ATTACHMENT 1

May 23, 1989

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Vermont Yankee Nuclear Power Corporation (Vermont Yankee Nuclear Power Station)	Docket No. 50-271-OLA (Spent Fuel Pool)

Testimony of Gordon Thompson

I. Identification of Witness

Q. Please state your name, position, and business address.

A. My name is Dr. Gordon Thompson. I am Executive Director of the Institute for Resource and Security Studies in Cambridge, Massachusetts.

Q. Briefly summarize your experience and professional qualifications.

A. I received a Ph.D. in applied mathematics from Oxford University in 1973. Since then I have worked as a consulting scientist on a variety of energy, environment, and international security issues. My experience has included technical analysis and presentation of expert testimony on issues related to the safety of nuclear power facilities.

In 1977, I presented testimony before the Windscale Public Inquiry in Britain, addressing safety aspects of nuclear fuel reprocessing, including spent fuel storage. During 1978 and 1979, I participated in an international scientific review of the proposed Gorleben nuclear fuel center in West Germany, a review sponsored by the government of Lower Saxony. As a result of my participation, the Lower Saxony government refused to license high-density pool storage of spent fuel at Gorleben.

Between 1982 and 1984, I coordinated an investigation of safety issues relevant to the proposed nuclear plant at Sizewell, England. The investigation was sponsored by a group of local governments in Britain, under the aegis of the Town and Country Planning Association. This investigation formed the basis for testimony before the Sizewell Public Inquiry by myself and two other witnesses.

From 1980 to 1985, first as a staff scientist and later as a consultant, I was associated with the Union of Concerned Scientists (UCS), at their head office in Cambridge, MA. On behalf of UCS, I presented testimony in 1983 before a licensing board of the US Nuclear Regulatory Commission (NRC), concerning the merits of a system of filtered venting at the Indian Point nuclear plants. Also, I undertook an extensive review of NRC research on the reactor accident "source term" issue, and was co-author of a major report published by UCS on this subject in 1986.

Since early 1987, I have been one of the principal investigators for an emergency planning study based at Clark University, Worcester, MA. The object of the study was to develop a model emergency plan for the Three Mile Island nuclear plant. Within this effort, one of my primary responsibilities has been to address the characteristics of severe reactor accidents.

My other research interests include: the efficient use of energy; the supply of energy from renewable sources; radioactive waste management; the restraint of nuclear weapons proliferation; and nuclear and conventional arms control. I have written and made public presentations in each of these areas.

At present, I am Executive Director of the Institute for Resource and Security Studies, Cambridge, MA. This organization is devoted to research and public education on the efficient use of natural resources, protection of the environment, and the furtherance of international peace and security.

A detailed resume is included in the attachments to this testimony.

II. Overview of Testimony

Q. To what contentions does your testimony refer?

A. The testimony refers to environmental contention (3).

Q. Please summarize your testimony.

A. My primary purpose in this testimony is to show that there is a significant danger associated with high-density pool storage of spent fuel at the Vermont Yankee plant, and that much safer alternatives exist. Specifically, I show that a partial or total loss of water from the pool can be expected to initiate an exothermic steam-zirconium or air-zirconium reaction which could lead to a release to the environment of a substantial amount of the long-lived radioactivity contained in the spent fuel. Release of the cesium alone could significantly contaminate 19,000 square miles of land. Moreover, I show that this phenomenon can be totally avoided by use of low-density storage within the pool, with placement of the remainder of the spent fuel into an alternative form of on-site storage, such as dry cask storage.

In support of these arguments, I show that there has been no theoretical analysis or empirical investigation to examine the outcome of partial or total water loss under conditions representative of the proposed high-density pool storage at Vermont Yankee. In the absence of such analysis or investigation, I show that an exothermic steam-zirconium or air-zirconium reaction must be assumed over a wide range of parameters in the event of partial or total water loss.

I further show that this problem can be separated from questions about the appropriate physical form or mode of operation of the Vermont Yankee plant itself. Specifically, I show that the potential for a substantial release of radioactivity from spent fuel through the zirconium reaction mechanism can be eliminated under all conditions of practical importance, including severe earthquakes and core melt accidents at the Vermont Yankee plant.

Finally, I show that alternative forms of on-site storage, such as dry cask storage, are available at a reasonable cost. I show that investment in these alternatives has not been subjected to a credible cost-benefit analysis. Moreover, I argue that this form of analysis is inappropriate for high-density pool storage because the risk can be totally avoided at a relatively moderate expense.

III. Experience of Witness in This Area

Q. Please summarize your experience in regard to the danger associated with high-density pool storage of spent fuel.

A. I first became aware of the potential for danger of this kind during the 1977 Windscale Public Inquiry in Britain, at which I conducted cross-examination and presented testimony. During 1978 and 1979 I studied the matter further while participating in an international scientific review of the proposed Gorleben nuclear fuel center in West Germany.

As part of my contribution to this review, I studied the implications of a loss of cooling of the proposed spent fuel pools. My report (Thompson, 1979) showed that exposure of fuel as a result of evaporation of pool water would lead, over a wide range of conditions, to an exothermic steam-zirconium reaction accompanied by the generation of hydrogen and the release of radioactive material from the fuel. I also drew attention to the possibility of water loss through drainage.

This report was debated at a public hearing in March 1979 staged by the Lower Saxony government. As a result of my findings and the accompanying off-site consequence analysis performed by Jan Beyea (Beyea, 1979) the Lower Saxony government included the following statement in its declaration of 16 May 1979 concerning the Gorleben proposal:

"This radioactive potential is so immense that it must not be possible to release it by an incident.

The State Government is not willing to license the concept of DWK in its present form. They insist that the entry store for spent fuel elements is made inherently safe such that the cooling does not depend on the functioning of technical equipment or on human reliability."

Ultimately, the proposed nuclear fuel center was not built at Gorleben. However, an away-from-reactor spent fuel storage facility has been located there. In conformance with the above-stated Lower Saxony government position, this facility employs dry casks rather than high-density pools.

Subsequent to my involvement with the Gorleben review, I became aware of a related report prepared at Sandia Laboratories (Benjamin et al, 1979). I noted that this report focuses upon complete drainage of water from a spent fuel pool, which the report's introduction describes as "the most severe type of spent fuel storage accident that has been hypothesized." However, the body of the report confirms my own prior conclusion that partial loss of water is a more likely initiator of exothermic zirconium reaction than is total drainage. In the case of partial water loss, the concern is that a steam-zirconium reaction will occur, while in the case of total water loss the concern is that an air-zirconium reaction will occur.

In May 1980, I submitted testimony to the Minnesota Energy Agency (Thompson, 1980). This testimony, which was heard in Minneapolis in June 1980, concerned the danger of a proposed increase in the density of racking of spent fuel in the pool serving the Prairie Island reactors. Between that occasion and early May 1989, I have reviewed this area briefly while preparing documents on wider issues of nuclear power safety. While preparing the present testimony, I have conducted a review of slightly greater depth.

IV. Proposed Storage of Spent Fuel at Vermont Yankee

Q. Please summarize your understanding of the proposed spent fuel storage arrangement at Vermont Yankee.

A. Exhibit 1 shows a typical BWR fuel assembly, which I assume to be similar to those at Vermont Yankee. I also assume that the layout of the Vermont Yankee spent fuel pool will be similar to the cross-sectional view shown in Exhibit 2.

In the earlier years of its operation, Vermont Yankee presumably used a low-density type of spent fuel rack. Exhibit 3 shows one BWR rack design of this kind, and it will be noted that the space for each fuel assembly has an opening along its length. This feature, combined with the fact that the racks were apparently spaced five or six inches apart, would allow relatively free convective circulation of air or steam following partial or total water loss. The resultant cooling would reduce, to zero under many conditions, the probability of an exothermic zirconium reaction.

Another type of early BWR rack is shown in cross-section as item (f) of Exhibit 4. This form of rack, which may have been used at Vermont Yankee, may inhibit convective circulation of air or steam to a greater extent than the design shown in Exhibit 3.

For comparison, Exhibit 5 shows a low-density open-frame PWR spent fuel rack. It is clear that this design would allow vigorous convective circulation of air or steam.

Under the proposed arrangement, Vermont Yankee's spent fuel pool will apparently be filled as shown in Exhibit 6, with a vertical cross-section as shown in Exhibit 7. It will be noted that the racks will be tightly packed, with a typical spacing of two inches between racks and a similar two-inch spacing around much of the pool's perimeter.

I assume that the new racks will be similar to the design shown in Exhibit 8. This design, especially when combined with a limited spacing between racks, will effectively suppress convective circulation of air or steam.

The burden of long-lived radioactivity in the Vermont Yankee pool can be illustrated by its cesium content. According to Attachment A of the licensee's 1 July 1987 responses to NECNP interrogatories, the pool will contain 20.2 million Curies of cesium in 1990 and 27.4 million Curies of cesium in 2004. The respective contributions of cesium-134 (half-life of two years) and cesium-137 (half-life of thirty years) are not provided. However, it is clear that the pool's burden of cesium-137 will exceed 20 million Curies during the coming decade. For comparison, the core of Vermont Yankee will contain about 2.3 million Curies of cesium-137 and 3.7 million Curies of cesium-134 at shut-down.

V. State of Knowledge Regarding the Potential for Exothermic Zirconium Reactions at Vermont Yankee

Q. Please summarize your understanding of the state of technical knowledge regarding the potential for exothermic steam-zirconium or air-zirconium reactions following partial or total loss of water from the Vermont Yankee spent fuel pool.

A. First, it appears that there has been no theoretical or empirical investigation of this potential in the specific case of Vermont Yankee. Moreover, I have not identified any such investigation to address this potential for high-density storage of BWR fuel in a configuration similar to that proposed for Vermont Yankee.

