LA-UR-01-1800

GSI-191: SUMMARY AND ANALYSIS OF US PRESSURIZED WATER REACTOR INDUSTRY SURVEY RESPONSES AND RESPONSES TO GL 97-04

Technical Letter Report

AUGUST 2001, REVISION 0

PREPARED BY
D. V. RAO, B. C. LETELLIER, K. W. ROSS, L. S. BARTLEIN, AND M. T. LEONARD

LOS ALAMOS NATIONAL LABORATORY
DECISION APPLICATIONS DIVISION
PROBABILISTIC RISK ANALYSIS GROUP (D-11)

M. L. MARSHALL, NRC TECHNICAL MONITOR

PREPARED FOR
US NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
DIVISION OF ENGINEERING TECHNOLOGY

ACKNOWLEDGEMENT

The work reported here was sponsored by the U S Nuclear Regulatory Commission (NRC).

Mr. Michael Marshall, RES/DRA, coordinated the survey with the pressurized water reactor (PWR) industry. He played a key role in designing the survey and coordinating the survey activities with the industry groups. Mr. Robert Elliott, NRR/DSSA, was interested in the preliminary insights that can be gained from an analysis of industry survey responses. Both Marshall and Elliott actively participated in the study.

The Nuclear Energy Institute (NEI) coordinated the survey and collection of industry responses. The authors would like to particularly acknowledge the contributions of Mr. D. Modeen of NEI and Mr. T. Andreycheck of the Westinghouse Owners Group (WOG). The PWR licensees took an active role and prepared the survey responses. Although this report identifies several limitations of the survey, it should be recognized that the survey fulfills the original intent of both NRC and the Los Alamos National Laboratory (LANL).

The authors would like to thank two LANL staff for their help. Ms. Juanita Lujan produced this document, and Ms. Mary Timmers edited it.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT.)

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AJIT	Air-Jet Impact Testing
B&W	Babcock and Wilcox
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners' Group
BWST	Borated Water Storage Tank
CS	Containment Spray
DEGB	Double-Ended Guillotine Break
DPSC	Diamond Power Specialty Company
ECCS	Emergency Core Cooling System
FSAR	Final Safety Analysis Report
GL	Generic Letter
GSI	Generic Safety Issue
HEPA	High-Efficiency Particulate Air
HPSI	High-Pressure Safety Injection
LANL	Los Alamos National Laboratory
LBB	Leak Before Break
LBLOCA	Large Break LOCA
LOCA	Loss-of-Coolant Accident
LHSI	Low-Head Safety Injection
LPSI	Low-Pressure Safety Injection
MBLOCA	Medium Break LOCA
NEI	Nuclear Energy Institute
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
PD	Positive Displacement
PIRT	Phenomena Identification and Ranking Table
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RG	Regulatory Guide
RHR	Residual Heat Removal
RMI	Reflective Metallic Insulation
RWST	Refueling Water Storage Tank
SS	Stainless Steel
UFSAR	Updated Final Safety Analysis Report
WOG	Westinghouse Owners' Group
ZOI	Zone of Influence

GSI-191: SUMMARY AND ANALYSIS OF US PRESSURIZED WATER REACTOR INDUSTRY SURVEY RESPONSES AND RESPONSES TO GL 97-04

1.0. INTRODUCTION

1.1. Background

In the event of a loss-of-coolant accident (LOCA) within the containment of a pressurized water reactor (PWR), piping thermal insulation and other materials in the vicinity of the break will be dislodged by break-jet impingement. A fraction of this dislodged insulation and other materials, such as paint chips and concrete dust, will be transported to the containment floor by the steam/water flows induced by the break and the containment sprays. Some of this debris may eventually be transported to and accumulate on the suction sump screens of the emergency core cooling system (ECCS) pumps. Debris accumulation increases the differential pressure across the sump screen and, in some cases, may degrade ECCS performance to the point of failure. The Generic Safety Issue (GSI)-191 study titled “Assessment of Debris Accumulation on PWR Sump Performance” addresses the issue of debris accumulation on the PWR sump screen and the consequent loss of ECCS pump net positive suction head (NPSH). Los Alamos National Laboratory (LANL) has been supporting the US Nuclear Regulatory Commission (NRC) in the resolution of GSI-191.

Based on the findings of the boiling water reactor (BWR) ECCS strainer blockage study, review of facility Safety Analysis Reports, and several plant visits, the NRC and LANL identified a set of plant design features (e.g., sump design) and sources of debris (e.g., insulation materials and containment coatings) that were considered to strongly influence debris generation, transport, and accumulation in PWRs. One of the tasks under GSI-191 is to compile a database of insulation, containment, and ECCS sump design and operation information for the operating US PWRs. It was determined that such a database would benefit the GSI-191 study in two ways.

1. It would provide the most up-to-date information on the insulation and sump configurations at each operating PWR unit. Such information can be used in the design and conduct of research programs related to GSI-191.
2. It would provide a means by which the results of the GSI-191 study can be used to draw conclusions regarding the risk significance of this issue to the overall population of operating US PWRs.

The NRC formulated a set of questions that captured the information needs and forwarded them to the licensees of the operating US PWRs. Appendix A presents the questions prepared by NRC along with an explanation to the licensees on how the information would be used in the GSI-191 study. The licensee response to these survey questions was voluntary and consisted of written responses and engineering drawings (as deemed necessary by the individual licensees). The Nuclear Energy Institute (NEI) report *Results of Industry Survey on PWR Sump Design and Operations* (June 7, 1999) forwarded the industry responses to the NRC. The most recent addendum (January 14, 2000) forwarded the last set of industry responses.

LANL performed a thorough review of the industry responses. This report presents a summary and analysis of the industry survey of the plant designs and features that most likely affect generation, transport, and accumulation of debris in operating US PWRs.

1.2. Scope and Objectives

The licensees’ responses to the survey questions varied significantly in both scope and detail. Typically, the responses reflected the licensees’ interpretation of the survey questions and the availability of information solicited by that question. In some cases, the licensee response consisted of detailed explanations and copies of the most recent engineering drawings (or data sheets). In some extreme cases, the responses consisted of references to appropriate sections of the plant Updated Final Safety Analysis Report (UFSAR) with no further explanation provided. LANL undertook a thorough review and analysis of the industry responses with the following objectives.

1. Summarize the industry responses in a form that is logical and can be accessed easily. To meet this objective, industry responses were compiled in the form of tables and bar charts. This effort did not attempt to interpret the results or draw conclusions from the results; it simply sorted the industry responses as necessary.
2. Analyze the information to gain insights into variability in the (a) containment features, (b) ECCS sump designs, and (c) debris sources that are present at each of the responding units. From the analysis, determine the range over which each parameter varies across the plant population and its median value.
3. Identify industry responses that appear inaccurate or require further clarification.
4. Use the industry responses together with the licensee responses to NRC Generic Letter 97-04, "Assurance of Net Positive Suction Head (NPSH) for Emergency Core Cooling and Containment Heat Removal Pumps" to gain very preliminary insights about the significance of this problem to each unit.

This report summarizes the results of the LANL review activities. No discussions on how this information will be used in the ongoing experimental programs or risk-estimate studies are presented here.* The results of the LANL review and analyses are presented in the following sections.

Section 2 presents an overview of the industry responses followed by a statistical analysis of the responses to (a) determine the median value and standard deviation for each response and (b) identify the outlier units or ECCS design features.

