VULCAN NAVAL REACTOR TEST ESTABLISHMENT

THE LAST 8 YEARS

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ABSTRACT

Prototype testing of Royal Naval nuclear submarine reactor plant takes place within a MOD(PE) establishment in the far north of Scotland, operated by Rolls-Royce and Associates. Since the mid 1980s the original prototype has been converted into a unique PWR leak test facility, and a second prototype has been commissioned to operate the next generation reactor plant, PWR2, destined for first seagoing use in the VANGUARD Class.

Introduction

Now under its fourth title since its inception in 1957, this MOD(PE) outpost employing about 400 Rolls-Royce and Associates and six Royal Navy personnel continues to test prototype reactor plant in advance of operational use in the Submarine Flotilla. Major developments have taken place since, the last review of Vulcan, written by Captain J. R. Bussell in June 1984[1], and this article will bring earlier readers up to date. For those unfamiliar with Vulcan and its purpose, a brief summary is given below.

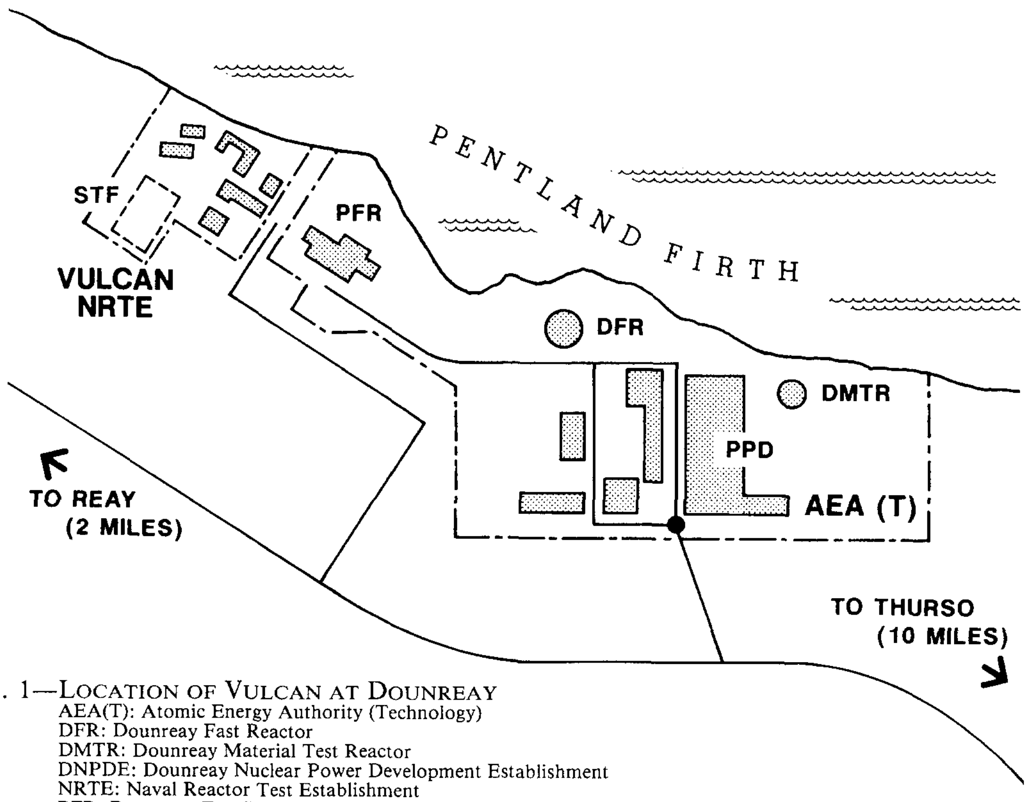

FIG. 1—LOCATION OF VULCAN AT DOUNREAY
AEA(T): Atomic Energy Authority (Technology)
DFR: Dounreay Fast Reactor
DMTR: Dounreay Material Test Reactor
DNPDE: Dounreay Nuclear Power Development Establishment
NRTE: Naval Reactor Test Establishment
PFR: Prototype Fast Reactor
PPD: Process Plant Division
STF: Shore Test Facility

FIG. 2—VULCAN NRTE TODAY

The Establishment

The history starts in January 1953 when the Ministry of Supply announced the decision to construct a Fast Breeder Reactor to be run by the United Kingdom Atomic Energy Authority. Because of the unqualified risk associated with the plant it was desirable that it should be located some distance from centres of population. It also needed a sea coastline to allow for effluent discharges, a foundation of solid rock, availability of up to 12 million gallons of fresh water a day and sufficient land area to accommodate further experimental reactors. Three sites were identified, one in Wales and two in the North of Scotland, from which Dounreay was chosen on the grounds of low population density.

When later in the 1950s the Admiralty decided to construct a prototype nuclear submarine propulsion plant, Dounreay was an obvious choice of venue. The UKAEA had land available adjacent to their establishment to lease to the Admiralty and they could provide the necessary supporting services of electricity, water, medical services, radioactive waste disposal, and a body of expertise and facilities which could be activated in the unlikely event of a nuclear accident.

Construction of the Dounreay Submarine Prototype (DSMP1) and supporting facilities lasted from 1957 to 1965, and a naval presence was established from 1961 under a Captain Superintendent. 'Government Owned Contractor Operated' is now a fashionable phrase, but in this respect the Admiralty Reactor Test Establishment was ahead of its time as Rolls-Royce and Associates were awarded the operating contract in 1965, with the small naval staff acting as the 'customer' and holding responsibility for the nuclear safety of the MOD-owned facilities. Today the naval presence comprises:

- the Naval Superintendent (Cdr MESM)
- the Naval Operations Officer (Lt-Cdr MESM)

- three Assistant Naval Operations Officers (2 Lieuts MESM and 1 WOMEA (EL)(SM))
- a CPO Writer.

Although now a (PE) Establishment the trappings and traditions of HMS *Vulcan*, the name given to the site as a Naval Home Command fleet establishment between 1970–1981 remain and uniform is worn by naval personnel.