A body of literature and a history of litigation have grown up in the United States in connection with this potential. However, the underlying state of knowledge has developed marginally since 1979. In that year, the aforementioned Sandia Laboratories report (Benjamin et al, 1979) was published, focussing upon total loss of water. Yet, the danger of partial water loss was at least recognized. The Sandia report stated (at pages 73 and 76):

"Many spent fuel holder designs provide only a single inlet hole for convective flow through each fuel element, located in the baseplate or near the bottom of the holder. If there is a complete pool drainage, the air must circulate down and under the fuel elements before passing through the baseplate inlet hole into the fuel assembly. An incomplete drainage could block this flow and reduce the effectiveness of natural convective cooling. Open frame configurations are, of course, exempt from this possibility because the flow does not have to pass through an inlet hole in order to gain proximity to the fuel element.

A detailed analysis of spent fuel heatup in the event of an incomplete drainage has not been undertaken. However, an approximate analysis has been performed to estimate the amount of aggravation that might occur if the water ceased to drain after exposing all but the bottom portion of the fuel elements." and

"The approximate method used for bracketing the thermal radiation downward to the water and upward to the building is not considered to be precise enough to allow prediction of the minimum allowable decay time in the event of an incomplete drainage. This problem could be approached by formulating a detailed thermal radiation model to calculate shape factors and include the shadowing of radiating surfaces by fuel rods and tie plates. By incorporating this radiation capability into the overall heat transfer models described in Sections 3.3 and 3.4, a credible prediction of the minimum allowable decay time could be obtained. No attempt to do this, however, has been made."

Exhibit 9 shows some of the results of the 1979 Sandia study, including the case of partial water loss (the "blocked inlets" case). Sandia's approximate analysis indicates that cladding temperature would rise into the range where exothermic and auto-catalytic zirconium reaction could occur, thus confirming my finding for the proposed Gorleben pools (Thompson, 1979). Curiously, however, the Sandia analysts gave no attention to the potential for a steam-zirconium reaction. This omission has persisted in more recent literature. Indeed, the entire problem of partial water loss appears not to have received attention in subsequent literature.

Where high-density racking of the type illustrated by Exhibits 6 and 8 is employed, a partial water loss allows only two significant modes of heat transfer from exposed fuel cladding far from the upper end of the assembly. The first mode is radiation. As indicated in the above quotation from the Sandia report, accurate calculation of heat transfer by radiation would demand a specially written model. However, scoping analysis (Thompson, 1979) suggests that radiative heat transfer would be inhibited in this situation. The second mode is forced convective cooling by steam generated from residual water in the pool. An important feature of this mode is that, if no other heat transfer modes are significant, cladding temperature is independent of the decay heat output (and, hence, the age after discharge) of the spent fuel assembly (Thompson, 1979).

These findings were brought to the attention of the US nuclear industry by my Prairie Island testimony (Thompson, 1980). I am not aware of any technical rebuttal of these findings.

After the 1979 Sandia report, the next significant technical document generated under NRC or industry sponsorship was an unfinished study on the potential for propagation of an air-zirconium reaction in a totally drained pool (Pisano et al, 1984). Although this study was not completed, it is frequently cited in subsequent literature as a purportedly authoritative source. According to one of those later reports (Sailor et al, 1987), the study was not finished because "the project ran out of funds before the report was published."

Pisano et al's unfinished study, which was specific to PWR fuel, shows that (Pisano et al, 1984, Executive Summary) "a self-sustaining reaction can be propagated from one region of a pool to another." However, the study also shows that considerable uncertainty surrounds the relevant phenomena.

More recently, a group at Brookhaven National Laboratory has published a report (Sailor et al, 1987) which draws upon the 1979 study of Benjamin et al and the 1984 document of Pisano et al. In addition, the Brookhaven group performed some analogous calculations of their own. As in the Sandia study (Benjamin et al, 1979), high-density racking of BWR spent fuel in a configuration typical of the proposed Vermont Yankee arrangement was not examined. Instead, "cylindrical" racks were assumed. No analysis of partial water loss was made.

The Brookhaven study concluded (Sailor et al, 1987, page 107) that the probability of a self-sustaining air-zirconium reaction following total water loss is 10 percent to 40 percent for BWRs. Due to the limited range of conditions examined, this statement must understate the potential for a zirconium reaction following either partial or total water loss at Vermont Yankee. However, one useful recommendation is made by the Brookhaven group as follows (Sailor et al, 1987, page 107):

"It is also recommended that a test program be initiated to confirm the capability of natural air convection cooling capability for high density storage racks. Such tests could be performed with old low power spent fuel (2 to 4 kW/MTU) and minimal instrumentation (such as thermocouples placed near the top of the fuel bundle)."

An indication of the potential for air-zirconium reaction following total loss of water from a BWR spent fuel pool with low-density racking is provided by Exhibit 10. The types of rack shown are "cylindrical baskets," equivalent to item (f) in Exhibit 4, and "directional baskets," equivalent to item (e) in Exhibit 4. In both cases, a large (typically sixteen-inch) gap is assumed to exist around the perimeter of the pool.

Exhibit 10 shows that, under the assumed conditions, an air-zirconium reaction may or may not be initiated, depending on the rack design and the removal or retention of the fuel channel. This analysis is not applicable to the case of partial water loss, but it suggests that a low-density storage configuration can be found such that neither an air-zirconium nor a steam- zirconium reaction would be initiated under any conditions. If open rack designs such as that shown in Exhibit 5 are considered, and removal of the fuel channel is also considered, there seems no reason to doubt that autocatalytic zirconium reactions can be avoided entirely.

VI. Probability and Consequences of a Zirconium Reaction in the Vermont Yankee Pool

Q. Please state your conclusions about the probability and off-site consequences of an autocatalytic steam-zirconium or air-zirconium reaction following partial or total loss of water from the Vermont Yankee spent fuel pool under the proposed racking configuration.

A. One mechanism for water loss is earthquake-induced failure of the pool structure. The potential for such failure at Vermont Yankee has been examined by a group at the Lawrence Livermore National Laboratory (Prassinos et al, 1989). This group estimated the mean annual probability of failure to be 6.7X10-6 (one failure per 150,000 years), with an upper 95 percent confidence limit of 2.4X10-5 (one failure per 42,000 years).

Exhibits 11 and 12 illustrate the Livermore group's analysis. It will be seen from Exhibit 11 that the "high confidence of low probability of failure" capacity of the pool structure (5 percent chance of failure with 95 percent confidence) was estimated to be 0.5 g. By comparison, the Safe Shutdown Earthquake at Vermont Yankee is 0.14 g. Exhibit 12 shows the estimate median probability of earthquake loading exceeding 0.5 g to be about 7X10-6 per year.

The same Livermore report also examined the effect of a six-inch drop of a shipping cask on the wall of the Vermont Yankee pool. The report concluded (Prassinos et al, 1989, page 7-6):

"The results of the idealized analyses indicate that pool walls similar to those of both the Vermont Yankee and Robinson plants would suffer severe damage as a result of the worst-case cask drops. The indicated regions of potential reinforcing steel yield are quite extensive. While the integrity of the pool liner is difficult to predict, it seems likely that the liners could be severely damaged (tearing, cracking of welds, and pull-out of anchors). Based on these results, loss of pool water certainly cannot be ruled out."

The probability of a cask drop will be dependent on future scheduling of discharge of spent fuel from the pool. Also, that probability will be highly uncertain.

Loss of water could also be initiated by a severe reactor accident, in three ways. First, severe reactor accident scenarios can be associated with violent releases of energy through mechanisms such as hydrogen explosion, high-pressure melt ejection or steam explosion. Such violent phenomena could initiate pool leakage. Second, a severe reactor accident could create on-site contamination of sufficient severity that access of personnel was precluded. In that event, water in the pool could evaporate over the days following the accident. Third, an accident occurring during refueling could lead to a draining down of the pool to the top of the fuel assemblies (see Exhibit 2) followed by evaporation of the remaining water. Access of personnel for mitigative actions could be precluded by contamination arising from involvement of the reactor core in the event.

Finally, the pool might lose water as the result of an act of sabotage. The history of sabotage-related events shows this to be a non-trivial consideration (Andrews et al, 1986; Hirsch et al, 1985).

Once an autocatalytic zirconium reaction has been initiated, one must ask: could the reaction spread through the pool? As mentioned above, an unfinished report (Pisano et al, 1984) has indicated that an air-zirconium reaction could spread from one assembly to an adjacent assembly with lower heat loading. The potential for such spreading will be greater in the case of a steam-zirconium reaction initiated by partial water loss, as cladding temperature is less dependent on assembly heat loading in this case. Thus, considering the various uncertainties, one cannot exclude the spreading of the reaction to encompass the entire pool.

The above-mentioned Brookhaven report (Sailor et al, 1987) assumes that cesium would be released from fully affected spent fuel with a release fraction of one. Thus, one must examine the implications of releasing the entire pool inventory of cesium. Other radionuclides would also be released, but cesium serves to illustrate the nature of the offsite consequences.

Exhibit 13 shows the extent of offsite contamination which would be associated with hypothetical releases of cesium-137. The extent of contamination is indicated by the area of land contaminated such that residents would receive a radiation dose of 10 rem in 30 years, or an accident-induced dose rate roughly three times background.

As mentioned above, the inventory of cesium-137 in the Vermont Yankee pool will exceed 20 million Curies over the next decade. From Exhibit 13, it can be seen that a release of this magnitude would, under typical meteorological conditions, contaminate about 50,000 square kilometers, or 19,000 square miles, of land. For comparison, it should be noted that the combined area of Vermont and New Hampshire is also 19,000 square miles.

VII. Alternative Modes of Spent Fuel Storage

Q. Are alternative, safer modes of spent fuel storage available?

A. A variety of dry storage modes exists, and experience has been gained in using some of these modes. I focus here on the dry cask storage mode, which has been the subject of considerable investigation and for which operational experience has been obtained (DOE, 1989). Dry cask storage is not susceptible to the accident scenario described here for high-density pool storage, and it also has operational advantages (NRC, 1989).