Section 3 describes additional information of importance to the assessment of PWR recirculation sump performance. This information was not collected through the NEI survey, but could be gleaned from licensee responses to GL 97-04: "*Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps*."

Implications of the survey findings are described in Section 4 with two particular applications in mind. First, findings regarding specific plant characteristics that affect sump performance are delineated to facilitate an NRC staff review of a particular PWR sump design, potential debris sources and the extent to which these characteristics favor or preclude degradation of ECCS recirculation flow. Second, findings of value to ongoing or future research activities (i.e., experiments and analysis) are described.

2.0. REVIEW AND ANALYSIS OF INDUSTRY SURVEY RESPONSES

2.1. Overview of Industry Responses

The licensee responses were forwarded to the NRC in three major installments over a period of 6 months. The first group of responses was forwarded in June 1999, and it contained the responses of 42 PWR units. The second group was forwarded in September 1999 and included responses from five more units. The final installment was forwarded in January 2000. At the end of January, a total of 58 PWR units (listed in Appendix B) had responded to the NEI survey.

In the course of evaluating the information obtained from the NEI survey, uncertainties arose regarding the interpretation of individual responses to certain questions. These uncertainties resulted in some limitations in potential applications of the surveyed information. These limitations are described in Appendix C.

2.1.1. Containment and Sump Parameters. A large number of units provided detailed layout drawings, ECCS sump design information, and operational details. The LANL staff used these drawings to supplement some of the industry responses and to fill in gaps in the licensee responses.

---

* This information is provided primarily in "GSI-191: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance," LA-UR-01-4083, Rev. 1, Los Alamos National Laboratory, August 2001.

Figures 2-1 through 2-7 present individual licensee responses to questions related to the following.

1. The pool depth at switchover (Question 1a)
2. The time at switchover to sump recirculation (Question 1b)
3. The maximum containment pool depth above the containment floor (Question 1c)
4. The sump-screen area (Question 3e)
5. The sump-screen curb height (Question 3n)
6. The sump-screen clearance size[1] (or hole diameter) (Question 3f)
7. The containment floor open area for water accumulation (Question 4b)

Some important observations related to containment and sump design are given below.

1. The water pool height at the time of switchover can vary significantly depending on the plant type and ECCS design[2]. Braidwood, Byron, North Anna Units 1 and 2, and Surry Units 1 and 2 have shallow water pools (1 ft high) at the time of switchover. Several other plant units reported having lower than a 2-ft water height at the time of ECCS switchover. These low pool heights are a reflection of three factors: (1) the unique design(s) of the ECCS required early switchover, (2) the fact that the licensing-basis pool height calculations do not take credit for some of the water sources [e.g., some of the refueling water storage tank (RWST) inventory], and (3) the licensee treated accumulation of water in the dead areas (e.g., reactor cavities) very conservatively.
2. The minimum calculated time to ECCS suction switchover to the recirculation sump varies from a few minutes (5 min for Surry Units 1 and 2 and North Anna Units 1 and 2) to up to an hour (Beaver Valley Units 1 and 2). Our review of the FSARs suggests that the responses from Calvert Cliff Units 1 and 2 and San Onofre Unit 2 are erroneous (and therefore were not included in this discussion). It does appear that only a few units accounted for level measurement uncertainties while estimating the minimum time for ECCS switchover. This may mean that minimum switchover time for some of the units may actually be sooner than the licensee response indicated.
3. The maximum pool height can reach in excess of 15 ft for the ice-condenser units. However, it would take several hours to a day before the maximum depth is reached.
4. Sump-screen areas vary considerably from unit to unit. Among the units that responded to this survey, A. W. Vogtle Units 1 and 2 reported having the lowest sump screen area (11 ft^2) and Callaway[3] reported having the largest screen area (700 ft^2).
5. Although a majority of the units reported a sump-screen hole size of 0.125 in., sump-screen hole size also varies considerably. However, 26 out of 58 respondents indicated a sump screen hole size larger than 0.125 in., reaching up to 0.6 in. Prairie Island Units 1 and 2 do not have sump screens.

2.1.2. Debris Sources. The survey questions solicit information from licensees regarding the (a) types and quantity of thermal insulation used in the containment of each unit, (b) types and area of containment coatings used in the containment, (c) types and area of fire barrier materials used in the containment, and (d) the concentration of boron.

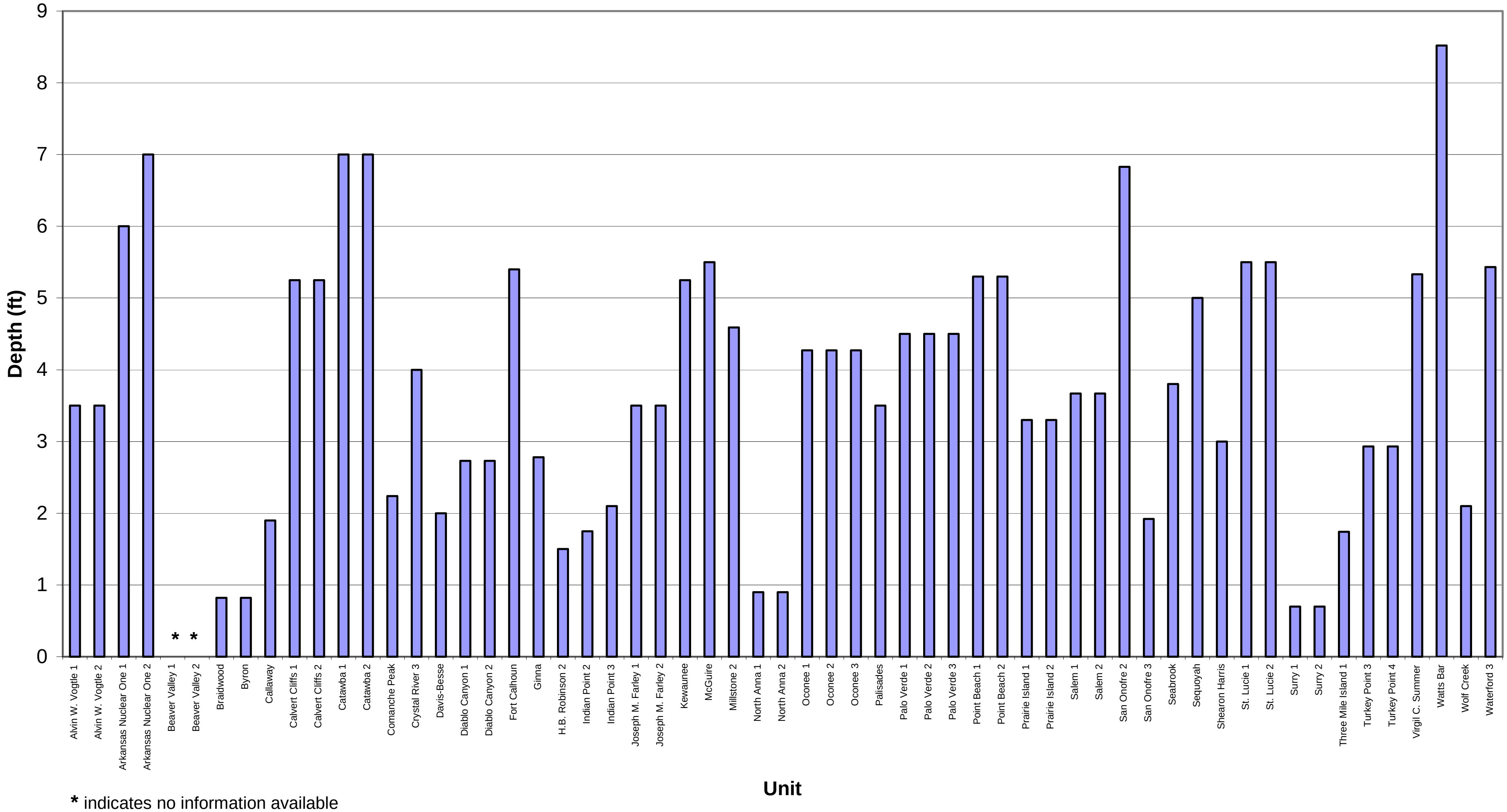
The individual licensee responses to questions related to debris sources varied considerably. In general, the licensees have provided the type(s) of insulation, containment coating, and fire barrier materials. Figures 2-8 through 2-10 present the number of units containing each type of thermal insulation, fire barrier material, and Level 1 containment coatings. Almost all the units responding to the

