Technical Evaluation of "The Safety of Nuclear Powered Ships"

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SUMMARY

In its 1992 assessment of "The safety of Nuclear Powered Ships", the government's Special Committee on Nuclear Propulsion estimated how hazardous it would be for nuclear ships to use New Zealand ports. Unfortunately, the Special Committee failed to evaluate the hazards in terms of the product of risk and impact and thus failed to recognize that the day-by-day hazard of nuclear accidents accrues from rare catastrophes--almost Chernobyl-sized accidents.

Based on the record of major land-based reactor accidents, the nuclear hazard is more than 99% attributable to catastrophes rather than to normal accidents. This results from the fact that overwhelming nuclear accidents--like Chernobyl--actually happen almost as often as large nuclear accidents--like Three Mile Island. In failing to compare nuclear hazards, the Special Committed failed to appreciate the magnitude of the overall hazard posed by shipboard nuclear reactors.

The hazard posed by shipboard nuclear reactors is here calculated from data and references cited by the Special Committee. The emphasis is on actual experience with major nuclear accidents, and the worst accidents are included rather than ignored. Then a mortality rate of one radiation-caused death for every 250 curies of iodine-131 escaping from a nuclear reactor accident is used to estimate of the hazard of a nuclear powered ship berthed in a New Zealand port for a full year at one cancer death. This hazard is ten times the maximum hazard that is ordinarily

deemed to be socially "tolerable". Even a single visit by a nuclear ship to a New Zealand port has 1/60 of this hazard and is unacceptable without special precautions.

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INTRODUCTION

The "main burden" undertaken by the Special Committee on Nuclear Propulsion was to "give an estimate of the risk or hazard arising from the presence of a nuclear powered ship in a New Zealand port [p.1*]." Unfortunately, by the end of the second chapter of the report, the Special Committee had found that a comprehensive hazard assessment wasn't feasible. Thus, much of the insight that could be gleaned from enumerating hazards was lost, and the Committee's assessment reduced to cross-checking different predictions and judging the reliability of position statements.

Although nuclear-powered vessels have logged thousands of ship-years of operation, little of this experience has been in foreign ports. Instead, almost all nuclear ship operating experience has been with naval vessels in home ports or at sea, and even these records are largely military secrets. Where the secrecy has partly broken down--with the collapse of the Soviet Union--nuclear accidents involving shipboard reactors have been disclosed retrospectively.

The Special Committee referred to accident reports and evaluations by Greenpeace and others who had claimed that the Soviet nuclear powered ice breaker 'LENIN' experienced a reactor meltdown about 1966 [pp.55-57]. The Special Committee expressed "scepticism". On 23 November 1992, the Russians admitted dumping three reactors from the 'LENIN' into the Sivolky Gulf of the Kara Sea in 1967 [W. Sullivan, "New York Times", 'Soviet Nuclear Dumps Disclosed', 24 Nov. 1992]. According to the US Navy, "Soviet Naval reactor accidents are to blame for approximately 80 deaths since the early 1960's, and the loss or retirement of a number of ships [Adm B. DeWars, Statement before the US House Armed Services Committee (7 April 1992) 8]." Although Adm DeWars's statement is listed in the Bibliography, the Special Committee does not mention it in its evaluation of the "Operational Record of Nuclear Powered Warships (Sec.5.7).

Neither the Special Committee's Terms of Reference nor its stated intent suggest any limitation either to nationality or to military or civilian type of nuclear powered ship. Accordingly, the Soviet record is clearly part of the relevant safety record; indeed, it is <u>the</u> part of the nuclear safety record in which some candor from the US Navy may be hoped. Although the Special Committee does refer to the accident record of Soviet nuclear ships in Secs.5.6 and 5.7.2, the Special Committee eliminated the Soviet record of accidents by limiting its deliberations "to the nuclear navies of the United Kingdom and the United States [p.3]." In short, the Special Committee effectively threw out the record of nuclear reactor accidents aboard ships, and then concluded that the ships which had no recorded accidents had almost certainly been safe and would continue to be safe.

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* References are bracketed. References without additional notation refer to the Report of the Special Committee on Nuclear Propulsion, "The Safety on Nuclear Powered Ships," Department of the Prime Minister and Cabinet, Parliament Buildings,

Wellington, New Zealand, (December 1992) 269pp. This is the "Special Committee's report".