An indication of the cost of cask storage is provided by Exhibit 14. This shows costs for cask storage which are comparable with costs for other storage modes.

No detailed analysis of the cost of cask storage has been conducted for Vermont Yankee. However, the licensee's response of 1 December 1988 to NECNP's interrogatories provides an estimate of $19-22 million for cask storage equivalent to the proposed capacity increase of the pool. On the same page, the licensee estimates that $10.5 million will be expended for the proposed pool capacity increase.

Q. Could dry cask storage be used to eliminate the possibility of a release arising from autocatalytic zirconium reaction following loss of water from the pool?

A. As mentioned above, there is every reason to believe that a low-density racking configuration can be devised which will eliminate the possibility of such a reaction under any condition of practical importance, including a severe earthquake or a severe reactor accident.

The surplus spent fuel could be transferred to an onsite dry cask storage facility.

From the US licensing history for dry casks, it might be inferred that a period of several years would be required to design, license and construct an onsite cask storage facility. However, cask technology is relatively simple and there is no fundamental reason for such a delay.

Q. Are there analyses which compare the cost and benefit of safer modes of spent fuel storage at Vermont Yankee?

A. Apparently there are no such analyses specific to Vermont Yankee. However, the NRC has recently sponsored a generic study which purports to compare costs and benefits of accident preventive and mitigative options for spent fuel pools (Jo et al, 1989). Unfortunately, that study is flawed in at least four respects. First, it assumes without justification that the conditional probability of an autocatalytic zirconium reaction, following total water loss from a BWR pool, is 0.25. Second, it does not examine the implications of partial water loss. Third, in addressing the potential advantage of low-density pool storage, it states that lower density can decrease the probability of zirconium reaction, following total water loss, by a factor of five. In fact, as shown, above, the probability can be reduced to zero. Fourth, it does not examine the potential for a pool accident to be initiated by a reactor accident.

Q. Do you regard this type of cost/benefit analysis as appropriate for the spent ,uel situation?

A. Probabilities of accidents are highly uncertain. What is clear in this case is that the danger can be effectively eliminated at a relatively small cost. Moreover, the potential for offsite damage -- such as contamination of 19,000 square miles of land -- is very large. Therefore, the only responsible action is to eliminate the danger.

VIII. Relationship Between the Potentials for Spent Fuel Pool Accidents and Reactor Accidents

Q. Can the potential for a severe spent fuel pool accident be effectively eliminated without significantly affecting the physical form and mode of operation of the Vermont Yankee reactor itself?

A. As indicated above, a spent fuel pool accident could be initiated by a reactor accident. It may be argued that this should not be considered in the licensing process because severe reactor accidents are beyond the "design basis." Yet, extensive NRC studies (e.g., NRC, 1987) have shown that the potential for severe reactor accidents is very real. A licensee study (Yankee Atomic, 1986) has described this potential for Vermont Yankee.

The problem can be resolved by conceptually separating the potentials for reactor accidents and spent fuel pool accidents. The latter potential can be effectively eliminated at moderate cost without requiring any significant changes in the form and mode of operation of the reactor. It would be irresponsible to exclude such an improvement in public safety merely to preserve a legal fiction that severe reactor accidents are "incredible."

IX. Conclusions

Q. Please summarize your conclusions.

A. The Vermont Yankee spent fuel pool will contain, under the proposed arrangement, an inventory of long-lived radioactivity considerably greater than that contained in the reactor core. In the event of partial or total loss of water from the pool, a substantial fraction of this radioactivity could be released to the environment, contaminating a vast area of land.

Loss of water could arise as a result of an earthquake, drop of a shipping cask, a reactor accident, or sabotage. The probability of each such event is highly uncertain.

This danger can be effectively eliminated by adopting a lower density of spent fuel storage in the pool, while extra spent fuel is placed in an onsite dry cask storage facility. The technology for dry cask storage is simple, and could be implemented at relatively moderate cost.

Also, the danger can be effectively eliminated without requiring any significant change in the physical form or mode of operation of the Vermont Yankee reactor itself.

Neither the licensee nor the NRC has conducted an analysis adequate to provide a full understanding of this danger or the means for its elimination.

X. References

Q. Please list the references you have cited in your testimony.

A. In alphabetical order, these references are:

(Andrews et al, 1986) W.B. Andrews and 9 other authors, *A Ranking of Sabotage/Tampering Avoidance Technology Alternatives*, NUREG/CR-4462, January 1986.

(Benjamin et al, 1979) Allan S. Benjamin and 3 other authors, *Spent Fuel Heatup Following Loss of Water During Storage*, NUREG/CR-0649, March 1979.

(Beyea, 1979) Jan Beyea, "The Effects of Releases to the Atmosphere of Radioactivity from Hypothetical Large-Scale Accidents at the Proposed Gorleben Waste Treatment Facility," in Chapter 3, *Report of the Gorleben International Review*, published in the German language by the government of Lower Saxony, FRG, 1979 (English language version of Chapter 3 published by the Political Ecology Research Group, Oxford, UK).

(DOE, 1989) U.S. Department of Energy, *Final Version Dry Cask Storage Study*, DOE/RW-0220, February 1989.

(Hirsch et al, 1985) Daniel Hirsch and 2 other authors, *Nuclear Terrorism: A Growing Threat* (a report to the ACRS), Stevenson Program on Nuclear Policy, University of California at Santa Cruz, 7 May 1985.

(Jo et al, 1989) J.H. Jo and 5 other authors, *Value/Impact Analyses of Accident Preventive and Mitigative Options for Spent Fuel Pools*, NUREG/CR-5281, March 1989.

(NRC, 1989) US Nuclear Regulatory Commission, "Proposed Rule: Storage of Spent Nuclear Fuel in NRC-Approved Storage:Casks at Nuclear Power Reactor Sites," Federal Register, Vol. 54, pp. 19379-19388, 5 May 1989.

(NRC, 1987) U.S. Nuclear Regulatory Commission, *Reactor Risk Reference Document*, NUREG-1150 (Draft), 3 volumes, February 1987.

(NRC, 1978) U.S. Nuclear Regulatory Commission, *Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel*, NUREG-0404 (2 vols.), March 1978.

(Pisano et al, 1984) Nicola A. Pisano and 3 other authors, *The Potential for Propagation of a Self-Sustaining Zirconium Oxidation Following Loss of Water in a Spent Fuel Storage Pool* (Draft), January 1984.

(Prassinos et al, 1989) P.G. Prassinos and 8 other authors, *Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants*, NUREG/CR-5176, January 1989.

(Sailor et al, 1987) V.L. Sailor and 3 other authors, *Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82*, NUREG/CR-4982, July 1987.

(Thompson, 1980) Gordon Thompson, *Testimony to the Minnesota Energy Agency Concerning the Proposed Increase of Spent Fuel Storage Capacity at Prairie Island Nuclear Plant*, 10 May 1980.

(Thompson, 1979) Gordon Thompson, "Loss of Cooling to Spent Fuel Storage (SFS) Ponds," in Chapter 3, *Report of the Gorleben International Review*, published in the German language by the government of Lower Saxony, FRG, 1979 (English language version of Chapter 3 published by the Political Ecology Research Group, Oxford, UK).
(Wheeler, 1988) C.L. Wheeler, Review of the Natural Circulation Effect in the Vermont Yankee Spent-Fuel Pool, NUREG/CR-5048, January 1988.

(Yankee Atomic, 1986) Yankee Atomic Electric Co., *Vermont Yankee Containment Safety Study*, August 1986.

XI. Affirmation and Oath

I declare, under penalty of perjury, that the foregoing testimony is true and correct to the best of my knowledge.

Gordon R. Thompson

Gordon Thompson

Signed and sworn to before me this ~~23rd~~ 24th day of May, 1989.