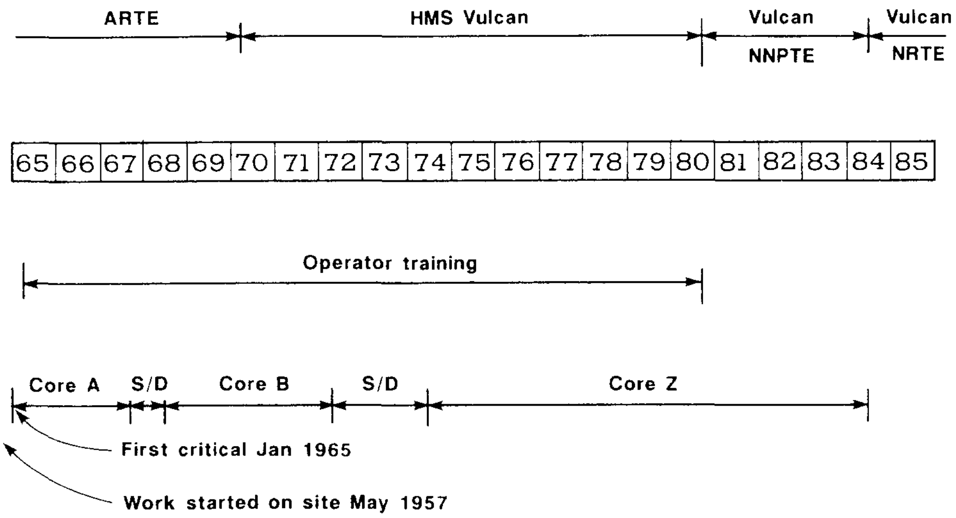

FIG. 3—DSMP1 HISTORY
ARTE: Admiralty Reactor Test Establishment
DSMP: Dounreay Submarine Prototype
NNPTE: Naval Nuclear Propulsion Test Establishment
NRTE: Naval Reactor Test Establishment
S/D: Shut down (for refit)

DSMP1

Initial start up of the prototype VALIANT Class machinery with reactor Core 'A' installed took place in January 1965, and over the ensuing 19 years the prototype was to prove the performance of Cores A, B and Z (summarized in FIG. 3) and make an invaluable contribution to the nuclear safety and availability of naval nuclear propulsion plants as well as training over 3000 naval and civilian operators[1]. To list a few major examples:

(*a*) At initial build the discovery of cracks in the welds of small bore inconel tubing resulted in a major reappraisal of material selection, resulting in the choice of stainless steel throughout for submarine propulsion plants.

(*b*) The early development of water chemistry standards in a stainless steel primary system.

(*c*) Evaluation of VALIANT, SWIFTSURE and TRAFALGAR Class instrumentation, rod control systems, control panels, and proof of the manning concepts.

(*d*) Discovery of a serious problem with cooling water vortices within the core, leading to the development of a 'fix' which was subsequently fitted to the Submarine Flotilla.

(*e*) Demonstration of burn-up of core Z beyond the original design value.

(*f*) Demonstration of chemical decontamination of the primary circuit as a major contribution to dose reduction in refit.

Despite the benefits to the naval nuclear propulsion programme DSMP1 did not completely fulfil one of its purposes; to operate the prototype ahead of seagoing plant and thereby detect generic defects in advance of experience from submarine installed machinery. Originally DSMP1 was built using high strength mild steel for the large bore pipework known as the 'primary loops' which carries the high temperature, high volume flow cooling water from the reactor to the steam generators. Inconel was used for smaller bore cold systems. Following the weld failures during build referred to earlier, the DSMP1 cold systems were rebuilt using mild steel alloy, and the material for submarine plant changed to stainless steel throughout. As a result DSMP1 was assembled with different basic materials from those of the Submarine Flotilla.

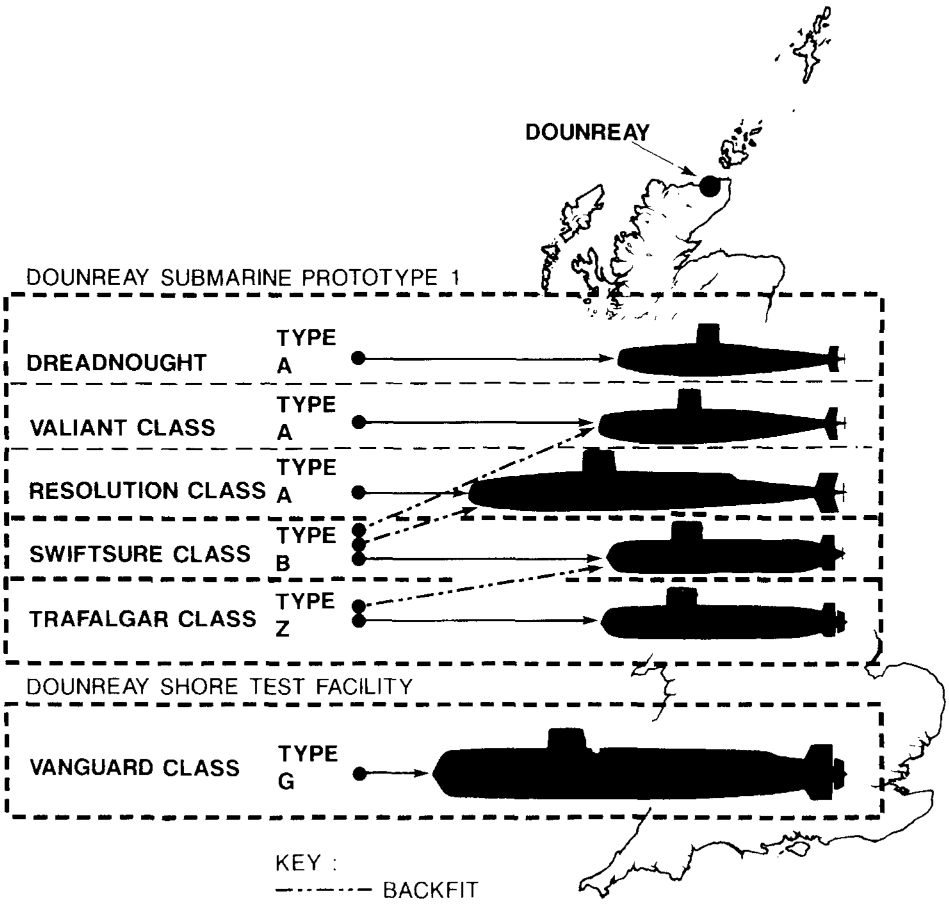

FIG. 4—SUBMARINE POWER PLANT DEVELOPMENT

Core Nomenclature

Core A	1st UK design
B	2nd generation UK design
C, D, E, F	design schemes only, not manufactured
Z	3rd generation UK design (as a variant of Core B this core was originally designated BZ)
G	1st core designed for PWR2