Yet even this conclusion may be overly optimistic. This reviewer has conducted environmental studies of US nuclear ports. Careful evaluation of the US Navy monitoring program shows that substantial nuclear accidents *could* occur in ports without detection by either the Navy or so-called "independent" monitors. Of major concern, the Navy claims that it has destroyed the crucial data which would confirm the validity of its monitoring. Without these data, this reviewer finds no scientific basis in the public record for US Navy assurances of the safety of nuclear ships in nuclear ports. (These concerns were made available to the Special Committee, and they were evaluated under "Myth seven: The amount of radioactivity emitted by nuclear powered vessels of the US Navy and the Royal Navy is dangerously high [p.162]." This reviewer considers the evaluation incorrect.)

The Special Committee also relied on the safety record of the Royal Navy. Mr John Harrhy, British naval architect and structural engineer who was secretary of the UK submarine safety working party, has responded to the Special Committee's conclusion that UK nuclear naval vessels are safe:

> **While I have no doubts of the integrity of the members [of the Special Committee], I have to say that they have been successfully duped by their sources of information from overseas** ["Christchurch Press", 'Nuclear group *duped*' (21 December 1992)].

Harrhy expressed particular concern about the "non-spherical shape of a warship reactor compartment" which would "prejudice any confidence in the safety envelope [containment]." With these concerns, it is difficult to rely completely on official assertions of the safety of nuclear powered ships. Furthermore, we are alerted to an important question of what confidence to place on the structural containment of radioactivity by walls built around a nuclear reactor.

Fortunately, the Special Committee's report included a variety of information which allows indirect evaluation of the hazard posed by nuclear ships. In particular, there is a record of serious nuclear accidents with large land-based nuclear reactors. To base calculations on this record, however, one must define what is meant by *serious*, *nuclear*, and *accident*, and one must pick a relevant set of reactors for consideration. No matter what definitions one picks, one faces valid criticism.

The Special Committee selected three "major" land-based reactor accidents which resulted in "real and severe" harm or in "commercial disaster", which "stand out in people's minds as a warning of what could happen", which "created serious hazards", and which were "the most publicised" [p.13, 53]. This particular record of "major" nuclear accidents is specially useful for nuclear hazard evaluation because the radiological consequences of each accident were thoroughly investigated and the results were made public. This record consists of three major nuclear accidents--Three Mile Island in the USA, Windscale in the UK, and Chernobyl in the CIS--allowing an international perspective which is appropriate to the prospect of foreign nuclear ships entering New Zealand ports.

With this small set of major nuclear accident data, we have a way to evaluate human experience with reactors in terms of numerical estimates of nuclear hazard. This will yield some interesting results. By failing to calculate and compare the nuclear hazards of accidents of various magnitudes, the Special Committee worked on the false assumption that the most severe nuclear accidents involving reactor meltdown and rupture of containment can be ignored. The Special Committee failed to recognize that almost all of the hazard posed by nuclear reactors is due to huge, catastrophic accidents. Instead, the Special Committee discounted "any accident involving a rupture in containment as being so unlikely ... that no purpose is served by considering it further [p.117]." Thus, in its evaluation of the consequences of nuclear accidents, the Special Committee omitted the bulk of the nuclear hazard posed by nuclear ships. And thus, the Special Committee's finding that the use of New Zealand ports by U.S. and U.K. nuclear powered naval vessels "would be safe [p.173]" is unfounded. The present evaluation corrects the failure to incorporate hazards posed by nuclear catastrophes.

HAZARD ASSESSMENT

A numerical estimate of hazard may be obtained from a "probabilistic risk assessment", as follows: the likelihood of each kind of accident is estimated and multiplied by its estimated consequences to obtain the hazard of an individual kind of accident. These products are summed to obtain the estimate of total hazard. The estimates are based on experience with the operating characteristics of components, with similar accident types, with similar technologies, and on expert opinion. From the standpoint of reviewing hazard assessments, there is a danger that the reviewer becomes numbed by all the numbers and loses sight of major vulnerabilities.