---

[1] The terms “clearance”, “hole size,” “hole diameter,” and “mesh size” are used interchangeably in this report. Each of these terms refer to the characteristic dimension of the perforation or opening the in sump screen.

[2] Pool heights are calculated using conservative assumptions. Actual height may be higher.

[3] However, from the explanations provided by the licensees, it appears that at least a part of the sump screen would not be submerged in water at the time of ECCS switchover. The licensee did not account for this issue while estimating the total screen area. Therefore, the screen areas reported by the licensee should be treated as the maximum values, and it is possible that the effective screen areas would be smaller than the reported screen areas.



***** indicates no information available

Fig. 2-1. Pool depth at switchover to recirculation (Question 1a).

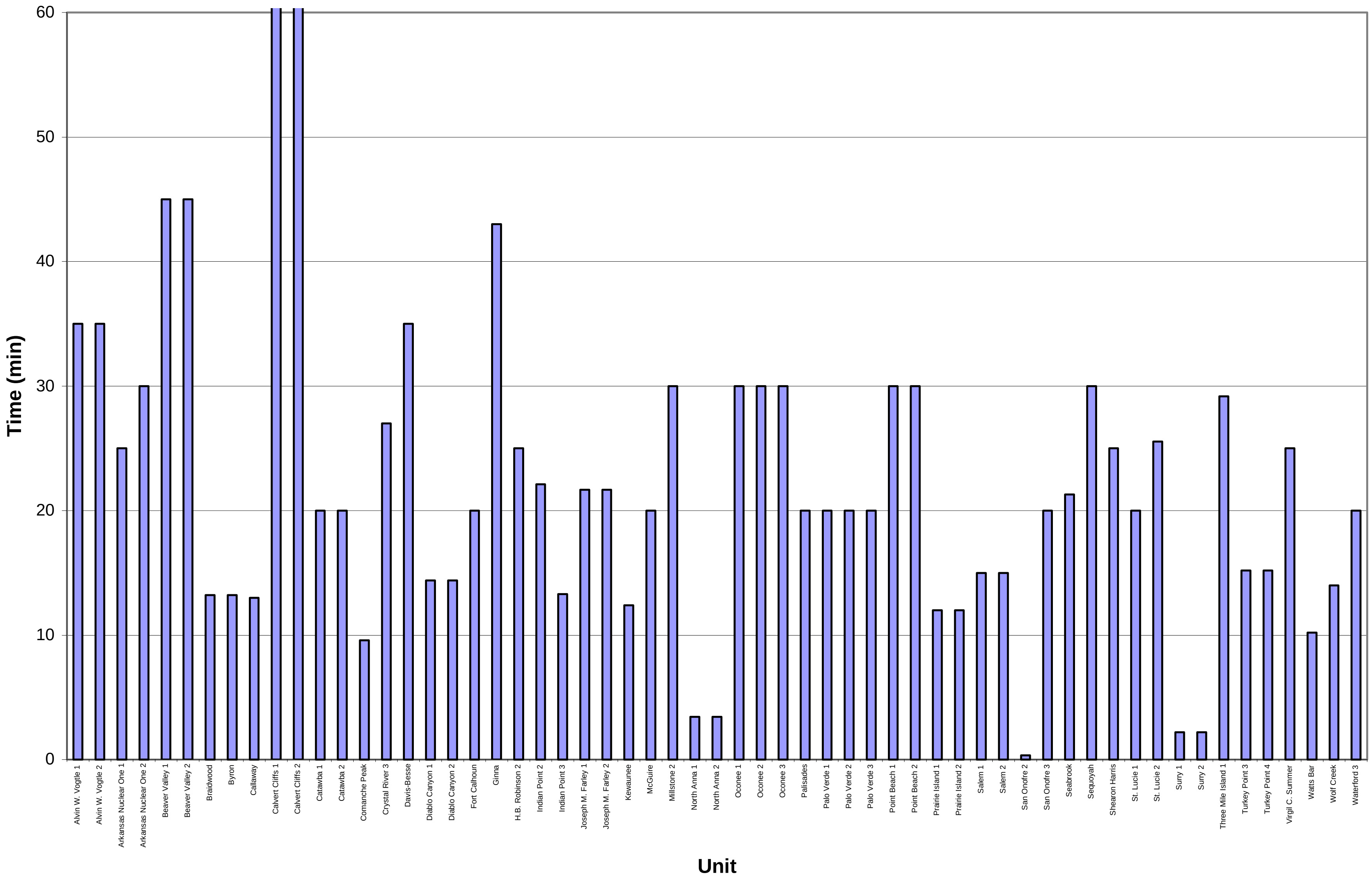


Fig. 2-2. Time at switchover to recirculation (min) (Questions 1b).