At the Core B to Z refit in 1973, the mild steel steam generator heat exchangers were replaced with modified SWIFTSURE Class units of stainless steel construction and large sections of the mild steel primary loops were replaced with stainless steel. Therefore only for the life of one Core Z (ten years at Vulcan) was the DSMP1 plant representative of submarines in service, and experience has shown that by comparison with the over 25 years that the early reactor plants have been in service, this period was insufficient for age-related generic defects to show themselves.

Loss of Coolant Accident Investigation Rig Dounreay (LAIRD)

Before naval reactor plant is operated after build or refit its theoretical behaviour under normal and abnormal operating conditions is proven to be safe through a paperwork exercise known as the Plant Safety Justification. In the late 1970s many areas of component and system performance under adverse conditions which were assumed in the safety justification were not fully supported by experimental evidence and therefore design and safety calculation models necessarily contained highly conservative assumptions.

The construction from 1979 to 1985 of a new Shore Test Facility (STF) to operate the prototype PWR2, and the completion of trials on Core Z, the ultimate core development for PWR1, enabled the DSMP1 plant to be converted into its final form as a full-scale hydraulic rig to investigate and simulate the most significant type of PWR failures. The first phase of conversion was to decontaminate the internal surfaces of the primary reactor circuit, to lower future radiation dose to plant workers and perform a prototype decontamination in advance of submarine refits. The process is referred to as MODIX, which contrary to popular belief does not stand for 'Ministry of Defence Interesting Experiment', but the more prosaic 'mild Multi stage Oxidative Decontamination with Ion eXchange clean up'. After the MODIX process had achieved over 90% reduction in reactor pipework dose rates, conversion began of the PWR1 plant to LAIRD (FIG. 5). This was a major engineering task involving the build of 11 leak paths (FIGS. 6 & 7) into the high pressure reactor circuit, any one of which could be lined up to discharge through a fast-acting valve into a quench tank of 50 tonne capacity.

Using extensive data logging to plot the rapid transients, computer-sequenced leaks representing typical severe PWR loss of coolant accidents are initiated and recorded for future analysis. After Phase I trials which were performed with no energy source other than that stored in the hot and pressurized primary circuit, electrical 'elements' capable of up to 4 MW output were installed for Phase II trials, in order to simulate the decay heat from a live

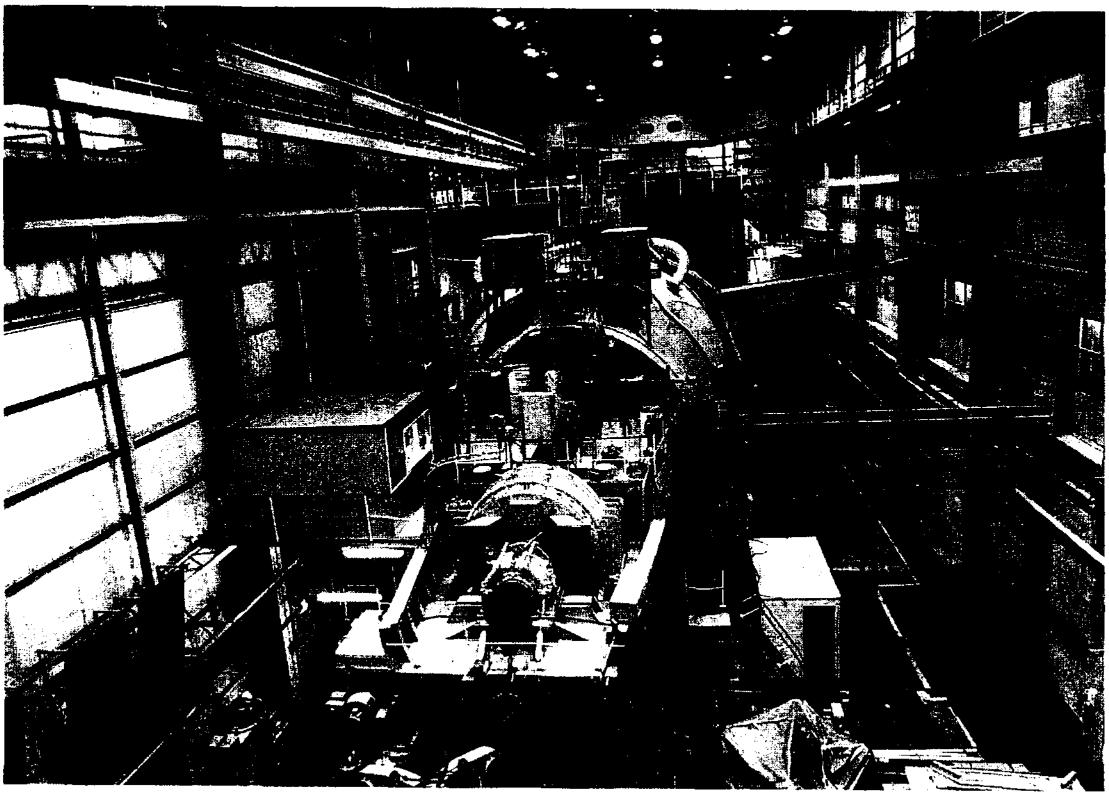

FIG. 5—LAIRD, ORIGINALLY DSMP1

core. This facility has been of great importance to the demonstration of the safe operation of PWR1 under fault conditions and data are also used to refine and confirm computer codes for future designs. In addition to the major loss of coolant accident trials summarized in TABLE I, LAIRD has been used for several other trials in support of current or future designs. These include Active Vibration Control (AVC), and equipment fit-up and test in support of the steam generator transition weld investigation.