Lisa J. Majoros

Notary Public

LISA J. MAJOROS, Notary Public
My Commission Expires Feb. 3, 1990

Exhibit 1

Source: NRC, 1978

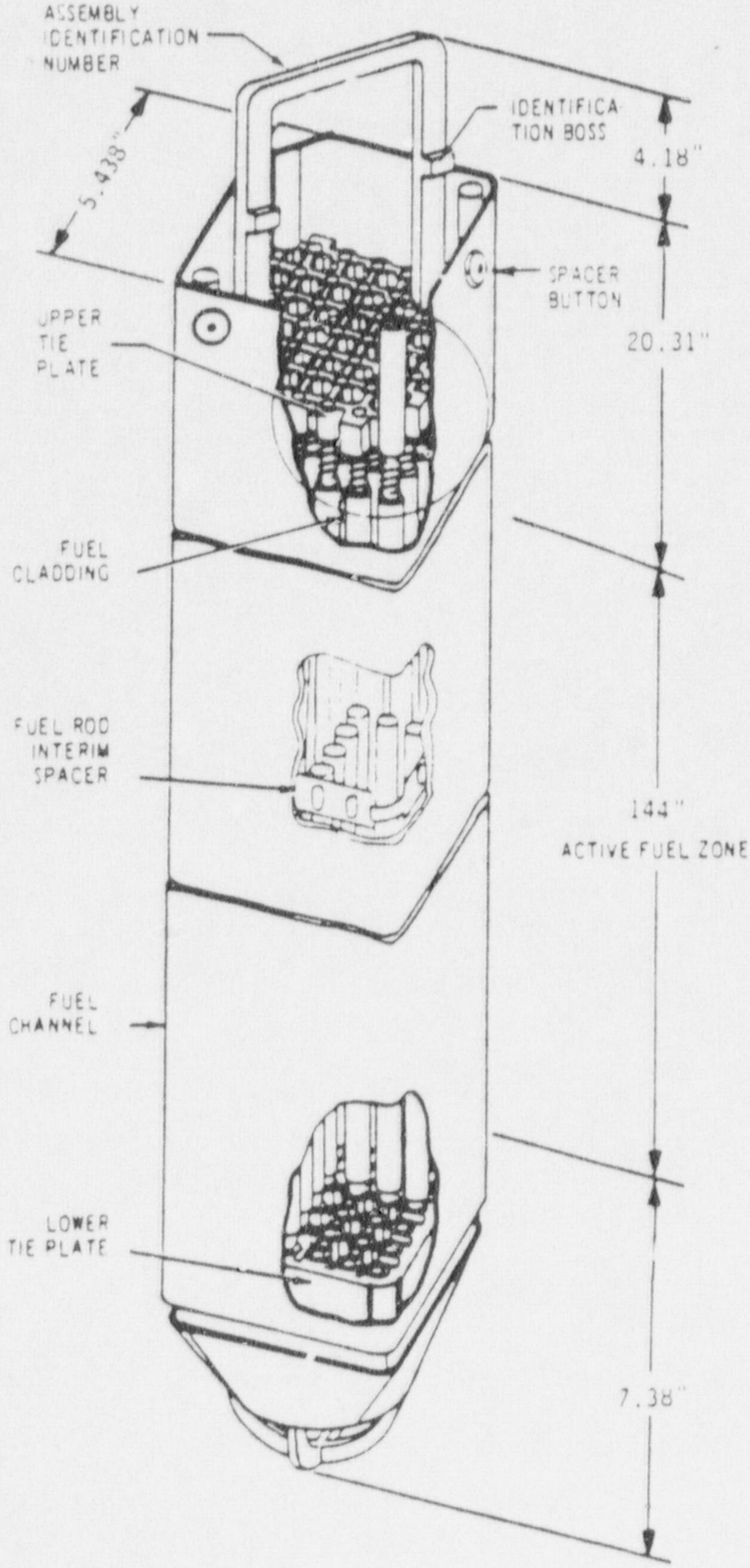
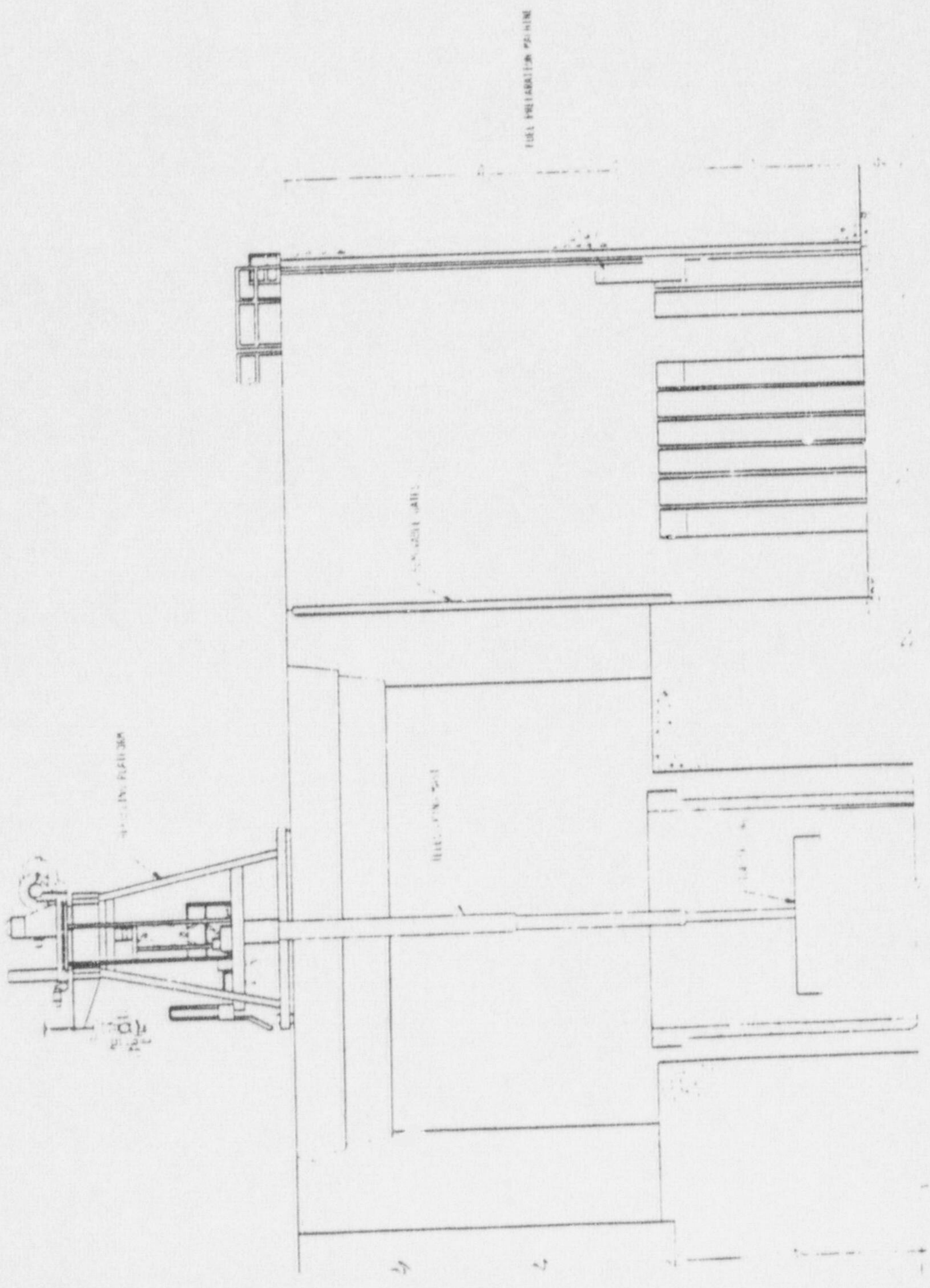


Figure G.2. BWR Fuel Assembly

Exhibit 2

<u>Source</u>: NRC, 1978



SECTION AA

Figure B.7 Fuel Handling Facilities Cross-Section - BWR.

Exhibit 3

<u>Source</u>: NRC, 1978

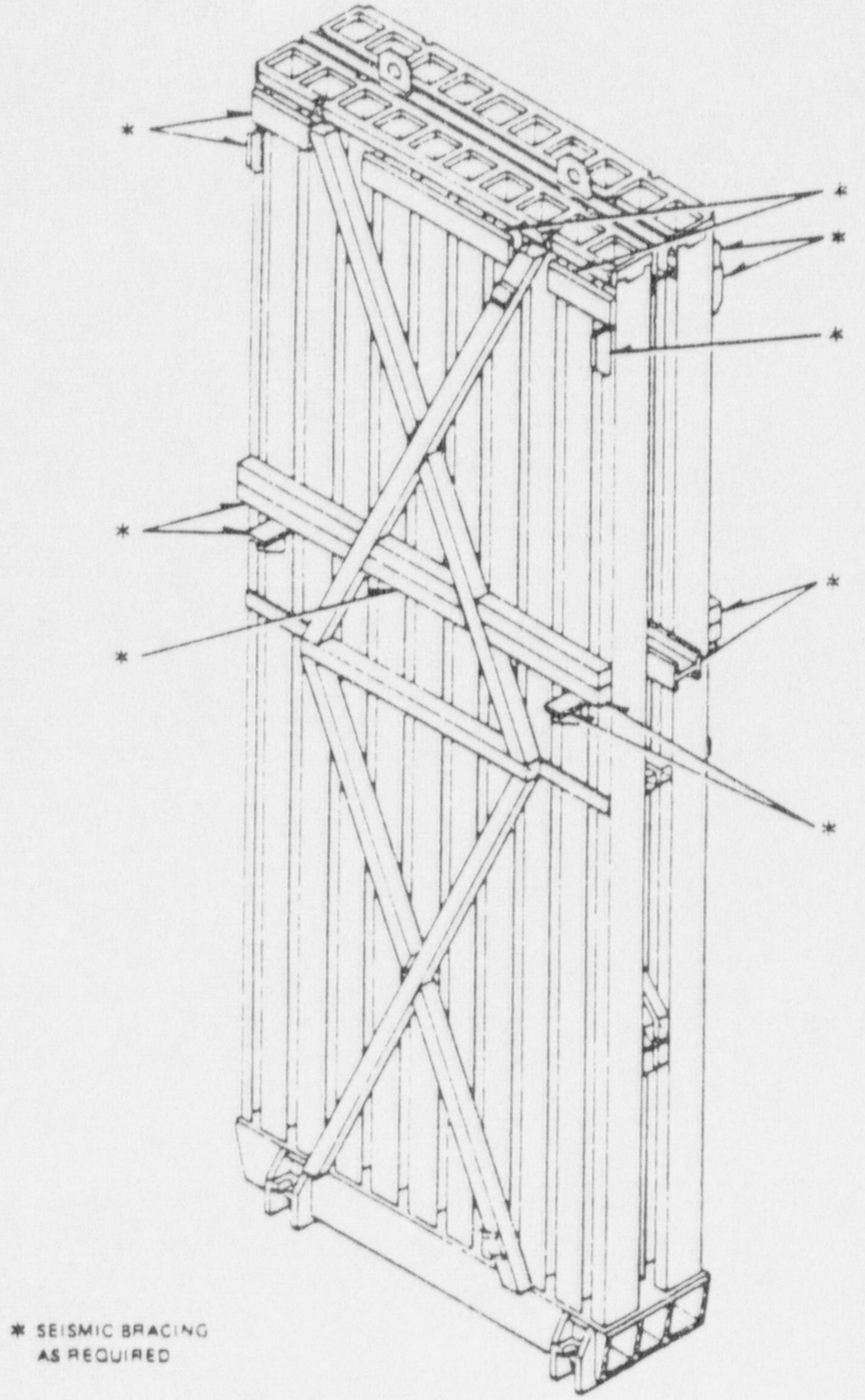


Figure 6.[illegible] Typical BWR Spent Fuel Storage Rack.