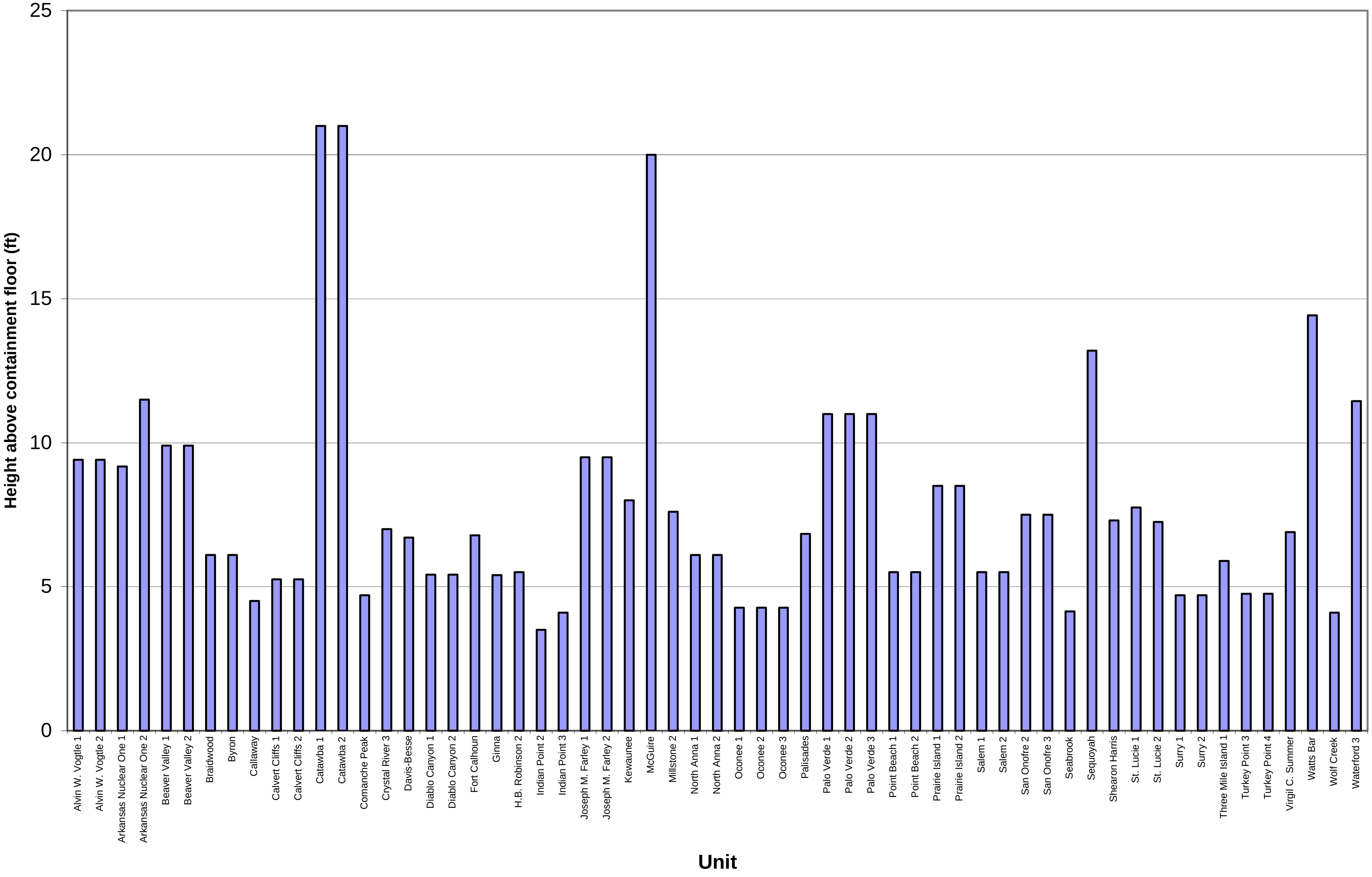


Fig. 2-3. Maximum pool depth above containment floor (ft) (Questions 1c).

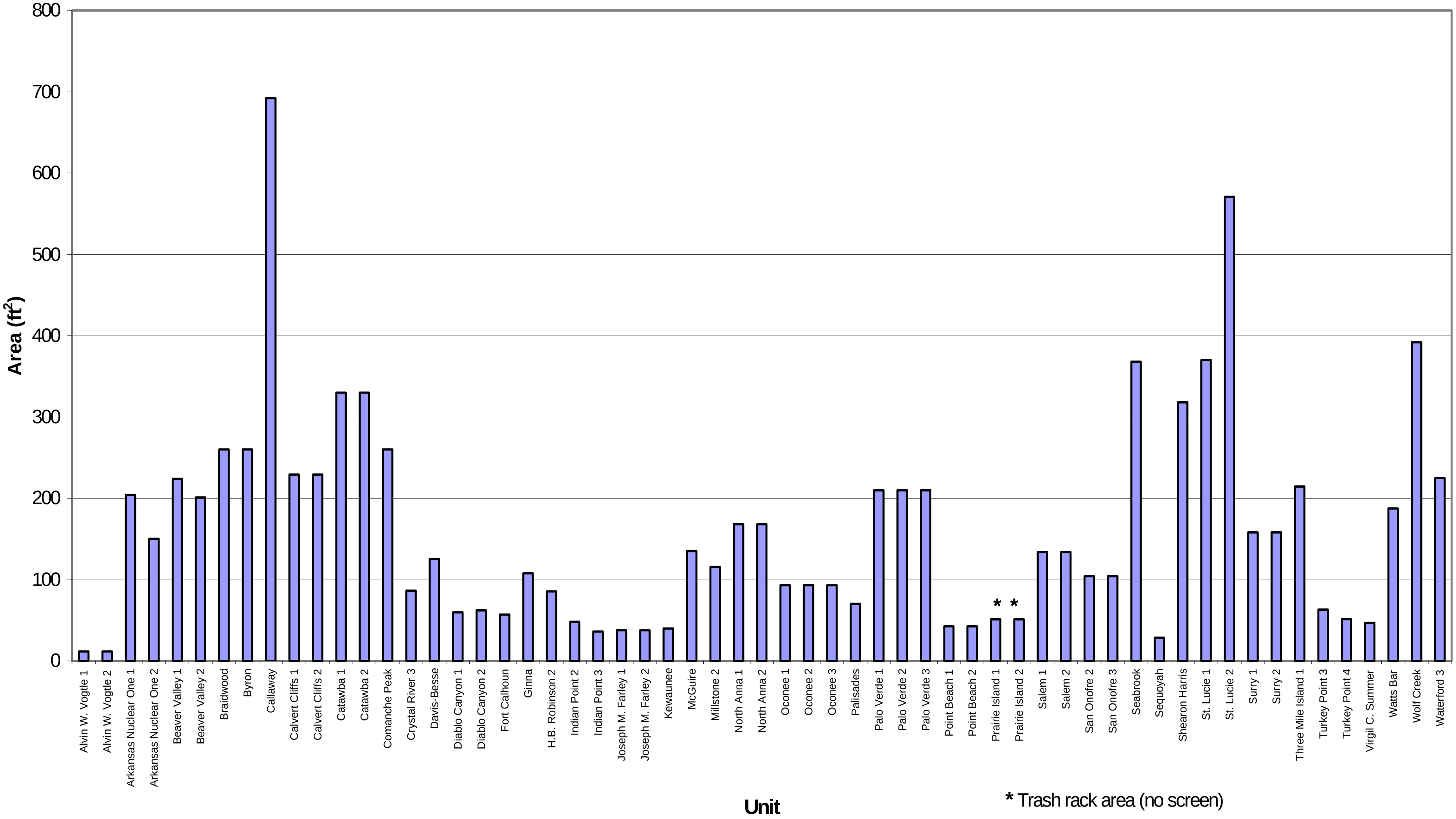


Fig. 2-4. Sump screen area (ft^2) (Questions 3e).