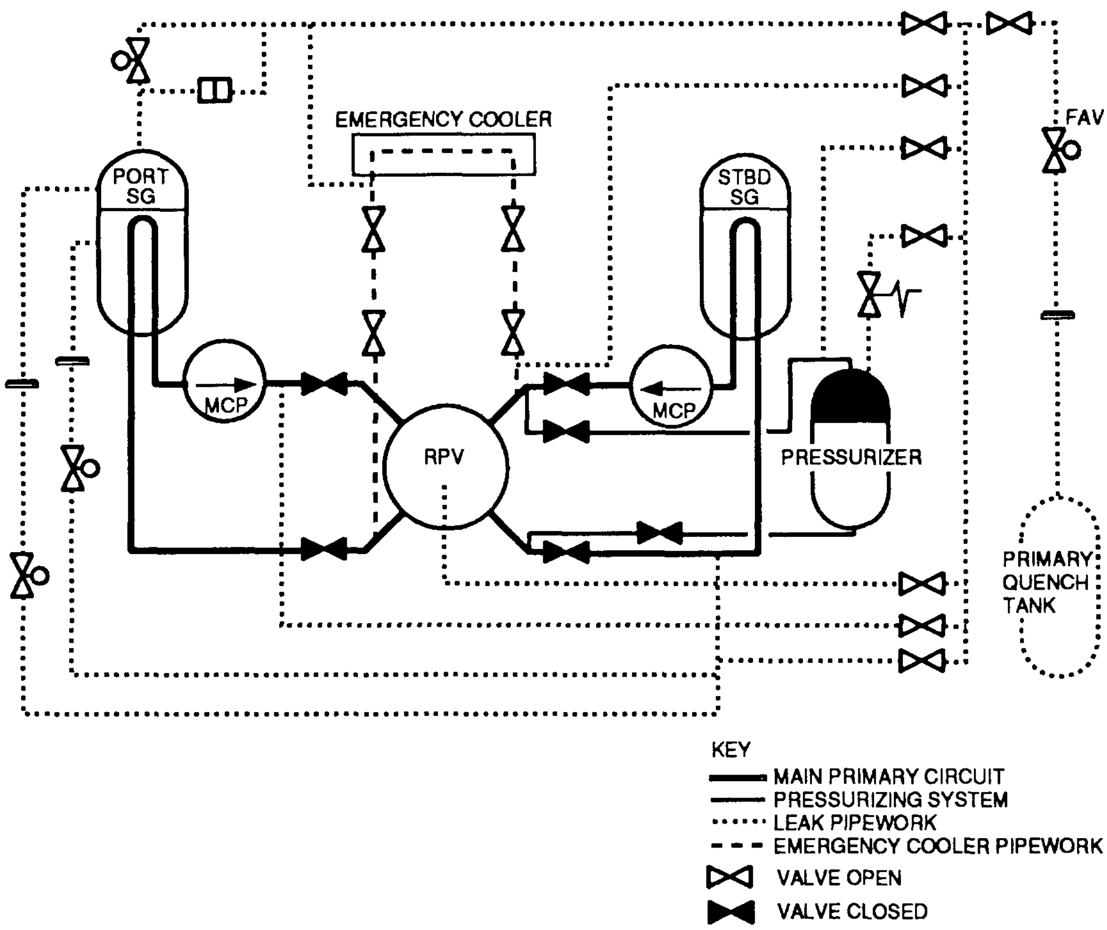

FIG. 6—DIAGRAMMATIC REPRESENTATION OF LAIRD
BST: Biological Shield Tank
FAV: Fast Acting Valve
MCP: Main Coolant Pump
RPV: Reactor Pressure Vessel
SG: Steam Generator

This unique facility cost about £5M to convert from DSMP1, and had an annual operating cost of £1.3M. Trials were conducted in two phases between June 1987 and November 1991 using six three-man shifts, after which trials have been achieved using day-shift workers only. The list of trials is not exhaustive however, and operation will cease in August 1992 when the plant will be placed in 'care and maintenance' until disposal or if necessary reactivation. By this time over 400 'blow downs' will have been achieved, each one representing a serious PWR accident. There will follow a run down in site manpower to about 360. The value of LAIRD'S contribution to the practical understanding of plant performance and the operation of engineered plant safety features has far exceeded that originally envisaged, and the trials data will be fundamental to the continuing necessity to prove safe operation of current and new designs.