A great variety of accident types and a huge range of consequences is possible with a nuclear power reactor located either on land or aboard a ship. To simplify the assessment enough that the salient risks stand out, likelihood is here expressed in terms of the chance per year of an accidental escape of radioactivity from a nuclear reactor, and the impact is expressed as curies of iodine-131 escaping to the atmosphere from the hypothetical nuclear accident. (One curie is 37 billion disintegrations of atomic nuclei per second.) This way of expressing the impact of a nuclear accident is simple and facilitates comparisons, but it does require interpretation. One interpretation is merely to list the routine operation of a nuclear ship reactor in comparison with the iodine-131 releases from each of the major reactor accidents to be considered, in the following table:

Table 1. Impacts of nuclear reactors in terms of iodine-131 escaping.

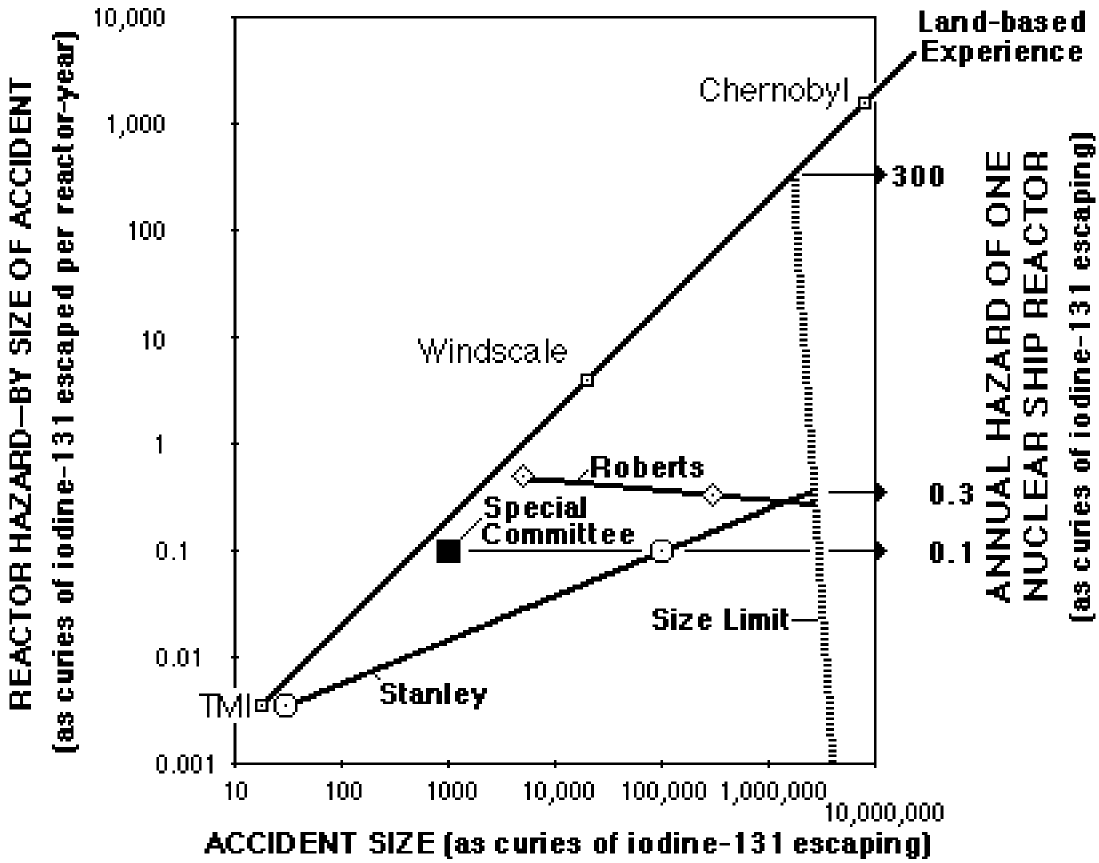
Event	Curies of Iodine-131 Escaped
US nuclear powered warship operation	**<<0.00002**
Three Mile Island (TMI) accident (1979)	**17**
Windscale accident (1957)	**20,000**
Chernobyl accident (1986)	**7,000,000**

Iodine is concentrated in the human thyroid gland, and radioactive iodine-131 causes cancer and other life-threatening thyroid disorders. Any nuclear hazard involving a release of radioactivity equivalent to much less than one curie of iodine-131 might be called "operational". Any annual reactor hazard involving a release of radioactivity corresponding to a few curies of iodine-131 might be called a "TMI-sized" hazard. Any annual reactor hazard involving the equivalent of a few thousand curies of iodine-131 might be called a "Windscale-sized" hazard. And any annual reactor hazard involving the equivalent of a few million curies of iodine-131 would be a "Chernobyl-sized" hazard.