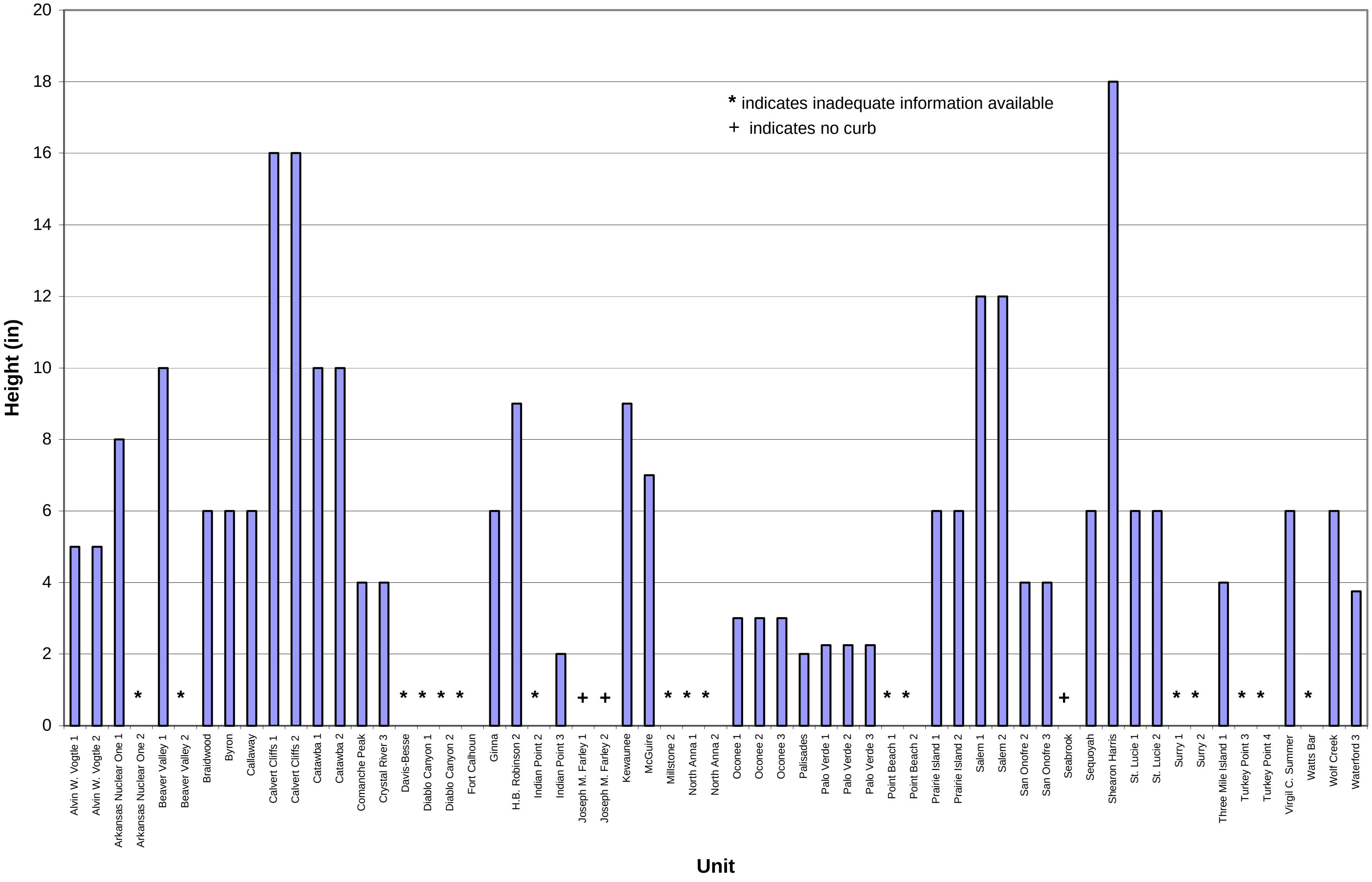


Fig. 2-5. Sump curb height (in.) (Question 3n).

***** indicates no information available

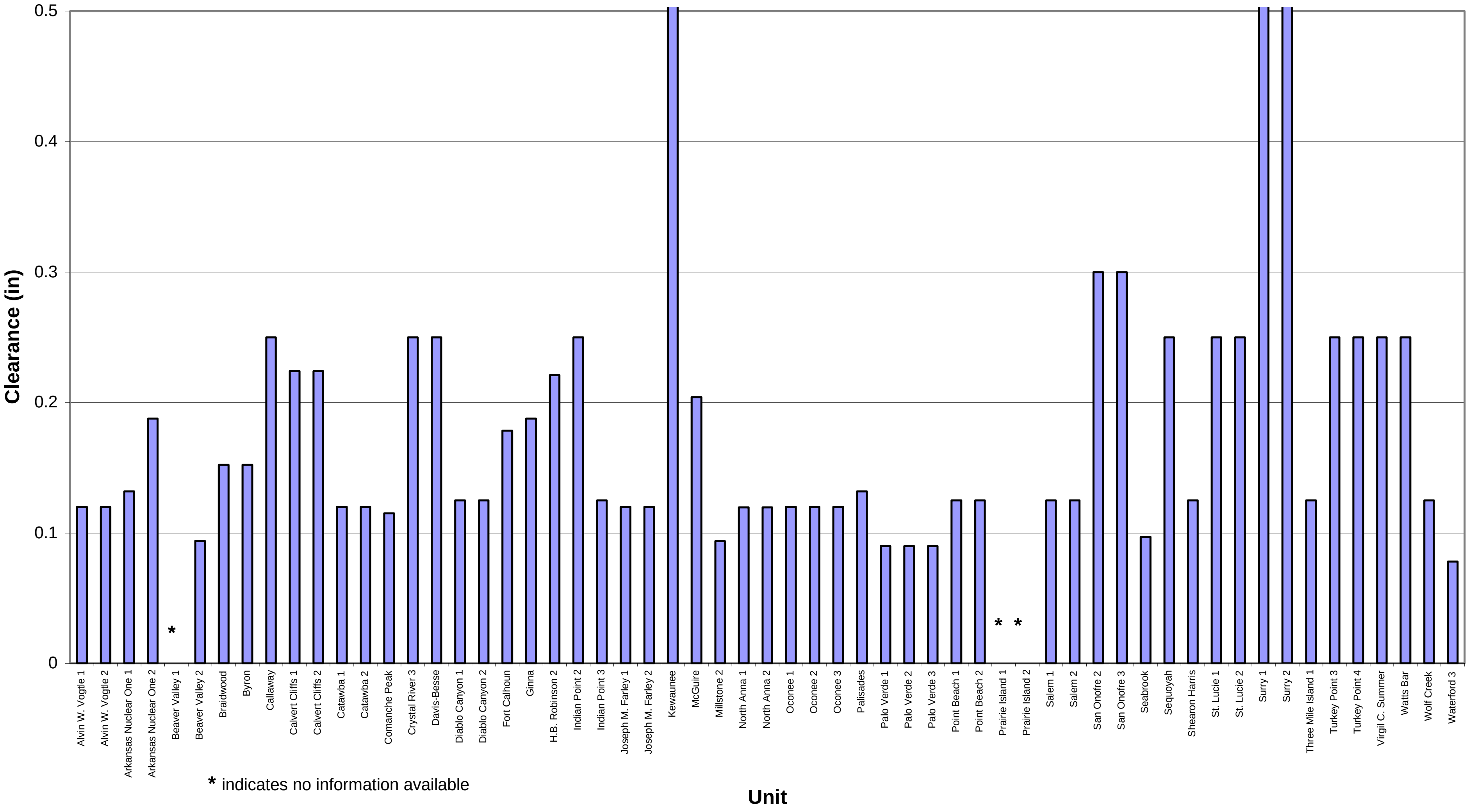
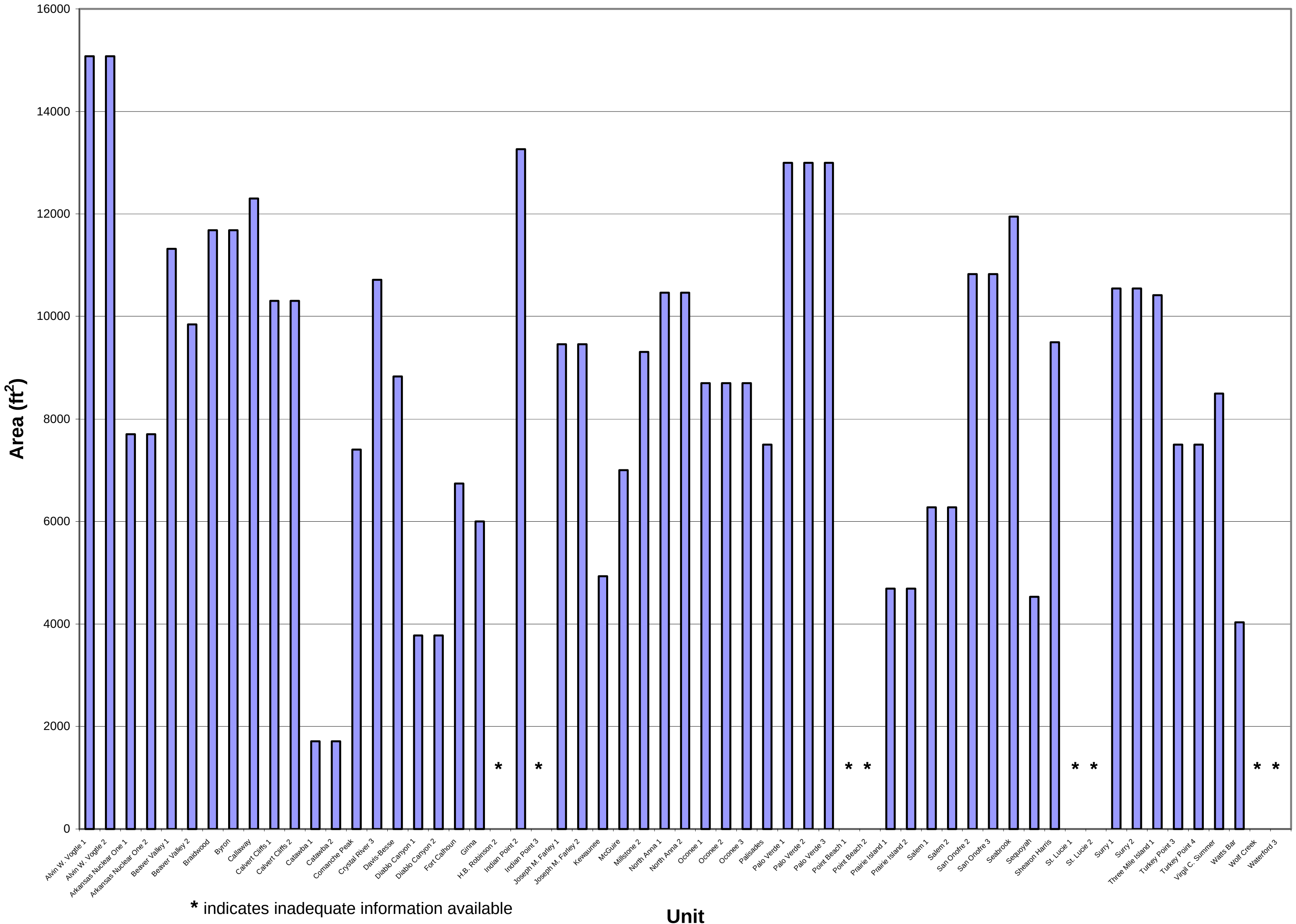