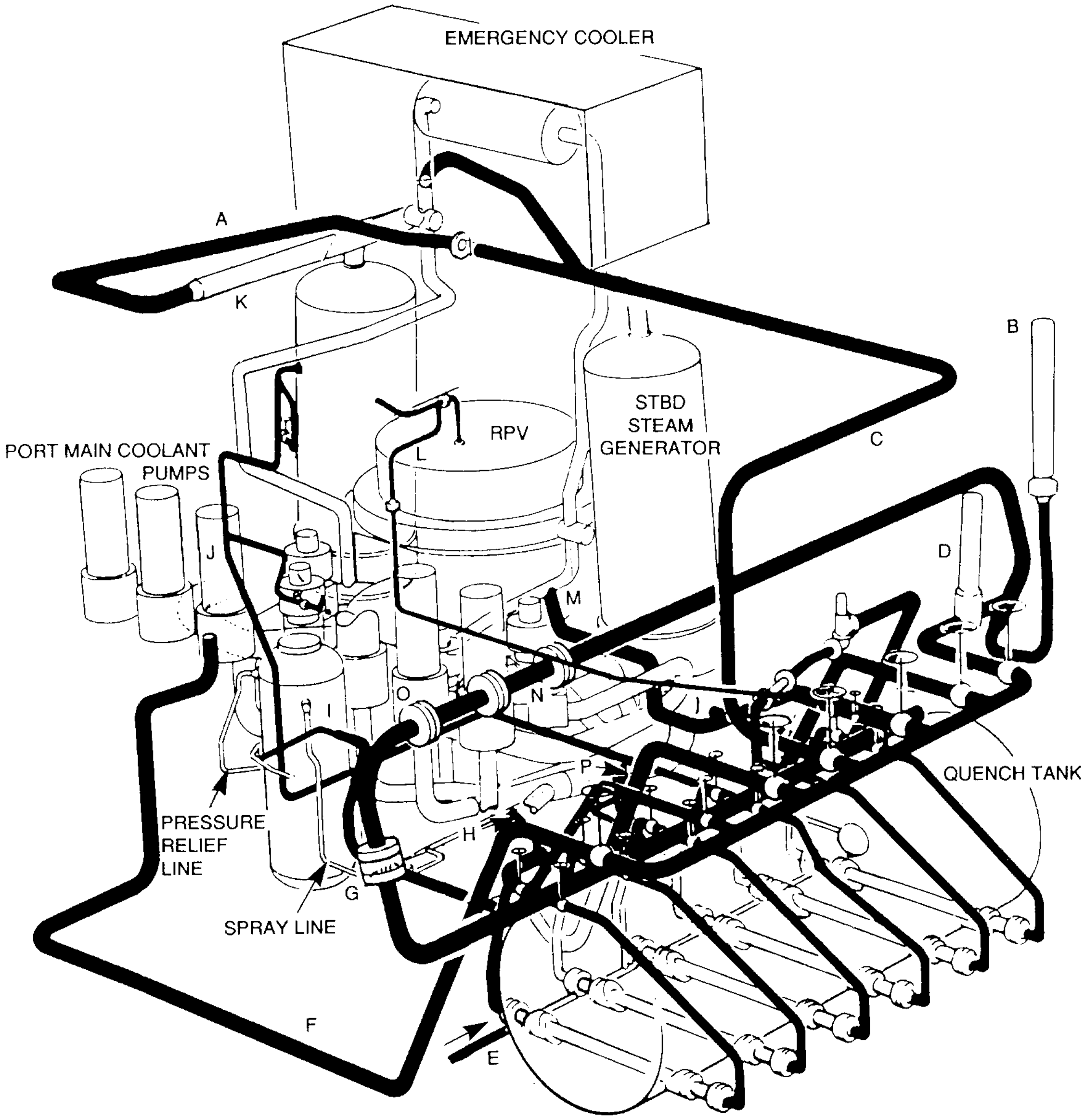

FIG. 7—LAIRD

large dark pipes: emergency core cooling system
small dark pipes: leak system
A major steam leak and high pressure decay heat removal (HPDHR) tube leak
B pressure alleviator
C reactor pressure vessel (RPV) outlet plenum leak and emergency cooler leak
D fast acting valve
E loop bypass injection via stbd. T_h (temperature, hot) loop steam generator (SG) and bypassing main isolating valve
F port T_c (temperature, cold) leak
G provision for bursting disc (flow initiation)
H spray line leak
I steam relief line (Three Mile Island) leak
J SG tube and HPDHR tube leak
K 8 inch main steam line capped
L RPV head leak
M RPV inlet plenum leak
N temporary spool piece for flowmeter
O leak control nozzle assembly
P stbd. T_h leak

Post Irradiation Examination

An important task at Vulcan is to conduct the Post Irradiation Examination (PIE) of spent fuel originating from the prototype and from operational submarines. As well as careful visual examination, modules are subjected to very accurate measurement to determine what changes in shape have taken place during burn up of the fuel. Of particular interest is any significant change in the size of the water gap between fuel plates, as changes here can lead to alterations in coolant flow through the channels and hence alterations to predicted heat transfer rates. The external dimensions of the core are also measured to ensure that no unacceptable deformation has occurred. This work takes place in the DSMP Pond which is an open stainless steel lined concrete tank of 37 500 gallons capacity enclosed within a clean area. The water specification is carefully controlled by means of a treatment system to remove radioactive particles and maintain the correct water chemistry and temperature. To ensure that no radiation hazard results from the highly radioactive fuel rods under examination, all work takes place using remote handling equipment which maintains at least 1.5 m of water above the fuel rods, the water acting as an excellent radiation shield. The value of the PIE work over the years has been great. The justification for significant extension to Core B life depended heavily on it, and Core Z PIE results were employed in underpinning the (PWR2) Core G1 safety justification. STF has its own pond, shown in FIG. 8, which will be activated during Core G1 defuel.