With these hazards in mind, we would like to look at a long and complete record of accidents involving nuclear-powered-ships-in-foreign-ports to estimate the hazards of visits of nuclear vessels to New Zealand ports. But, as mentioned in the Introduction, problems related to secrecy preclude reliance on this directly-applicable accident record. Thus, we turn to a second-best record, that of major nuclear accidents at land-based reactors. Over 5,000 *reactor-years* of experience have been logged with large land-based nuclear reactors over the last 50 years (with an average of over 100 reactors operating). Therefore, one-of-a-kind accidents have a likelihood of about one chance in 5,000 per year of reactor operation.

From our everyday experience, we might expect hundreds of large TMI-sized nuclear accidents for each huge Windscale-sized accident and hundreds of Windscale-sized accidents for each catastrophic Chernobyl-sized accident. But this is not the case. The record of releases of radioactivity from "major" accidents is that there is one recorded accident of a few curies of iodine-131, one of a few thousand curies, and one of a few million curies. This preponderance of disasters is outside our everyday experience and warns us to be cautious of nuclear reactors. This point is highlighted by plotting the nuclear hazards represented by the TMI, Windscale, and Chernobyl accidents against the size of these accidents. That is, the releases of iodine-131 (respectively, 17, 20,000, and 7,000,000 curies) are multiplied by 1/5,000 (per reactor year) and plotted against the size of the accident, in Fig.1, here. These three historic accidents are connected by the straight line labelled "Land-based Experience".

Fig.1. Hazards of Nuclear Reactors in relation to size of accident.


Land-based
Experience
Chernobyl
Windscale
Roberts
Special
Committee
Size Limit
Stanley
TMI
300
0.3
0.1
REACTOR HAZARD—BY SIZE OF ACCIDENT
(as curies of iodine-131 escaped per reactor-year)
10,000
1,000
100
10
1
0.1
0.01
0.001
10
100
1000
10,000
100,000
1,000,000
10,000,000
ACCIDENT SIZE (as curies of iodine-131 escaping)
ANNUAL HAZARD OF ONE
NUCLEAR SHIP REACTOR
(as curies of iodine-131 escaping)

From our "Land-based Experience" with nuclear reactors, we see on the left side of Fig.1 that TMI-sized accidents contribute only 0.003 curies of iodine-131 hazard for each year of reactor operation while Windscale-sized accidents contribute 3 curies of iodine-131 hazard But Chernobyl-sized accidents contribute 2000 curies of hazard.That is, almost all of the nuclear hazard of land-based reactors is contributed by huge, Chernobyl-sized accidents.

From the "Land-based Experience" line, we notice that the hazard from nuclear power plants is almost entirely attributable to accidents that would release much of the radioactivity present in the affected reactor. 5,000 reactor-years of experience tells us that the hazard from a land-based power reactor is equivalent to the escape of a few thousand curies of iodine-131 per year, and this is hazard is due almost entirely to accidents which are almost unimaginably large.

Instead of enumerating nuclear hazards as it had anticipated at the beginning, the Special Committee stopped with calculations of frequencies of events, and each of these three major nuclear accidents was considered to have less than one occurrence in 100 million years of reactor operation [arrows at bottom of Fig.5.2]. As the Special Committee describes a frequency of one occurrence in one million years as representing "one event in the time since the beginning of the Pleistocene Epoch in geology and mankind's first beginnings", we see that the accidents at TMI, Windscale, and Chernobyl simply *would not have happened* according to the approach used by the Special Committee. Here we face a conceptual problem in which experience is discarded by the Special Committee in favor of optimistic predictions. In the format of Chapter 13 of the report, "Myths and catch-cries", this problem is here described in terms of a myth appended to the Special Committee's list of 16:

MYTH SEVENTEEN : In this case, experience doesn't apply

Experience which does not accord with optimistic predictions is discarded. The justification is that the accident happened under conditions which differ from the present situation. Because each situation is unique, any experience which conflicts with a prediction is discarded.