Fig. 2-6. Sump screen clearance (in.) (Questions 3f).



***** indicates inadequate information available
(may reflect no curb)

Fig. 2-7. Containment floor open area (ft^2) (Question 4b).

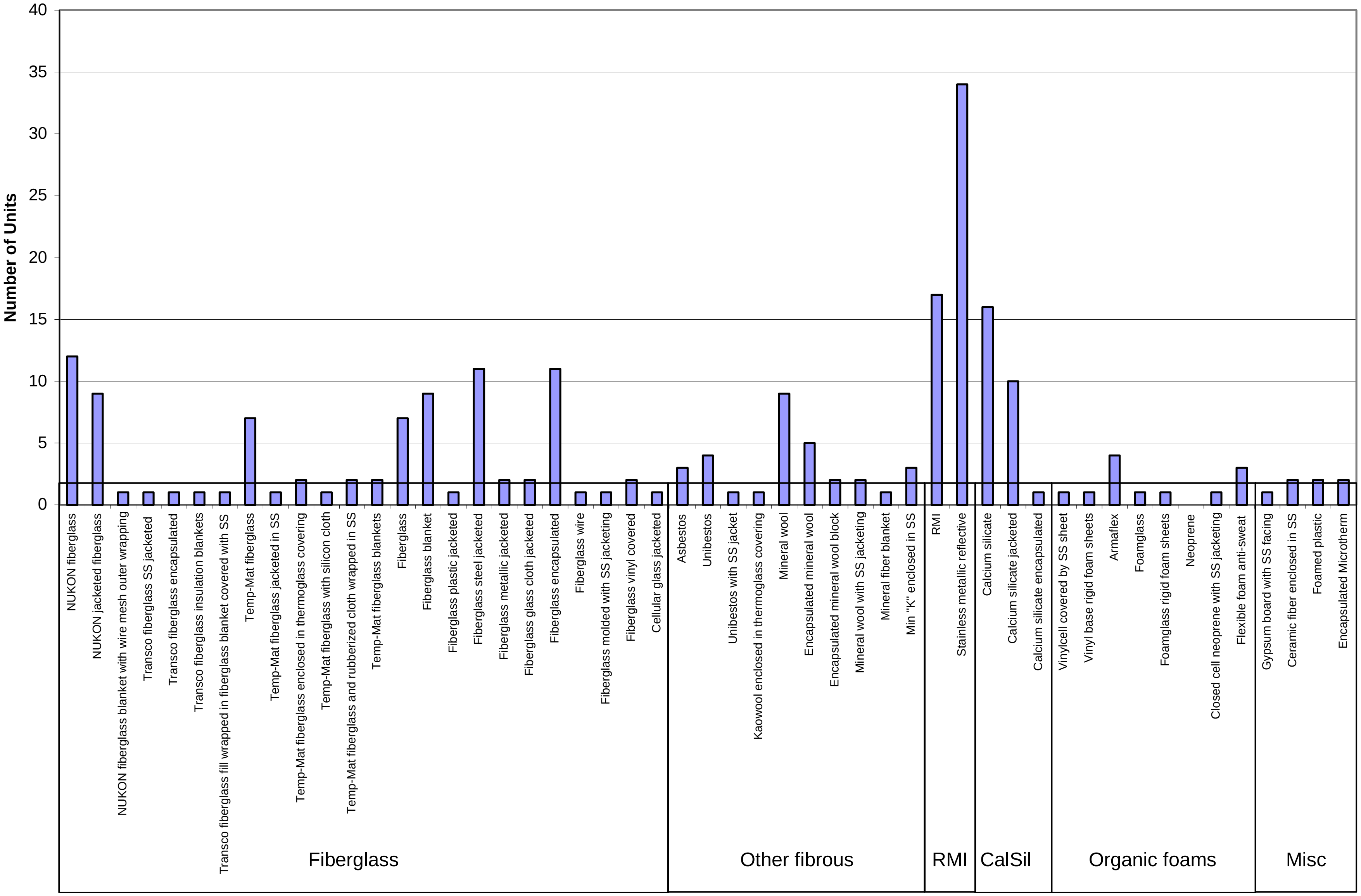


Fig. 2-8. Number of units with each reported type of insulation.