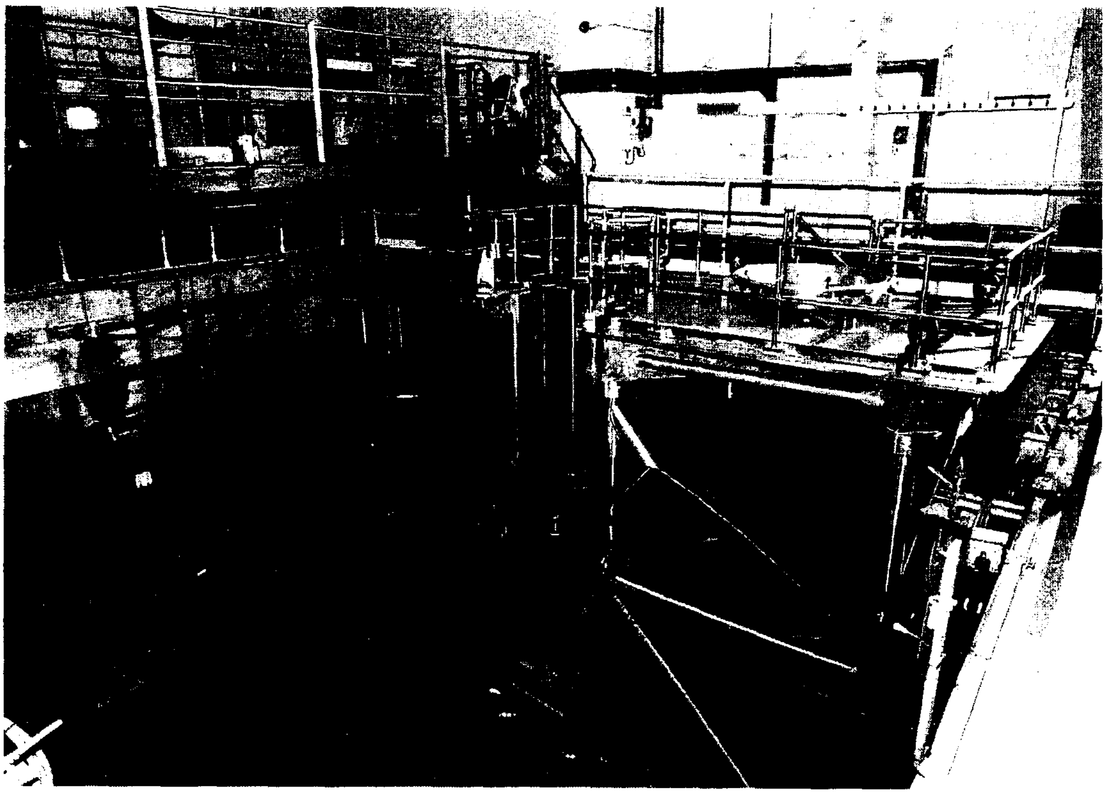

FIG. 8—STF POND, WITH EMPTY FUEL ELEMENT RACK ON LEFT

The Shore Test Facility

The Shore Test Facility building was almost complete by June 1985 when the PWR2 prototype reactor assembly was pushed into position after a 16 day sea and land transport operation described in an earlier article by Commander Wills[2]. The process of connection to the STF and the loading of Core G1, the prototype PWR2, core was completed by July 1987 and acceptance by the MOD took place on 2 October 1987, slightly under the estimated cost of £300M and a few days ahead of the date set five years before. The prototype has about 2000 channels of R&D instrumentation installed which include incore pressures, flows and temperatures which are scanned by a data logger at a rate of 3000 readings per second, plus a further 1000 channels at slower speed.

As submarine secondary machinery is now tested in Barrow, it is no longer necessary to incur the expense of replicating the full submarine propulsion plant, although the prototype reactor compartment is still positioned in a portion of submarine hull within the biological shield tank which is full of water to provide radiation shielding (FIG. 9). The reactor power is dissipated through dump steam expanders and condensers.

TABLE I—*Loss of Coolant accident trials in* LAIRD

Type of Trial	*Conducted in Support of*	*Reason for Trial*
Main Isolating Valve Emergency Cooling Isolating Valve Surge Line Isolating Valve.	Current Class Safety Justification	Phase I/II Trial To determine isolating valve performance against a variety of fast primary coolant leaks.
Leak Isolation Procedures	Current Class Safety Justification	Phase I/II Trial Evaluate current leak isolation procedures and ways of improving performance.
Pressure Steam Leaks/ Pressuriser Emptying Trials.	Current Class Safety Justification	Phase I/II Trial Simulation of TMI accident.
(Heated Core Fitted (Phase II))		
Plant Comparison Trials	Plant Controls	Phase II trial to note differences/ similarities between LAIRD and DSMP1 Core Z.
SG Tube Leak Trials	Current Class Safety Justification	To test SG relief valve performance.
Emergency Cooler Tube Leaks.	Current Class Safety Justification	To determine pressure transient into EC hard tank compared with in-service tank pressure predictions.
Emergency Cooling (High Pressure Decay Heat Removal)	Current Class Safety Justification	To test emergency cooler's ability to cool the core under voidage conditions in the RPV and general overall performance.
Extended Loss of Heat Sink Trials	Current Class Safety Justification	To monitor core behaviour under conditions of no net flow.
Emergency Core Cooling System	Future Class Safety Justification	To validate current computer models of VANGUARD Class Emergency Core Cooling System.
Transition Weld Failures 8″ leak Line	Transition Weld Investigation	Simulate a large primary to secondary failure to monitor plant's ability to survive ensuing transient.
Main Steam Stop Valve Performance	Transition Weld Investigation	To investigate the valve's ability to isolate carryover following a large primary to secondary leak.
Main Coolant Pump Non-Return Valve	Transition Weld Investigation	To investigate Non-Return Valve performance during the initial stages of a transition weld failure to validate current computer modelling techniques.

