nuclear Reactor Types

The reactor in use by RN submarines is colloquially known as the 'kettle'. The name derives from the relatively low pressure, low temperature steam (known as 'hot fog') developed in relation to oil fired boilers.

Power developed is between 40,000kW to 80,000kW and is small in relation to land based reactors used for electrical power generation.

The heat generated is transferred by forced convection of water to heat exchangers, which transfer the heat to a secondary water circuit creating steam to drive the turbines that propel the ship.

The cooling water for the condensers of the secondary circuit is drawn from and returned to the sea. The design of the sea inlets is

The USA developed primary circuit heat convection using liquid salts, hazardous materials in themselves, to improve the heat transfer from the cruciform fuel rods and thereby increasing the specific power output of the reactor.

At the same time they were conscious that the primary circuit circulating pumps, which consumed 20% of developed power, were significant noise sources. Therefore naturally convecting reactors were developed which reduced the need for circulating pumps but which required the development of fuel rod technology to reduce surface hot spots. The development in fuel rod technology required the controlled non-uniform dispersion of uranium over the cross section of the fuel rod.

Naturally convected reactors were low powered and the seventies saw the development of American submarines with several reactors.

Major surface warships, including aircraft carriers, may have as many as five reactor systems on board.

Throughout these developments there has been the determination to improve the military performance of the systems. Until the mid seventies there was little concern for public safety as it was assumed that a ship safe for its crew was safe -period.

Containment Structures- design philosophy

So how are the crew and the public-at-large protected?

The reactor and its cooling circuit are regarded as the primary containment structure. The reactor itself is a large cylindrical structure resembling an enormous automotive oil filter about 2m in diameter and 3m high. The walls can be 300mm thick and constructed from petals welded together. The quality assurance of these very thick structures is extremely difficult relying heavily on the human interpretation of radio graphic and ultra-sonic quality assurance data.

The pumps, filters, thermal expansion tanks and valves are potential sites for structural breakdown of the containment structure. Pure demineralised ionised water cannot be radio active but material from seals and moving surfaces can cause contamination.

Each day samples of primary circuit fluid are drawn off for examination. This sampling process is itself hazardous and I had first hand experience of a crew member who, spotting a water spill in the reactor tunnel, reacted by putting it to his tongue. It was a spill of primary coolant and the unfortunate man was whisked off to the Naval Hospital at Haslar.

While I was at Cape Kennedy I became aware of public protests against nuclear ship visits. It was claimed and I subsequently confirmed that primary circuit water from the thermal expansion tank was being discharged overboard whilst the vessels were in harbour as the thermal expansion tank was involved in the changing of coolant volume as the reactor was shut down and restarted.

This discharge was not possible from British submarines but conveyed to me the lack of consideration for public safety by the US Navy.

The primary circuit is protected by a secondary containment structure which is the structure of the submarine or surface ship. The secondary containment includes the biological shields needed to protect the crew when the reactor is under power. The biological shielding is directional. On a submarine the shielding will be confined to the circular forward and after bulkheads of the reactor compartment and will surround the reactor tunnel which connects the living and operational spaces to the machinery spaces. It is assumed that shielding is not required around the pressure hull as the radiation hazard in port with the reactor shut-down is regarded as acceptable.

Whilst a great deal of attention was spent designing the cylindrical pressure hull to resist the enormous water pressures to prevent collapse and therefore maximise diving depth it has only been recently that computer based structural finite element analysis techniques have actually been employed for bulkhead design although they were available twenty years earlier.

Surface ship shielding is horizontal from, and above the reactor compartment. It is assumed that shielding is not required beneath the vessel.

Despite the shielding crew are required to wear radiation monitors.

There is a significant difference in the structural quality assurance possible with warship containment and land based reactor containment.

only Dounreay

The large spherical domes that are characteristic of land based reactors are deliberate solutions that address the difficulty of containing a release of contaminating material.

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 vaporize 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 level 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. Firsly the pressure rise due to a failure of the primary circuit is extremely high because of the small secondary containment volume.

The pressure 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.

The resulting stresses in the structure as a consequence are very high thereby greatly reducing the tolerance of the structure to imperfections.

Imperfections arise in

1) the accuracy of the structural design in modelling the actual structure
2) the quality of structural materials used- the steel plate and stiffening,
3) the welding methods used- the welding rod material, the consistency of the welding equipment, the welding environment, the skill of the welding technician, and quality of supervision,
4) the radiographic and ultra sonic examination of the structural material and welds which depends on the quality of the equipment, the consistency of coverage, and of accurate interpretation of the data by skilled technicians.

Each of these quality assurances is made much more difficult by the very much higher stresses experienced by warship structures.