According to this incorrect reasoning, the historic record of major nuclear accidents does not have to be considered for one or more of the following reasons: because the accident happened to the Russians or to someone else; because old technology or out-of-date procedures or poorly trained personnel were involved; because the specific difficulty that led to the unique accident was different than the present situation; because the problem has now been corrected; or because the accident was an incredible one-of-a-kind fluke.

Any particular disaster can be discounted as extraordinarily unlikely. But a quantitative assessment of risks shows that there does exist an actual hazard, and out of this hazard, unique "impossible" accidents do arise. Thus, the Chernobyl-sized accident just happened to occur in 1986 in Russia rather than, say, at N-Reactor in Hanford, Washington USA--the American military reactor that the Chernobyl reactors were patterned after. But from the standpoint of risk assessment, we understand that the risk is being taken at each operating reactor, and the *first* Chernobyl-sized loss just happened to occur at Chernobyl in 1986 under the particular circumstances prevailing there and then. Other reactor operators and their neighbors may breathe a cautious sign of relief that they have been lucky, so far.

In ignoring the hazard of "any accident involving a rupture in containment accompanied by a major release of radioactivity" [p.117]", the Special Committee has missed the very heart of the hazard posed by shipboard nuclear reactors. In its pronouncement that nuclear ships are "safe" [p.173], the Special Committee has fallen prey to optimistic denial of our experience with nuclear disasters.

Although shipboard nuclear reactors are more vulnerable to several risks--for example, collision, grounding, and sabotage--than their land-based siblings, shipboard power reactors are only a few percent as large as their land-based siblings. Thus, the entire inventory of iodine-131 in a shipboard reactor is only 2,000,000 to 4,000,000 curies [pp.59-60]. This places an upper "Size Limit" on the catastrophe that can result from an accident involving a nuclear powered ship, as sketched in Fig.1. Thus we see that the likelihood of some accident releasing a particular fraction of the radioactivity in a shipboard reactor is generally greater than with a land-based reactor, but the impact is lesser because the shipboard reactor is smaller and contains less radioactivity. We may reasonably assume that the hazard--the product of likelihood and impact--is similar for the two different situations. Thus we apply directly our experience with major land-based nuclear reactor accidents. The iodine-131 hazard of a shipboard nuclear reactor in a New Zealand port would then be represented by the "Land-based Experience" line in Fig.1, up to the "Size Limit" line, and it would follow the "Size Limit" line back down to minimal risk of a complete loss of the reactor inventory.

We see that the nuclear hazard posed by a shipboard reactor accrues from accidents close to the intersection of the "Land-based Experience" line and the "Size Limit" line, where much of the shipboard reactor inventory escapes. This hazard is equivalent to the escape of 300 curies of iodine-131 per year. Thus the nuclear hazard posed by a single reactor on a ship berthed in a New Zealand harbor would be the impact of the iodine-131 equivalent of a dozen TMI-sized accidents per year. This hazard is due the the chance of a rare accident, almost as large as the Chernobyl accident. The cause of such an occurrence might be imagined in terms either of a large fire resulting in a multiple outage of onboard electric power controlling the reactor, of a severe collision with another ship, or of a well-executed terrorist attack.

The Special Committee solicited expert opinions on the risks of accidents involving nuclear powered vessels. P.B. Roberts of NZ DSIR submitted opinions, including estimates of the risks of a contained ("AEC 500") nuclear accident and a large uncontained accident as well as relevant comments on New Zealand's clean-green image. Roberts assessed a reference risk of one accidental escape of 5000 curies of iodine-131 in 10,000 years as "reasonable" [P.B. Roberts, "Core Melt Accidents in Marine Nuclear Reactors: Comments on Their Frequency and Comparative Risk," DSIRPS-C-72, (1992) 13]. This is the left point on the "Roberts" line in Fig.1.

The point labelled "Special Committee" in Fig.1 is the 1000-curie reference accident used in the report. It seems to be an early submission by Roberts [see P.B. Roberts, "Some Perspectives on the Consequences of Reactor Accidents," NZ DSIR (1992) 5].