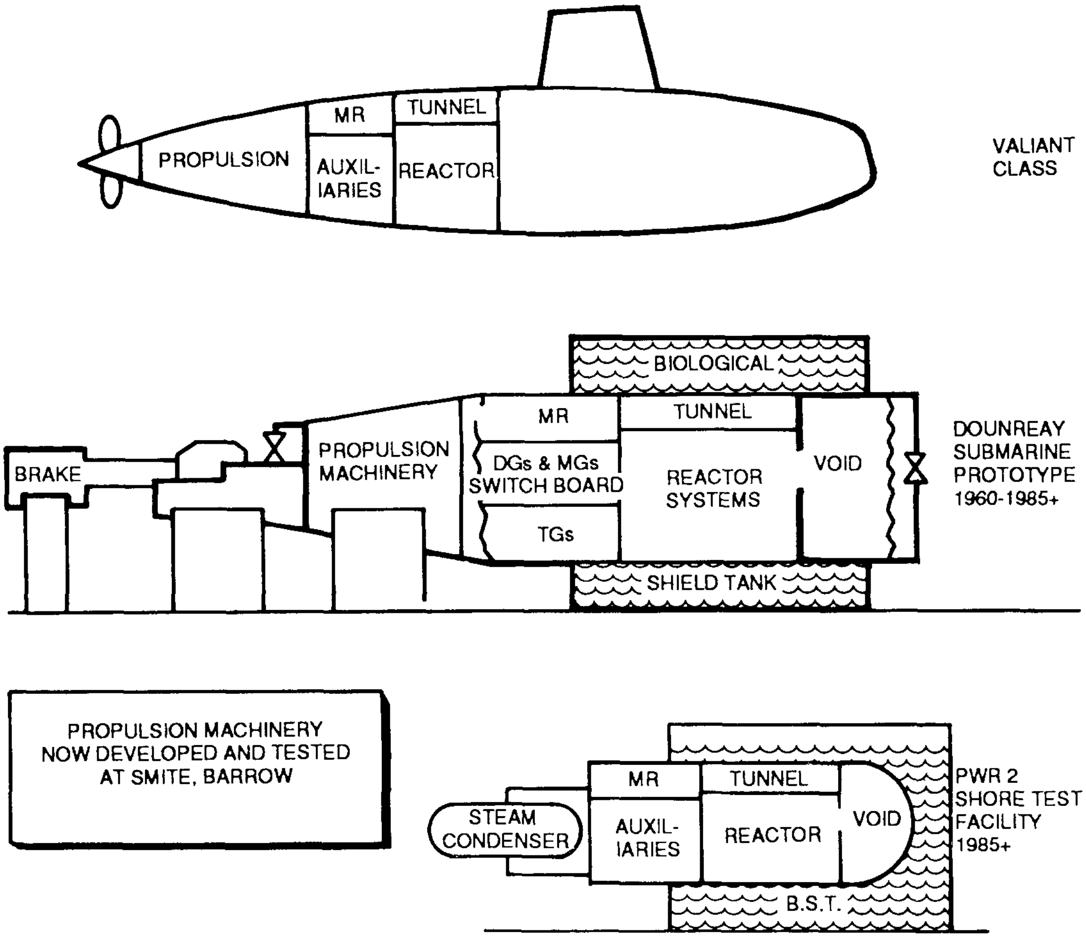

FIG. 9—SUBMARINE/PROTOTYPE RELATIONSHIPS
BST: BIOLOGICAL SHIELD TANK
DG: DIESEL GENERATOR
MG: MOTOR GENERATOR
MR: MANOEUVRING ROOM
PWR: PRESSURIZED WATER REACTOR
SMITE: SUBMARINE MACHINERY TEST ESTABLISHMENT
TG: (STEAM) TURBO GENERATOR INSTALLATION

STF Trials

By the time that reactor operation started at Vulcan, PWR2 had been designated for and designed into the VANGUARD Class, and trials proceeded with the aim of achieving 50% of core life in advance of the first operation of *Vanguard's* machinery. The R&D trials programme started smoothly yielding a wealth of information. However, in March 1989 a serious defect occurred in control rod drive motors (CRDMs), which are used to drive neutron absorbing rods in and out of the reactor core. Following an intensive investigation into the intermittent stalling of these components and a test programme to evaluate modifications, confidence was high that the problem was fully understood and that a solution had been successfully developed. However, during CRDM commissioning trials in early 1991 some additional problems with the revised design were experienced and a further period of investigation and rectification was necessary to provide a satisfactory conclusion to this problem. The end of the initial CRDM investigation coincided with a planned extended shutdown to allow equipment developed specifically for the VANGUARD Class (in particular rod control gear and reactor instrumentation assemblies) to be fitted and proved at least 1 year in advance of installation in *Vanguard*. In May 1991 this work finished and the reactor was started up to continue the core burn-up and trials programme, which is shown FIG. 10. Excellent progress was made in the second half of 1991 with 36% of the core burnt up by the end of the year, over double the highest burn-up rate achieved in any previous six month period.

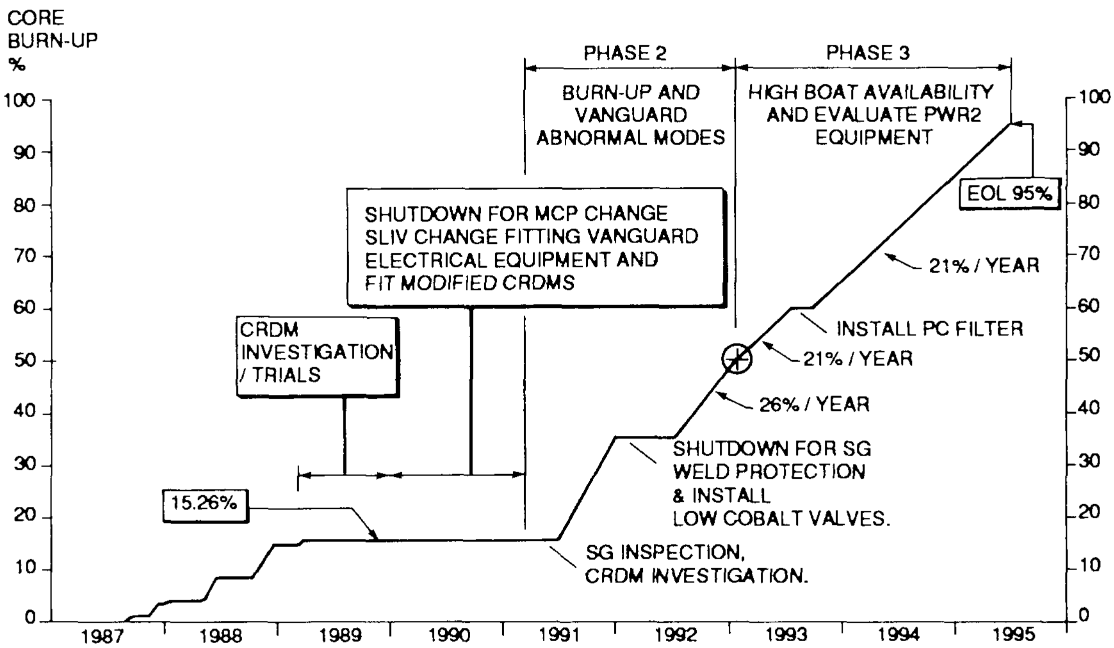

FIG. 10—CORE G1 PROGRAMME
CRDM: Control Rod Drive Motor
EOL: End of Life
MCP: Main Coolant Pump
SG: Steam Generator
SLIV: Surge Line Isolating Valve

The Future Role of the STF

Core G1 is scheduled to complete burn-up and trials in mid 1995. The principal planning assumption is that STF will continue operation in support of PWR2 and prototype test a new core design, Core H, which is planned for operation in later submarines of the VANGUARD and Batch 2 TRAFALGAR Classes. In addition to prototype core operation, it is likely that new items of submarine propulsion equipment and principles of operation will be tested, providing the fundamental Availability, Reliability and Maintainability (ARM) data in advance of submarine operation. On current forecasts these are:

(*a*) Operation with single-speed main coolant pumps.