Exhibit 4

Source: Benjamin et al, 1979

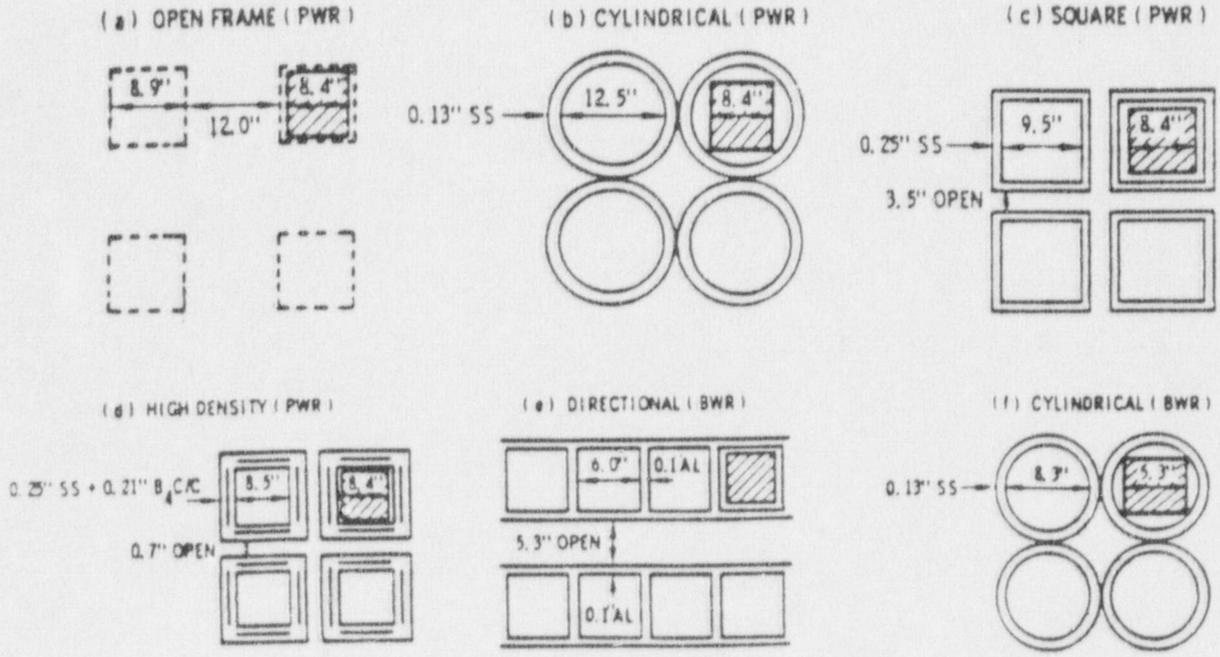


Figure 3. Cross Sectional Dimensions of Spent Fuel Holders Shown in Fig. 2.

Exhibit 5
<u>Source</u>: NRC, 1978

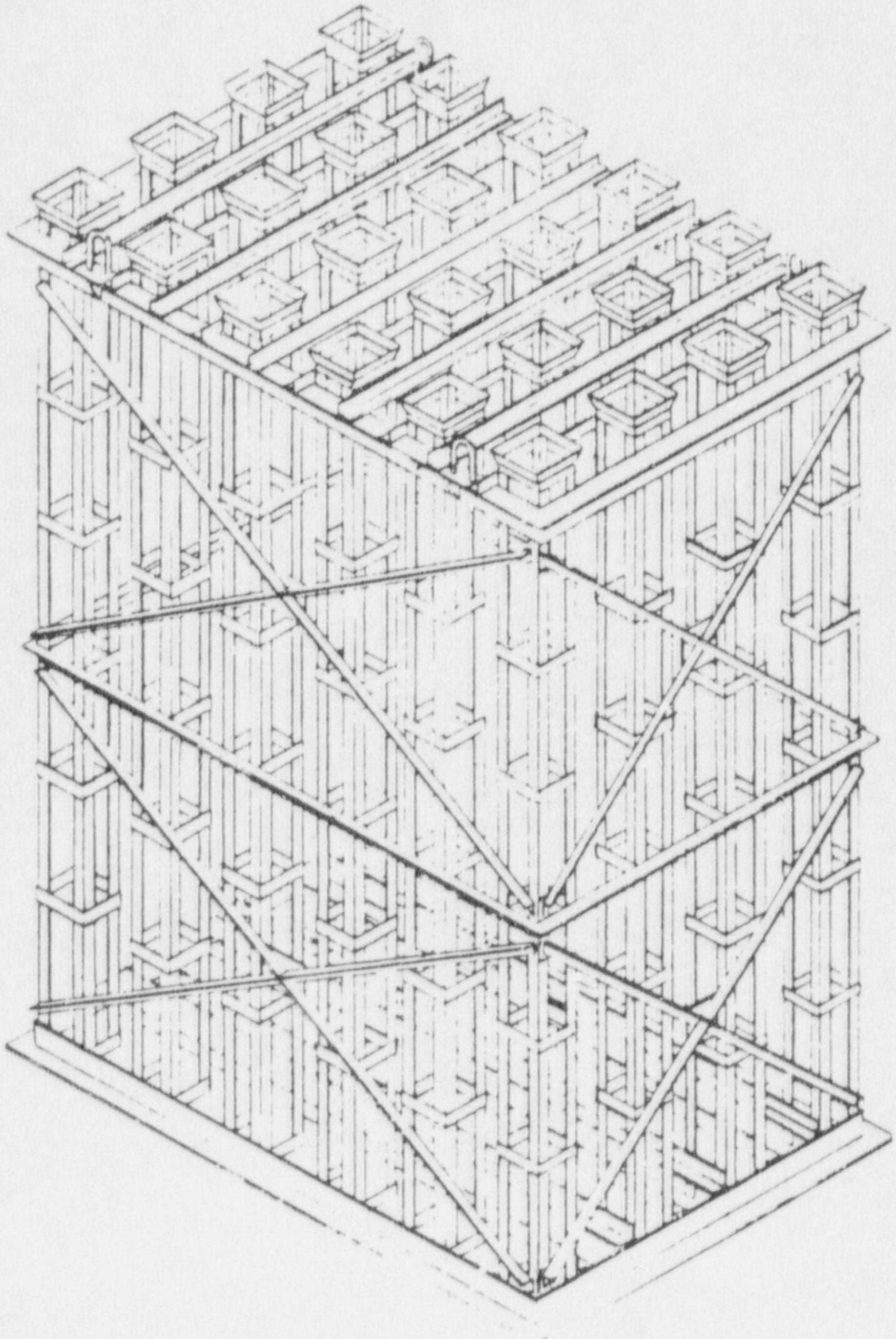


Figure B.2 Typical PWR Open Frame Fuel Storage Rack.

Exhibit 6

Source: Wheeler, 1988

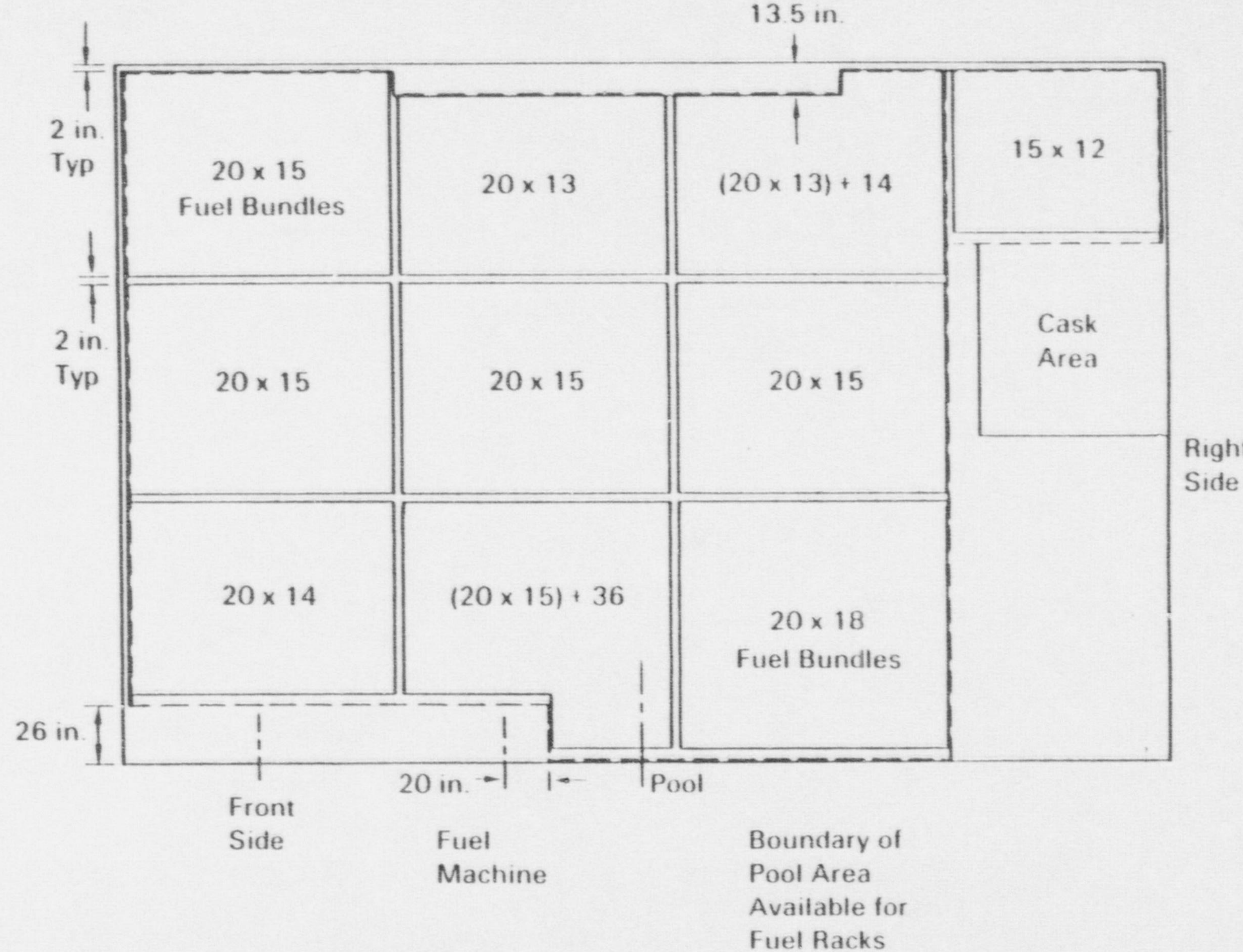


FIGURE 1. Cross Section of Vermont Yankee Spent-Fuel Pool Showing Proposed Storage Rack Layout