The Special Committee also cited statements by Mr Stanley, the UK Secretary of State for Defense. Stanley opined one release of 1,000 curies of iodine-131 to containment in 10,000 years of UK naval submarine reactor operation. The Special Committee opined that the fraction of radioactivity that might escape to the atmosphere from such an accidental release to secondary containment should be less than 1%, but to be cautious,10% was used for calculations [pp.120-121]. As the goal of the present evaluation is to be realistic, we here assume that 3% of radioactivity that is released from the reactor to the containment vessel subsequently escapes to the atmosphere. This fraction is used to position the left point of the "Stanley" line in Fig.1. Stanley also offered an opinion regarding a larger accident: one uncontained release of 100,000 curies of iodine-131 in a million years of submarine reactor operation. This is the righthand point on the "Stanley" line. That is, Stanley's uncontained nuclear accident is ascribed 1% the likelihood of his contained accident.

The smaller nuclear accidents assessed by Stanley and Roberts and the reference accident used by the Special Committee are *contained* accidents, meaning that the reactor containment has not been ruptured. All three predictions lie so close to the "Land-based Experience" line that there is no real disagreement between experience and prediction. The difference of opinion--the focal issue nuclear hazard--is the likelihood of Windscale-sized or Chernobyl-sized accidents in which the outer bounds of reactor protection are breached.

Figure 1 shows that the likelihood that Stanley and Roberts assign to their larger nuclear accidents is crucial to the outcome of their estimates of hazard posed by a nuclear reactor. So we scrutinize these likelihoods of larger accidents: both Stanley and Roberts consider the likelihood of their containment-rupture accidents to be 1% of their smaller accidents [p.62 and Roberts's "Core Melt...", p.13]. We see in Fig.1 that the opinion of 1% likelihood of the larger containment-rupture accidents <u>conflicts with experience which tells us that the larger accidents are about as likely as the smaller accidents</u>. Realizing that the entire question of the hazard posed by shipboard reactors hinges on this question of whether--and if so, how much?--the likelihood of uncontained nuclear accidents is less than the likelihood of contained nuclear accidents, we inquire after the basis for this crucial "1% opinion".

The question of the validity of the "1% opinion" was addressed by the Australian Senate Standing Committee on Foreign Affairs, Defence and Trade in its 1989 report ["Visits to Australia by Nuclear Powered or Armed Vessels: contingency planning for the accidental release of ionizing radiation," Government Publishing Service, Canberra]. The Australian investigators began their consideration with the argument that,

> **As a matter of logic an uncontained reactor core accident has to be considered less likely than a contained one** [Australian report, p.183]**.**

The alleged logic of the argument is, "If the core accident is independent of the containment breach then two independent events have to occur together to produce an uncontained core accident. It is more plausible that the accident and the breach are related. But even so the occurrence of the two events together is less likely [Australian report, p.184]." This allegation neglects the fact that a successful containment of a core accident is as much an "event" as a rupture of containment is an event. The probability of a non-breach (given a core-melt) is merely one minus the probability of a breach. The alleged logic is also refuted by the following statement which accords with the accident history of "Land-based Experience" in Fig.1:

Core-melting accidents are often devastating enough to breach containment.

In the particular situation of shipboard reactors, we see that reactor accidents initiated by certain collisions or by terrorist attacks might <u>*begin* with breaches of nuclear containment</u>.

After carefully reviewing the question of the "1% opinion", the Australian investigators concluded almost exactly where they had begun:

> **For reasons discussed earlier in this chapter, an uncontained accident is logically less likely than a contained accident. Again the Committee is <u>not in a position to quantify</u> how much less likely** [emphasis added, Australian report, p.205].

That is, the Australian investigators sought to quantify the likelihood of a rupture of nuclear containment, but they were unable. In other words, the right points on the "Roberts" and "Stanley" lines in Fig.1 represent the considered opinion of nuclear experts. But no particular technical basis can be ascribed to this opinion. In comparison, the Special Committee merely discounted any containment-rupture accident as too unlikely to warrant further consideration.