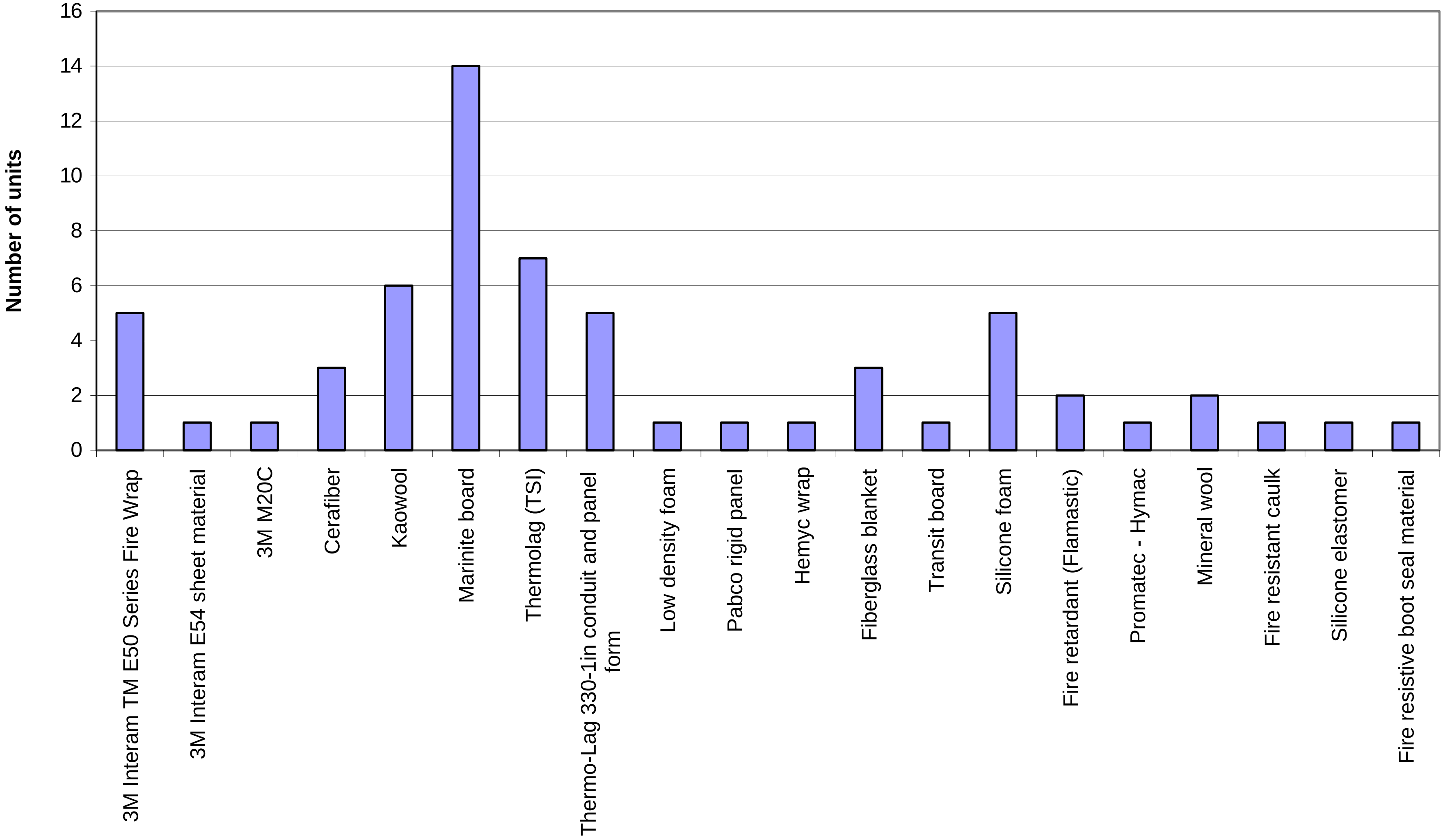


Fig. 2-9. Number of units with each reported type of fire barrier material.

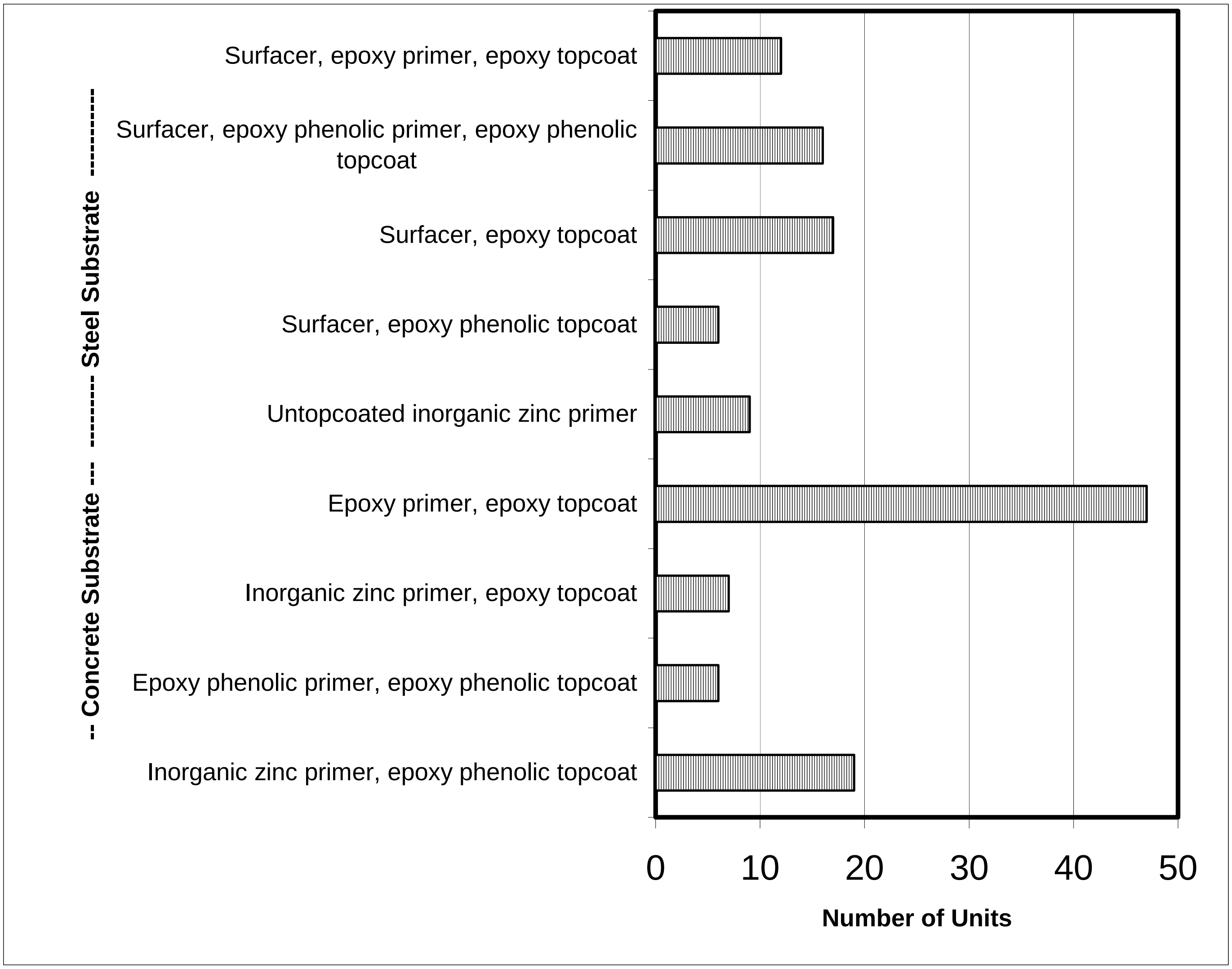


Fig. 2-10. Number of units containing each type of level 1 coating.

survey have indicated that some amount of fibrous insulation is present in their containment. The types of fibrous insulation varied significantly, but much of it is in the form of low-density fiberglass and mineral-wool. Several units have responded that fibrous insulation may be present in the plant without any substantial encapsulation. Some of the explanations suggest that many of the newer units (and units replacing steam generators) have been replacing reflective metallic insulation (RMI) with "high-performance" fiberglass insulation.