Exhibit 7

Source: Wheeler, 1988

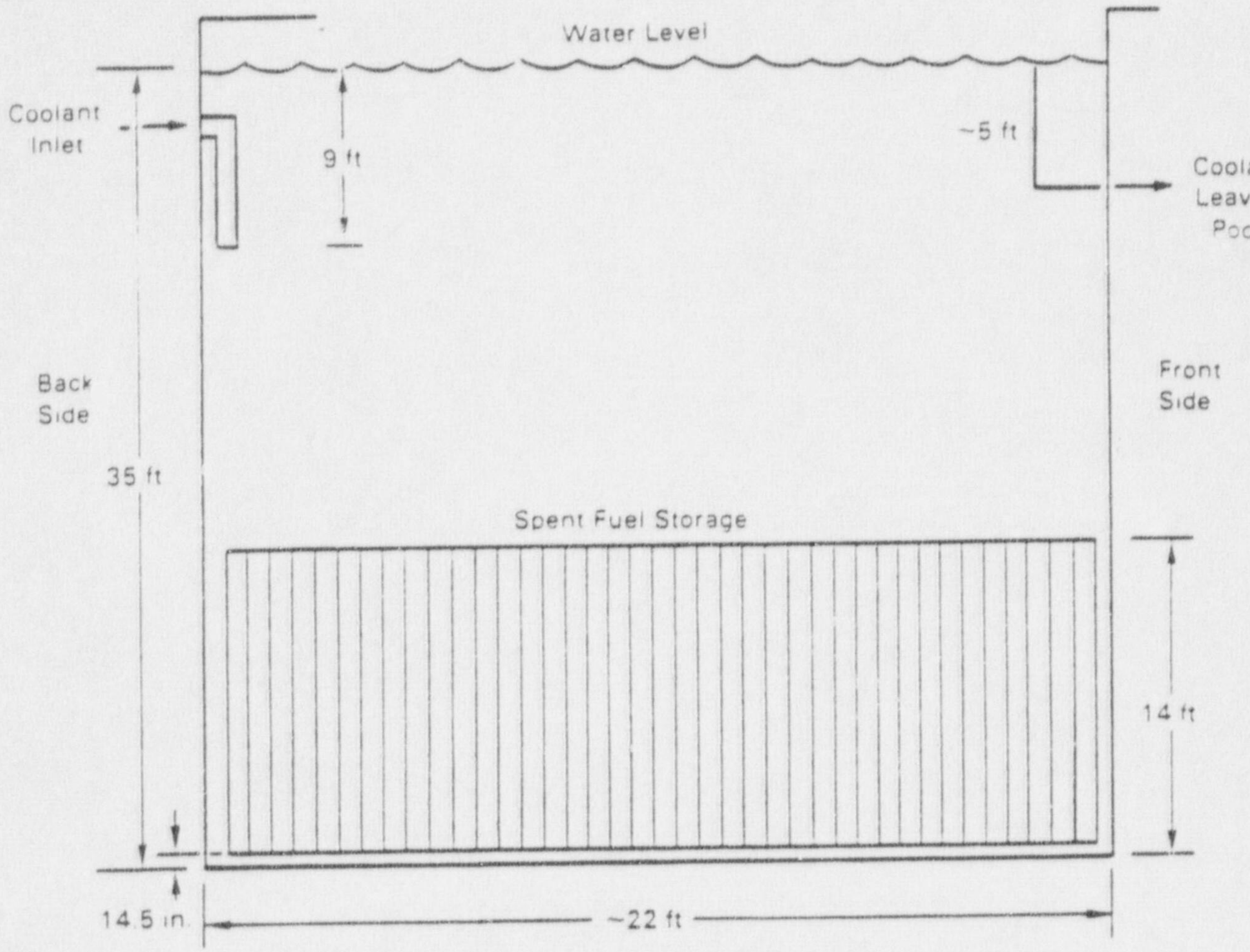


FIGURE 2. Vertical Cross Section of Vermont Yankee Spent-Fuel Pool

Exhibit 8
Source: NRC, 1978

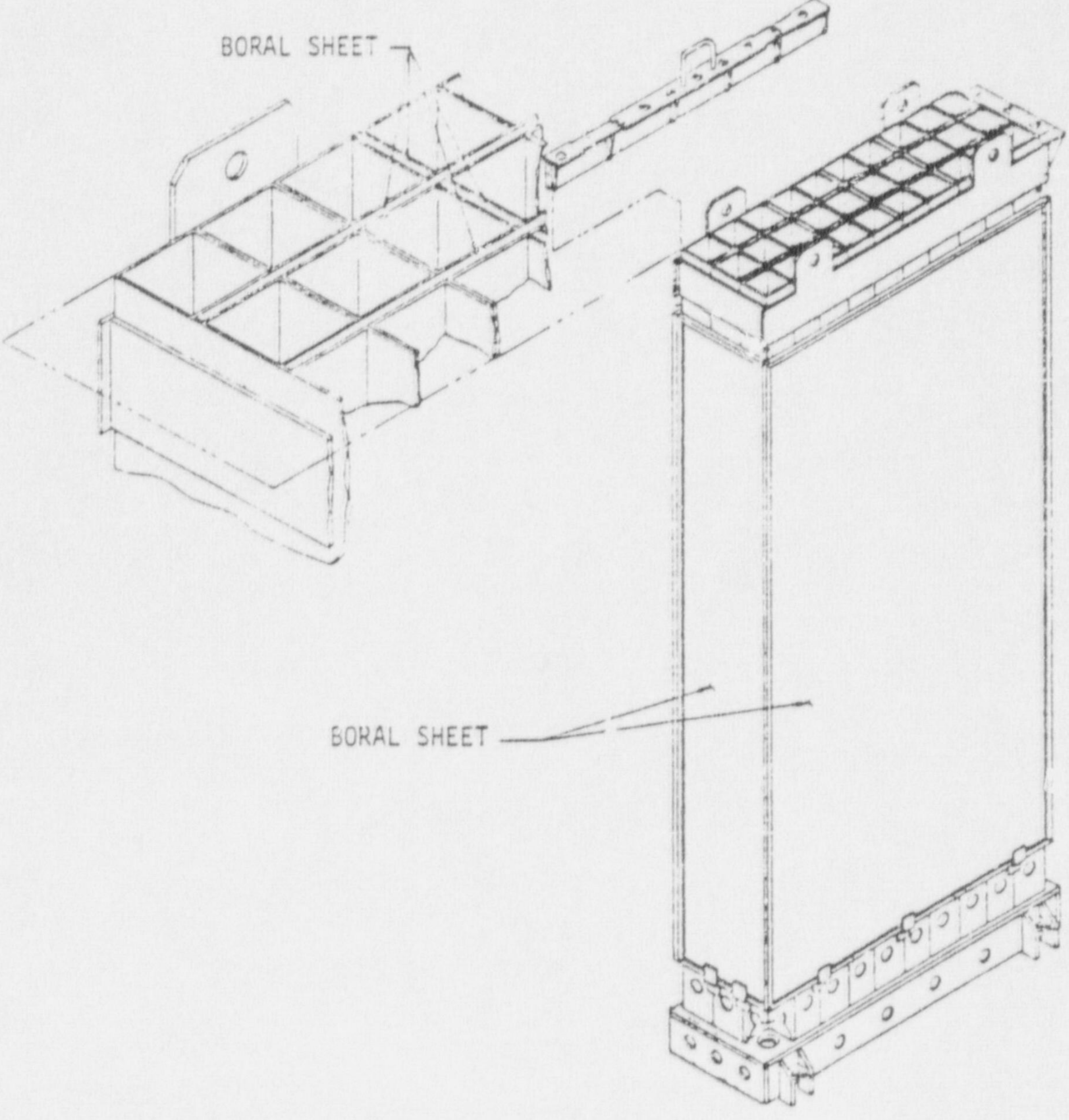


Figure D.10

Case B Typical Spent Fuel Rack - BWR Aluminum/Boral

Exhibit 9

Source: Benjamin et al, 1979