For example an acceptable imperfection in the shell of a dome of a land based reactor may be an interlaminar zone measuring 100mm square, or a void in a weld 50mm long and 3mm 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 8mm square or a weld void of 6mm long and 2mm diameter.

Finding the needle in the haystack is therefore much more difficult for the containment structure of a warship than a land-based reactor- and yet we are prepared to take these systems into port at the heart of most cities rather than confine them to remote regions as with land-based reactor systems.

Reactor Control

The consequences of reactor scram in a land-based reactor system generating electricity may be embarrassment by the supplier and inconvenience by the consumer.

A reactor 'scram' in a warship could prejudice the safety and survival of the crew because of loss of propulsion.

Nuclear powered warships are provided with secondary propulsion systems. The power of these systems is small and is designed to return the 'asset' to a safe refuge. The secondary propulsion would not prevent a surface warship from foundereing on shore in a gale or aid a flooding submarine reach the surface.

Warship reactor systems incorporate an over-ride to an automatic scram. It can be activated by the ship's captain if in his judgement the increased danger of operating the reactor above its normal pressures and temperatures is worth the risk if survival of his crew is at stake, or if there is a pressing military need.

Such over-ride facilities are not present in land-based reactor systems and speak loudly of the inadequate military philosophy towards public safety

Collision avoidance and safe manoeuvring envelopes

The added danger to nuclear propelled warships are collisions and groundings. The IMO laid down strict criteria for the structural protection of ship-borne reactor power plants following the construction of the Savannah and the public outcry. However no vessels have been constructed to this criteria as naval design services are not bound to civilian practices. Indeed the design criteria for RN warships takes absolutely no account of either standards set by Government agencies or the standards set by Classification Societies such as Lloyds. Military performance requirements prevail resulting in lightweight structures.

The standards set down by the IMO with regard to collision protection have been extensively revised with respect to chemical and gas tankers based on experience of these types of ships as the results of collisions. In many of the major ports around the world such as Tokyo chemical and gas tankers are prohibited entry to the port being confined to well defined remote areas from which other vessels are excluded.

The revision of structural protection and operating procedures have not filtered into the requirements for nuclear powered merchantmen simply because there are no proposals to build them.

The age of the nuclear propelled warships precludes their structural arrangements from satisfying any revised IMO philosophy. Devonport?

Nuclear propelled warships must be anchored 20-30nm from the city UK? centre, which in New Zealand because of the smallness of the port environments results in a complete lack of facilities.

Loss of control for technical and environmental causes is made worse by increased ship speed. A rudder failure, or a failure in navigational systems is a greater hazard at speed. Therefore where it is important to reduce risk the speed of the ship needs to be reduced.

Such manoeuvring envelopes and anchoring restrictions preclude entry of these vessels, in peacetime, to confined ports such as Wellington and Lyttleton. Anchoring restrictions would preclude the use of Auckland.

Training, Operational Personnel, and Decisions by Rank

Training of deck and engineering personnel for Nuclear Warships is suspect as the drop-out rates of those in the training programme are negligible. In contrast the drop-out rate for the 'Perishers'-the submariners' skipper's course- is greater than 50%. This demonstrates selection of personnel with an emphasis on military-type thinking rather than high technical or administrative achievement. Few of the learned engineering professions recognize qualifications in engineering achieved in the Navy.

Further the Naval engineering profession is subservient to the deck officers who have little in-depth training of nuclear reactor systems. Yet these officers are in a position to determine and demand a course of action which may be potentially hazardous. Since rank prevails it is the training of the superior officer which determines the type of hazard response.

In the early nuclear warship development programme there was little doubt that the more intelligent and highly motivated personnel were selected for duty. With the expansion of the surface and submarine fleets the quality of operational personnel has declined.

The reactor system is treated in a more mundane fashion and the priorities allocated to maintenance and training have been degraded.

Training dispensations are given as there is inevitably a shortage in the required skills.

Younger men without the wide experience of the earlier pioneers are responsible for reactor plants. The requirements of promotion are based on generalist type personnel which has resulted in tours of duty of two years or less resulting in questionable engineering competence - a situation recognized by civilian engineering institutions.

Repair and Maintenance of Containment Structures

As power is consumed in a nuclear reactor the breakdown of fissile uranium into neutron absorbing metals causes poisoning of the reactor. The neutrons being reabsorbed are unavailable to sustain the reaction which creates thermal energy.

This poisoning is inevitable. Perhaps only a few percent of useful uranium decays before the reactor loses its power.

Therefore at four yearly intervals the reactor core has to be changed.

This involves the penetration of the containment structure and its re-establishment on completion of refuelling. The primary and secondary containment structures are breached every four years and each time a comprehensive quality assurance exercise has to be undertaken to check that the containment system is safe.

As the structures age or fatigue the quality examination becomes harder. Critical imperfections become smaller and harder to detect.