If we were to accept the opinions of nuclear experts without asking for a technical basis, the Special Committee might just as well have asked Stanley and Roberts if they thought that nuclear ship visits to New Zealand would be safe. Then the Special Committee could have published their affirmative opinions as its results and saved almost $400,000 while, at the same time, leaving the basis of the evaluation clearer to the public. But we have by now developed a certain caution with regard to optimistic predictions that humanity has finally overcome its somewhat disaster-prone history. Thus we see that containment cannot be confidently credited with any *particular* reduction of the hazard of a full-scale nuclear catastrophe. We have no good reason for accepting unsubstantiated expert opinion and abandoning the "Land-based Experience" line as our best estimator of real and present hazard posed by nuclear reactors. Therefore, we here accept the entire "Land-based Experience" line up to the "Size Limit" line as a realistic prediction of the hazard posed by a nuclear ship reactor in a New Zealand port. The nuclear hazard posed by a ship is thereby limited by the "Size Limit" of the reactor to the equivalent of 300 curies of iodine-131 per year, as marked on the right side of Fig.1. This hazard is due to a million-curie accident having a likelihood of about one chance in 5000 years of reactor operation.

The human consequences of an annual nuclear hazard equivalent to 300 curies of iodine-131 must now be considered. Roberts analyzed factors specific to New Zealand ports and estimated up to 25 extra cancer fatalities for a 5000-curie release of iodine-131. From this estimate (which is a tenth the consequence credited to the TMI accident [p.53]), a nuclear hazard of 300 curies would correspond to one extra (delayed) cancer fatality annually. Thus, <u>the presence of a nuclear ship in a New Zealand port is here assessed a nuclear impact (hazard) of one extra cancer death per year.</u>

Both the title of the Special Committee's report, "The Safety of Nuclear Powered Ships", and its stated objective--to estimate the hazard due to "the presence of a nuclear powered ship"--suggest that the appropriate basis for nuclear hazard assessment is *per year of the presence of a reactor*. This supposes that nuclear ships are coming and going or are often berthed in a New Zealand port. Then it seems reasonably to evaluate the hazard on a *reactor-year* basis. Furthermore, this is the usual way of assessing nuclear hazards and allows direct reference to usual societal risk thresholds to determine acceptability of a hazard.

On the other hand, the Terms of Reference for the report specify that the Special Committee's assessment is to concern

port entry

ship visits

ship operations

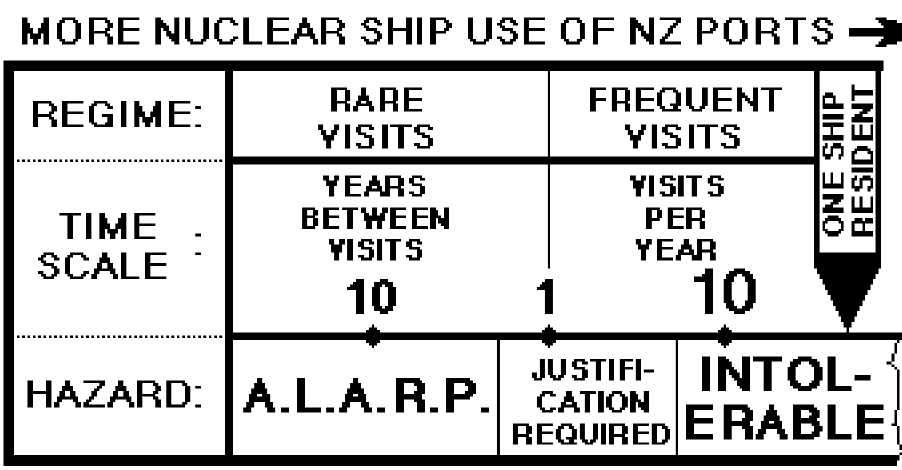
by nuclear powered vessels [pp.1-2]. Historically, the issue of public concern in New Zealand has been visits by US Navy nuclear warships. Thus, we might consider that the proper basis for evaluation of nuclear hazard is one "visit" by a nuclear ship. This "per visit" basis for hazard assessment also makes sense from the standpoint that a ship is usually the carrier of something of value--commerical cargo, military capability, passengers, personnel for rest and relaxation, diplomacy, etc.--and the value of shipping accrues largely by-the-visit. Therefore, it makes sense to consider the nuclear hazard of nuclear powered ships on a per-visit basis as well as on an annual basis.