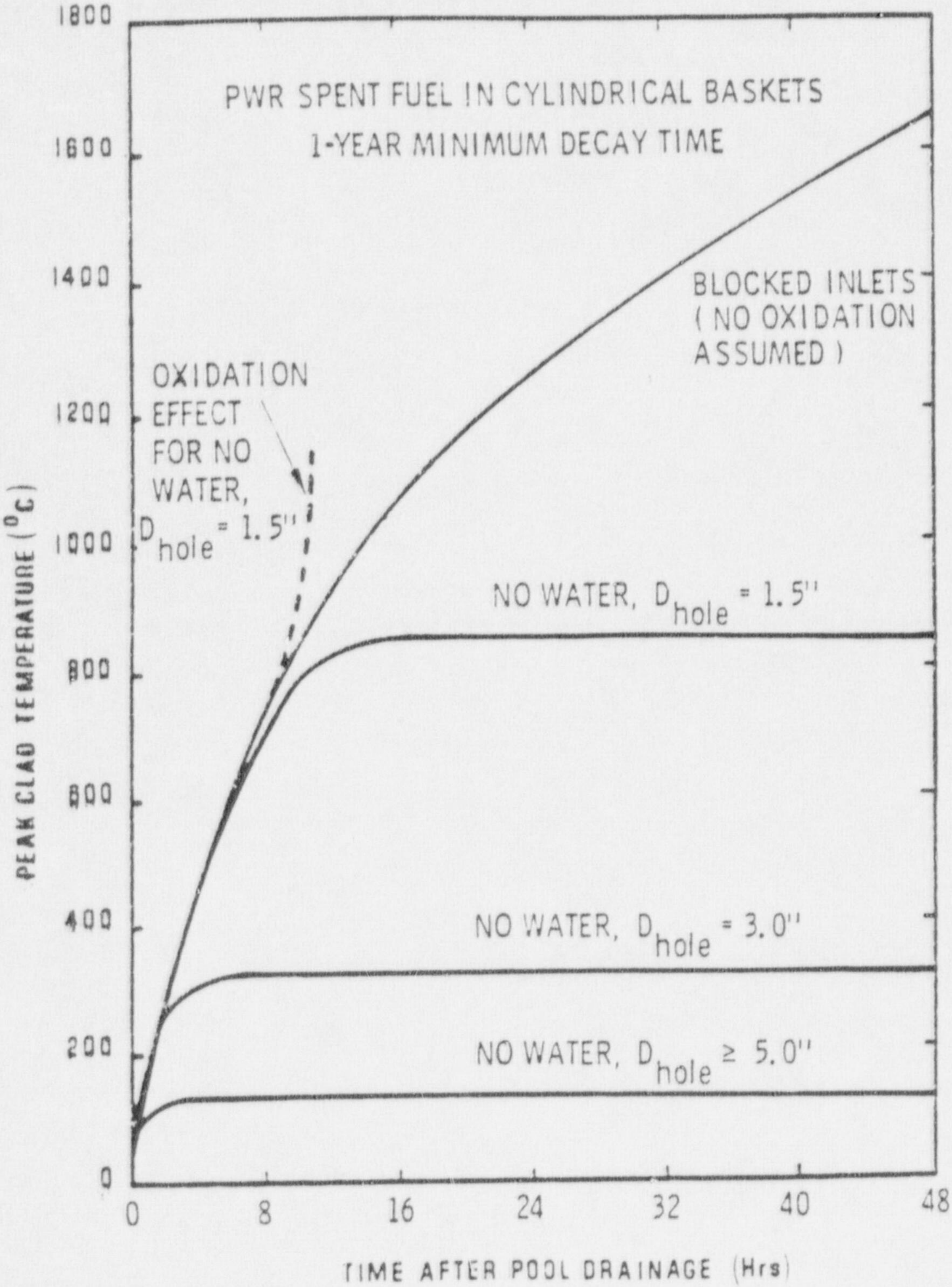


Figure 26. Estimated Heatup of PWR Spent Fuel With Residual Water Sufficient to Block Flow Inlets, Well-Ventilated Room

Exhibit 10
Source: Benjamin et al, 197

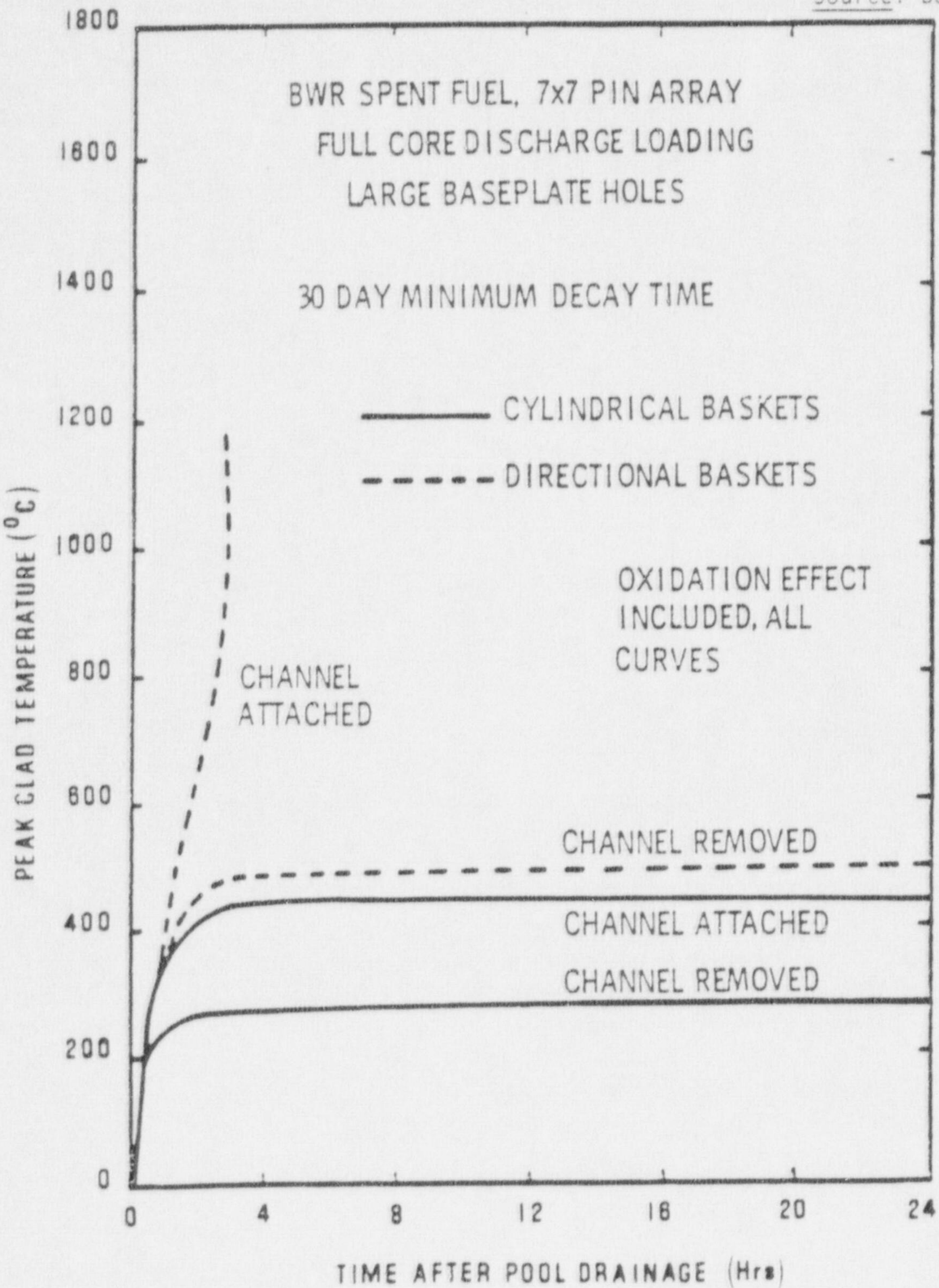


Figure 19. Effect of Storage Configuration on Heatup of BWR Spent Fuel, Well-Ventilated Room