(*b*) A new design of CRDM.

(*c*) Solid state high power AC/DC conversion machinery.

(*d*) A different range of R&D instrumentation to be fitted to the reactor core, providing new technical data for the improvement of military characteristics in future designs.

(*e*) The fitting of new Control and Instrumentation systems in line with technological advance in this area in support of manpower reductions in future submarine classes.

(*f*) Equipment is available which offers significant potential for dose reduction, requiring adaptation and testing for naval PWR use. The plant will provide prototype experience for PWR2 decontamination during refit in the likely event that this is considered necessary.

The Future Requirement for a Reactor Prototype

No viable alternative to PWR2 currently exists for the propulsion plant of new construction nuclear submarines. The plant is fitted to the VANGUARD Class submarines and seems likely to be selected for the Batch 2 TRAFALGAR Class. STF exists to underpin the seagoing operation of PWR2, and its significance to the ARM and safety of the VANGUARD Class which will take PWR2 to sea for the first time is of even greater importance than DSMP1 was to the RESOLUTION Class, which was preceded by the SSNs VALIANT and WARSPITE which had similar propulsion plants.

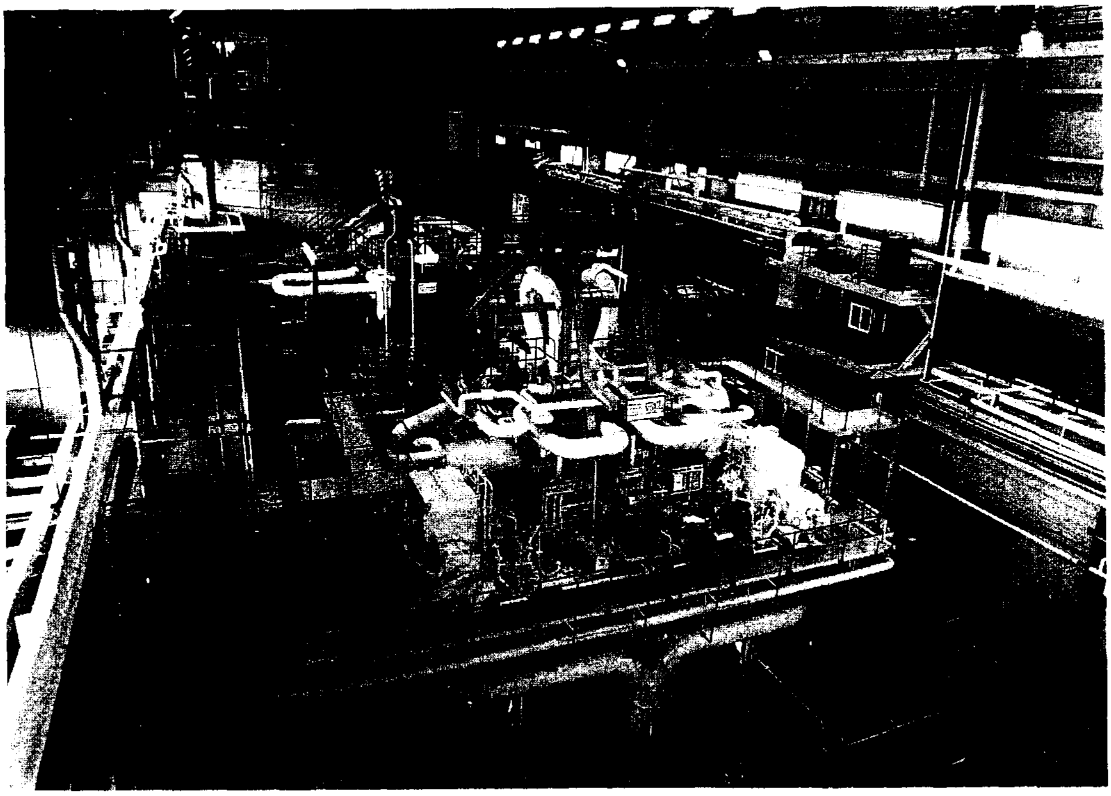

FIG. 11—INTERIOR VIEW OF THE STF

Conclusions

Operation of the reactor prototype at Vulcan has provided a major contribution to the safety and ARM of the Submarine Flotilla. Reliability of propulsion is a major element of submarine safety, and this reason in itself is good justification for comprehensive prototype testing. The reassurance given to nuclear safety is at least as important, and in this respect the prototype may be considered an essential element of the naval nuclear safety philosophy and an unavoidable part of the cost of ownership of nuclear submarines.

Operation of the facilities at Vulcan NRTE (at a 1991/92 cost of £15M) provides support to in-service boats and new designs, and is part of the overall framework of administrative, procedural, practical and experimental activities which underpins nuclear reactor operations at sea. In summary, operation of a prototype reactor is an essential part of the nuclear submarine flotilla infrastructure, and should be considered an inescapable element of the naval nuclear propulsion programme.

References

[1] Bussell, J. R.: Dounreay nuclear submarine prototype; *Journal of Naval Engineering*, vol. 28, no. 2 June 1984, pp. 210–218.

[2] Wills, L. I.: PWR2 at Dounreay—transport to site operation; *Journal of Naval Engineering*, vol. 29, no. 3, June 1986, pp. 609–626.