The Special Committee reduces its assessed hazard by a "safety factor [sic]" of "50 [sic]" to account for a few ship visits rather than continued presence of nuclear ships [p.63]. The average length of each visit of a nuclear ship is taken as 6 days. Hence, the nuclear hazard per visit is only (6 days per visit)/(365 days per year) = 1/60 of the nuclear hazard per year. (The Special Committee incorrectly supposed that it allowed for four visits per year.) Thus, the nuclear hazard per visit is equivalent to (300/60=) 5 curies of iodine-131 escaping or (1/60=) 0.02 delayed cancer death per ship visit.

We now consider the social acceptability of individual visits and more or less continuous berthing of nuclear ships in New Zealand ports. Based on the these estimated hazards and on the threshold assessment formulated by the Royal Society, as presented in Fig.9.4 of the report, this is summarized in Fig.2, on the next page.

Looking ahead to Fig.2, we see that even for rare visits by nuclear ships, occurring only once in several years, all reasonable steps to reduce risk are required to make the hazard of each visit "As Low As Reasonably Practicable" (A.L.A.R.P.). With visits rare enough to fall within the A.L.A.R.P. region, these visits are not frequent enough to be *routine*. This means each and every visit would require a special evaluation and special steps to assure that the hazard of the visit was minimized. From Fig.2, we further see that routine visits--more frequent than one visit per year--by nuclear ships introduce so much nuclear hazard that special justifications are required for their hazards to be tolerated. That is, the more frequent the visits by nuclear ships, the LESS routine the visits can be allowed to be because of the increase in hazard posed by the repetition of the risky visits.

Fig.2. Hazard Regimes for Nuclear Ship Use of New Zealand Ports.



Moving toward the right side of Fig.2, we see that more than a few nuclear ship visits per year would be considered so hazardous as to be "intolerable" in peacetime. The continued presence--"one ship resident" in the figure--of any nuclear ship in a New Zealand port is seen to be "intolerable", having a hazard that is 10 times the maximum that might be somehow justifiable. From this technical evaluation of nuclear hazard, we see that any entry of a nuclear powered ship into a New Zealand port is "risky".

This evaluation disagrees with the Special Committee's finding that nuclear ship visits to New Zealand would be "safe" [p.173]. The disagreement arises from the Special Committee's restriction of its assessment to naval vessels of the United States and the

United Kingdom and its credence of their official assurances that these ships are safe. Specifically, the differences in this evaluation from the findings of the Special Committee result from the following multiplicative differences which are the ratios of the values used in this evaluation divided by the values used by the Special Committee:

Table 2. Comparison of Multiplying Factors Affecting Nuclear Hazard.

Experience with little nuclear accidents vs. huge nuclear disasters	**500**
Roberts final vs. initial prediction of little reference accident	**5**
Experience vs. predictions with little accidents	**2**
Omission of four visits per year for annual estimate	**4**
This evaluation / Special Committee assessment	**20,000**

In short, the Special Committee under-estimated the hazard of nuclear ships by a factor of 20,000. This difference resulted in the Special Committee's opinion that nuclear ships pose "negligible" nuclear hazard; whereas, experience shows the nuclear hazard posed by nuclear powered vessels to be close to "intolerable".

CONCLUSIONS

1 **Based on experience with land-based reactors, the hazard posed by nuclear powered ships is due almost entirely to rare catastrophes--almost Chernobyl-sized nuclear accidents involving the escape of much of the radioactivity in the reactor.**

2 **From land-based experience with nuclear reactors, the hazard of the presence of a nuclear ship in a New Zealand port is estimated to be equivalent to the escape of 300 curies of iodine-131 per year. This corresponds to about one cancer death per year. This impact is generally considered to be socially "intolerable" by a factor of ten. Therefore, based on technical considerations of risk assessment, the long-term presence of nuclear powered ships in New Zealand ports is unacceptable.**

3 **Even a single peacetime visit by a nuclear powered ship poses enough risk of nuclear accident to require special considerations to assure that the risk is justified. The risk posed by nuclear powered ships is 20,000 times greater than assessed by the Special Committee.**

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