Exhibit 11

Source: Prassinos et al, 1989

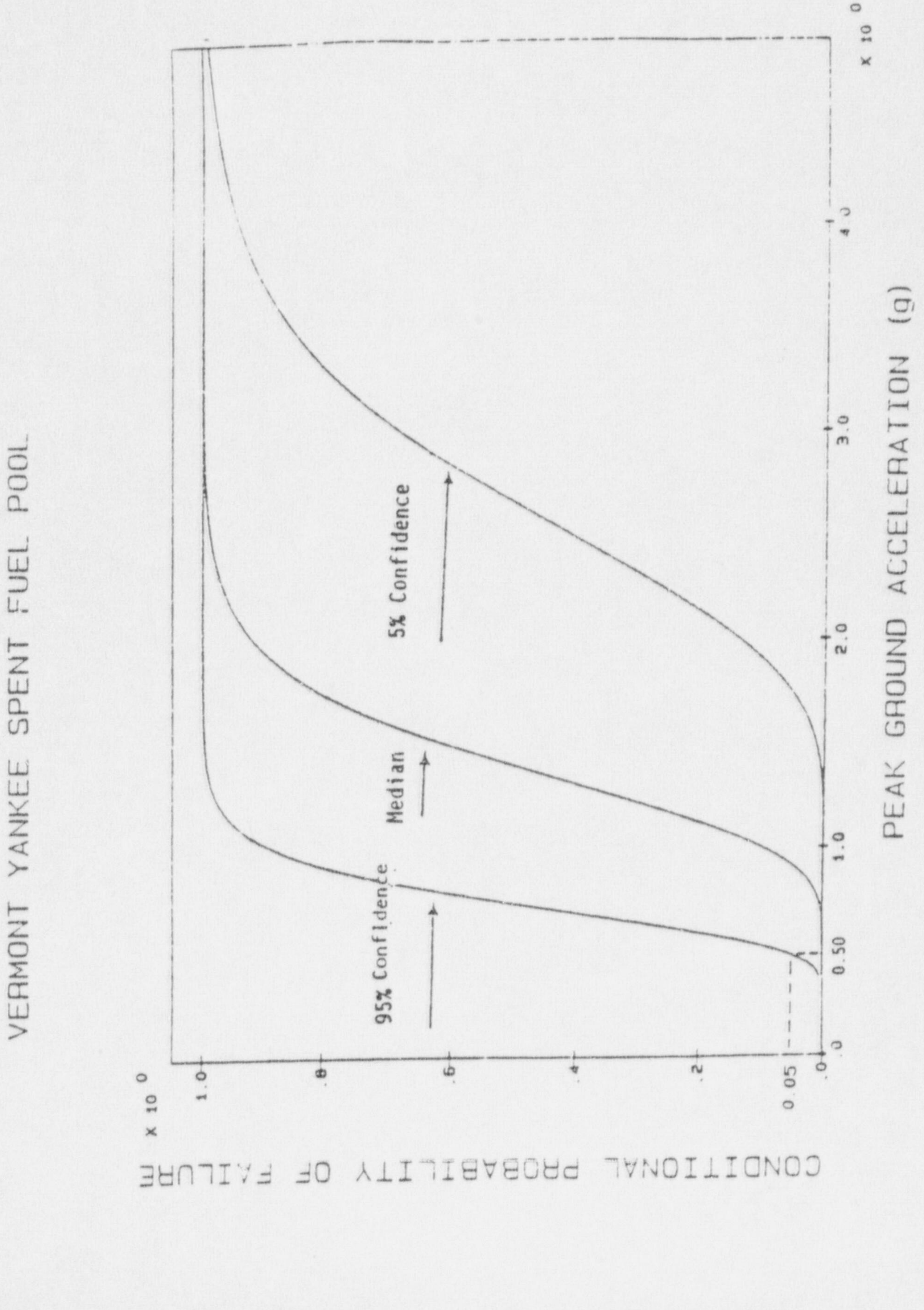


Figure 3-6: Spent Fuel Pool Structure Fragility

Exhibit 12
Source: Prassinos et al, 1989

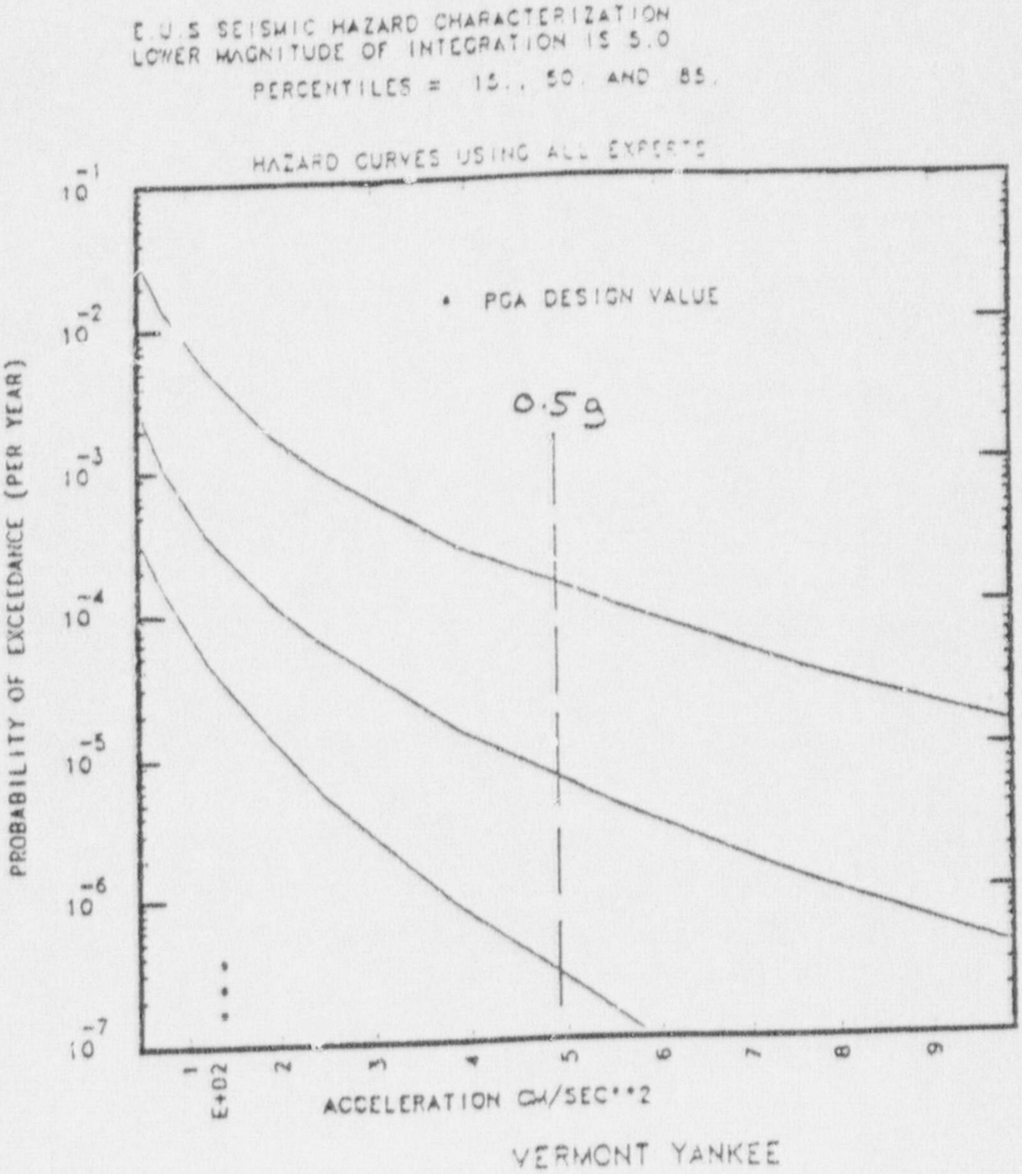


Figure 6-1: Seismic Hazard Curves for the VYNPS Site

Exhibit 13

Source: Beyea, 1979

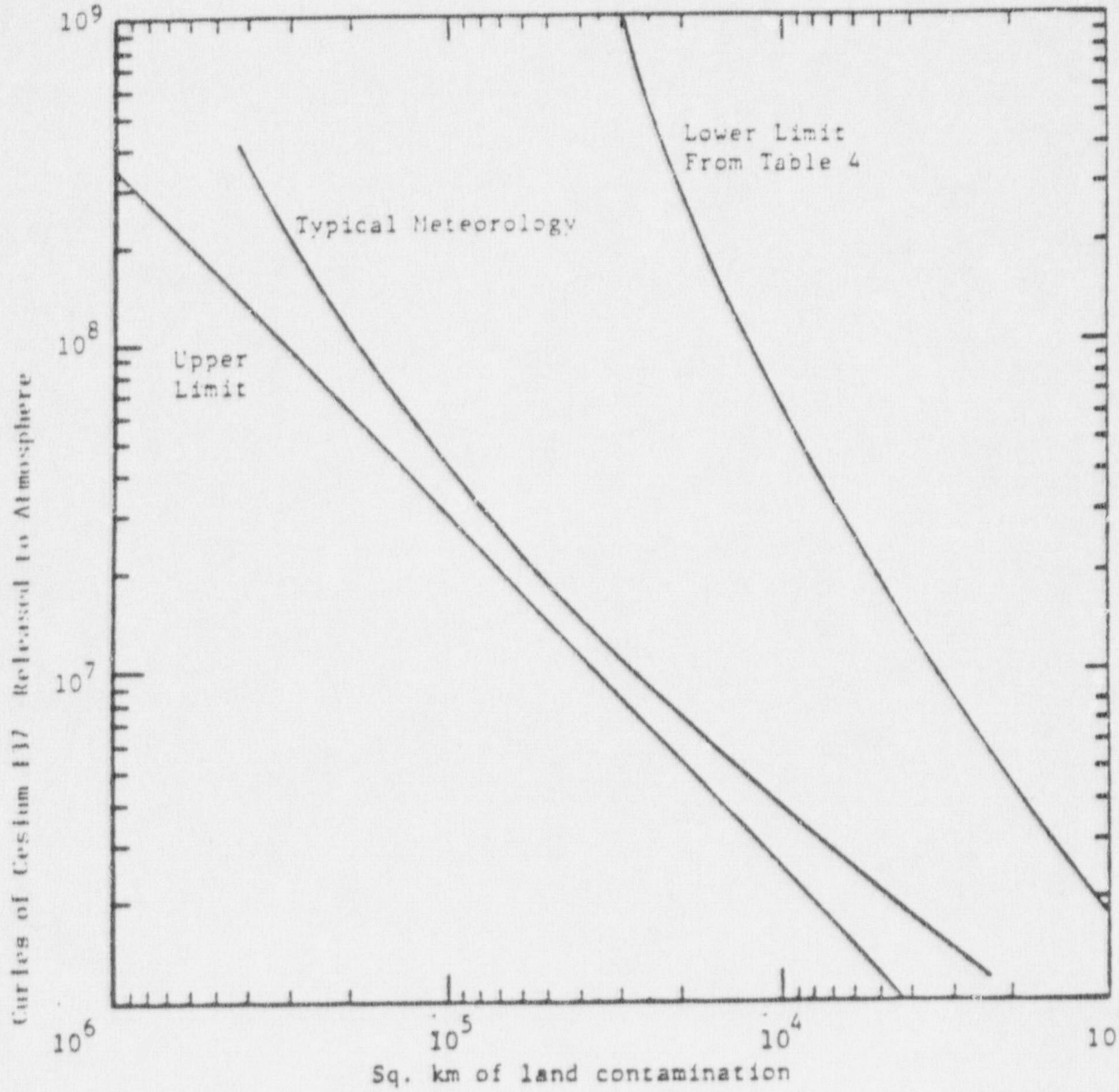


Fig IV. CONTAMINATED AREA AS FUNCTION OF RELEASED CURIES OF CESIUM

The "typical meteorology" curve assumes 5 m/sec wind speed, D stability class, .01 m/sec deposition velocity, 1000 M mixing layer, 300 m inital plume rise. The upper and lower limits are taken from Table 4. See note 124. The upper limit takes into account all possible variations in wind speed and deposition velocity.

Exhibit 14

Source: DOE, 1989

Estimated Unit Costs of Spent Fuel Storage Options

($ per kg of heavy metal)

Storage technology	Capacity increase 100 MTHM	300 MTHM	1000 MTHM
Consolidated fuel stored in reactor pool	40-75	30-50	NA*
Metal casks	60-115	55-105	55-100
Concrete casks	50-110	45-95	45-85
Horizontal concrete modules	60-80	45-60	40-55
Modular concrete vaults	105-155	70-105	45-70

*An increase of 1000 MTHM is not applicable to rod consolidation because at a typical reactor not much more than approximately 350 MTHM of additional storage space can be gained through consolidation.

CERTIFICATE OF SERVICE

I certify that on May 25, 1989, copies of the foregoing pleading were served by first class mail or overnight mail as indicated, on all parties listed below:

'89 MAY 30 P12:14

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