Development in ship-borne reactors has been to increase power and this has been going on since the containment systems were installed. However the containment structures were designed to resist the earlier lower powered reactors. As a consequence the pressures that might be experienced by the containment structure will be greater than anticipated, which will increase the difficulty of quality assurance.

Therefore as the ship ages, the increase in reactor power and the fatigue of the containment structure increases the risk of containment structural failure.

Hardware generation and age

Most of the nuclear powered surface warships are elderly in terms of design and yet immature in their execution. The rapid expansion of the nuclear powered surface fleet occurred over a relatively small period and it would be impossible to claim that any real evolutionary progress has been achieved.

It was remarkable that US submarines did not have sufficient safety systems. I had first hand knowledge of inadequacies of design of American submarines which represented the American military attitude towards safety.

The Thresher was lost because the reserve of buoyancy achievable from emergency high pressure air was inadequate and one tenth that of a British submarine.

An American submarine was lost alongside the wharf at San Diego because the ballast control was distributed throughout the boat and not centralised.

Despite progressive refits ships decline with age. The surface fleet of the Americans is at an age when they need to be scrapped. These ships do not receive the priority of the Trident Ballastic submarines or the newly developing killer submarines. The military budgetary restraints in the USA resulting from a post Cold War reduction in international tension are a cause for disbelieving the effectiveness of their current surface fleet.

Software generation and age

As engineering structures and systems age there is a deterioration in the software support available. Drawings and manuals are lost. Handbooks and operator's manuals are used although out of date. The divergence of reactor types reduces the effectiveness of training prorammes. Type training is not always possible and in some cases prototype reactors are at sea undergoing development.

Maximum Reactor Credible Incident

The concern is that a reactor failure might cause contamination which might threaten the environment and civilian population- and have an effect prejudicial for generations.

control rods?

The reactor 'kettle' is designed so that if there is a loss of cooling fluid or if the moderators fail to control temperature rise a melt down will result in several molten masses each of which is a non-critical mass thereby avoiding an explosion.

This ultimate feature has not been proven. However associated with a failure of the primary circuit is the vapourisation of the coolant into the atmosphere enclosed by the secondary containment structure. Steam itself has no radio active isotopes but it is reasonable to assume that a release of primary coolant will be accompanied by the release of radioactive metal particles and gases. The particles may plate on the boundaries of the secondary containment structure if it remains intact or there may be a release to atmosphere of particles and gases which would contaminate the environment.

Such a failure of the primary circuit is regarded as the maximum credible incident.

The probability of such an event is the subject of hazard analysis. In the UK Farmer, the Chief Scientist, set down an arbitrary criteria that radioactive release which would cause environmental radiation levels sufficient to cause death of civilians should be one occurrence in 10^7 years. At the time this seemed pretty reasonable until it was realised that the number of installations has reduced this probability to one occurrence in 10^4 years.

As there has been only a twenty year period it is hard to claim that the statistics are being achieved.

Sabotage

I have been serving on two RN warships where members of the crew committed sabotage. It is probable that sabotage represents a real but non-assessed risk to ship-borne nuclear reactors.

Nice one

The sinking of the Rainbow Warrior demonstrates the vulnerability of vessels to attacks from divers.

Resources to manage a hazardous incident

There are insufficient resources available within New Zealand to cope with a reactor incident which results in a release of radioactive material into the environment. This includes the management skills, people resources and appropriate materiel.

It is likely that the nation responsible for the ship would literally invade our country to take charge of the clean-up with an inevitable conflict in priorities.

The medical facilities required to deal with specialised treatment in the numbers of possible casualties simply do not exist in any of our major centres.

It is difficult to remove a flooded or sunken vessel. It took considerable time to remove the Wahine. The Lermentov is still on the bottom. It would take more than a month to remove a striken vessel with a leaking reactor even with a heavy lift ship from overseas. Such vessels would take two weeks to get here.

Lack of Justification for ship visits

The question has to be asked-Why?

Shore-leave for sailors. Showing the American or British flags does not require nuclear powered platforms.

Leave those sorts of ships in Australia and fly the the crew here. I'm sure there would be no shortage of sponsors.

Summary

I object strongly to any suggestion of visits to New Zealand of nuclear powered vessels regardless of country of origin.

This is based on my assessment that the dangers of ship-borne reactors are much greater than those of land-based reactors which have already provided ample evidence of failure.

The military mind is not completely sensitive to the safety standards and consciousness demanded by civilian authorities.

Naval reactor control systems incorporate unacceptable safety over-ride features.

The mobility of a ship-borne reactor compounds the hazards.

The age of the nuclear powered surface vessels likely to visit New Zealand increases the hazard.

New Zealand could not cope with a radioactive release into its environment. Such a release would devastate our overseas markets for our agricultural goods

Yours faithfully,

John Harrhy