Between 30 and 40 licensees provided the actual square footage (or percentage) of each insulation type. Figures 2-11 through 2-14 summarize the response of each unit that provided this information. The following conclusions can be drawn from Figs. 2-11 through 2-14.

1. There are six units that report "90+% reflective metallic insulation." Almost all the responding units reported that a fraction of insulation is non-metallic. The two most prevalent RMIs are 2-mil stainless steel manufactured and marketed by Transco Products, Inc. and 2.5-mil stainless steel manufactured and installed by Diamond Power Specialty Company (DPSC). There also appear to be limited quantities of aluminum RMI installed by Transco (this material is mostly on the reactor vessel).
2. Of the 40 PWR units that provided actual percentages of insulations, approximately 30 reported that in excess of 10% of the primary piping is insulated by fibrous materials (e.g., Nukon, mineral wool, and generic fiberglass). In a typical four-loop Westinghouse PWR, the total exposed surface[4] for insulation is approximately 48,600 ft^2. Therefore, our estimate is that it would take at least 600 ft^3 of fibrous insulation to cover 10% of the exposed surface area.
3. Five units have reported that at least 30% of the piping insulation is calcium-silicate. Some of the calcium-silicate appears to be encapsulated; other is exposed to the containment environment and would be susceptible to spray water flow.
4. Other sources of debris as reported by the licensees include the following.
    - *The Fire Barrier Materials*. Of the 58 units that responded to questions related to fire barrier materials, 12 stated that they do not have any fire barrier material. The remaining units stated that the quantity of fire barrier materials varied between 0 and 1500 ft^3.
    - *The Filter Materials*. The air-handling units inside the PWR containments have large quantities of fibrous filter material. Four units have stated that the amount of filter material can be as much as 12,985 ft^2, and others reported on the order of several thousand square feet. All of the responding units stated that the filters are not susceptible to being dislodged or dismantled during a LOCA. Some utilities stated that unlike thermal insulation, the filter materials are "LOCA qualified."
    - *The Containment Coatings*. Figure 2-10 presents the various types of containment coatings present in the PWR containments. The maximum surface area on which Level 1 coatings were applied is about 650,000 ft^2.
    - *Boron Particulates*[5]. All units reported the expected boron concentration in the sump water following a LOCA. This is the minimum licensing-basis boron concentration. The minimum value ranged from 4000 ppm to about 2000 ppm. Figure 2-15 presents these values for each unit.

---

[4] Not all the exposed surface is the primary piping. Some of this area reflects insulation on secondary coolant piping (e.g., steam lines). Note that in general, however, the surface area and type of insulation covering reactor vessel surfaces was not reported by the respondents.

[5] Boron or zinc oxide (from coatings) precipitate could form, depending on temperature and pH levels of the water pool.

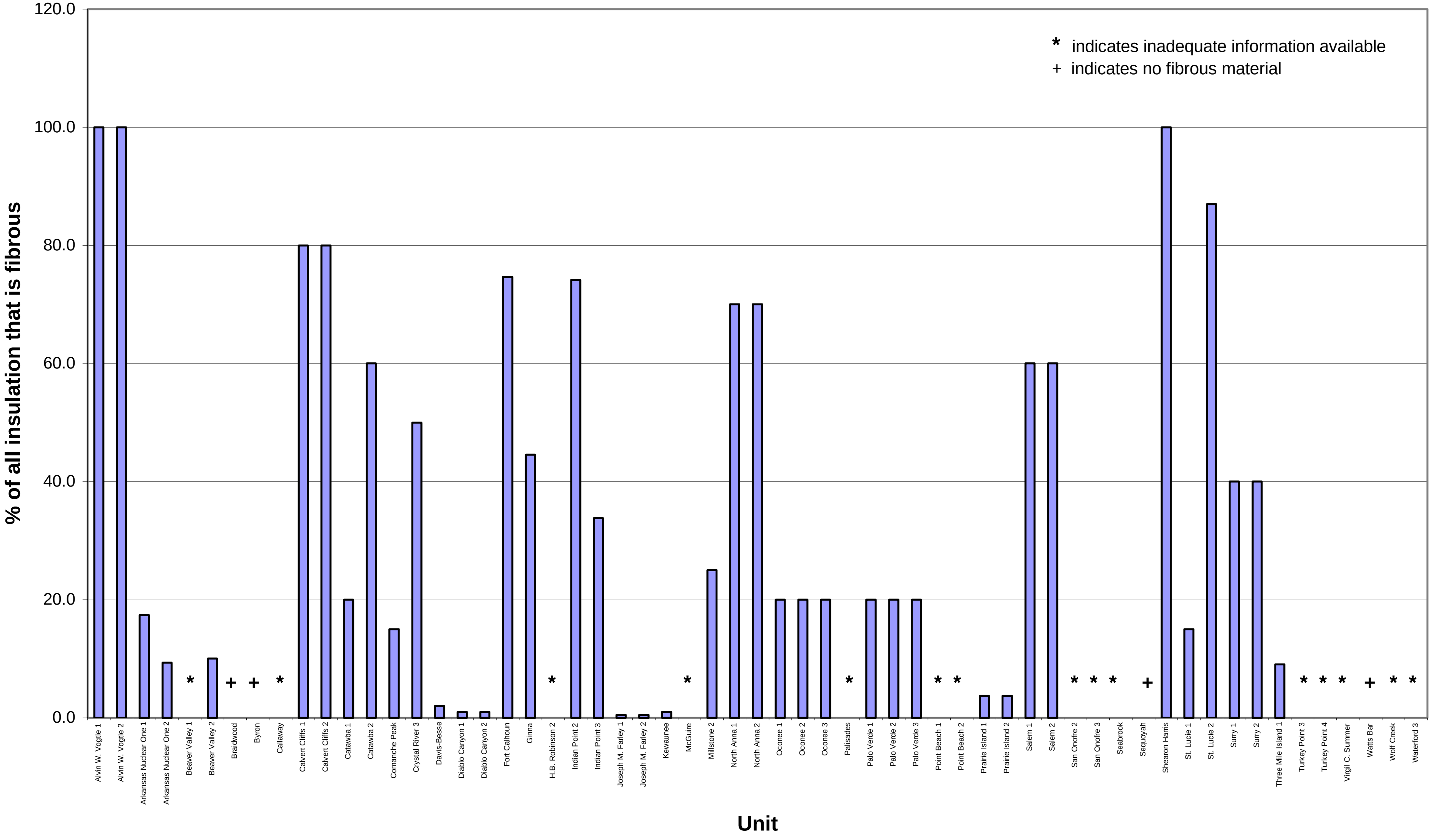


Fig. 2-11. Percentage of all insulation that is fibrous.

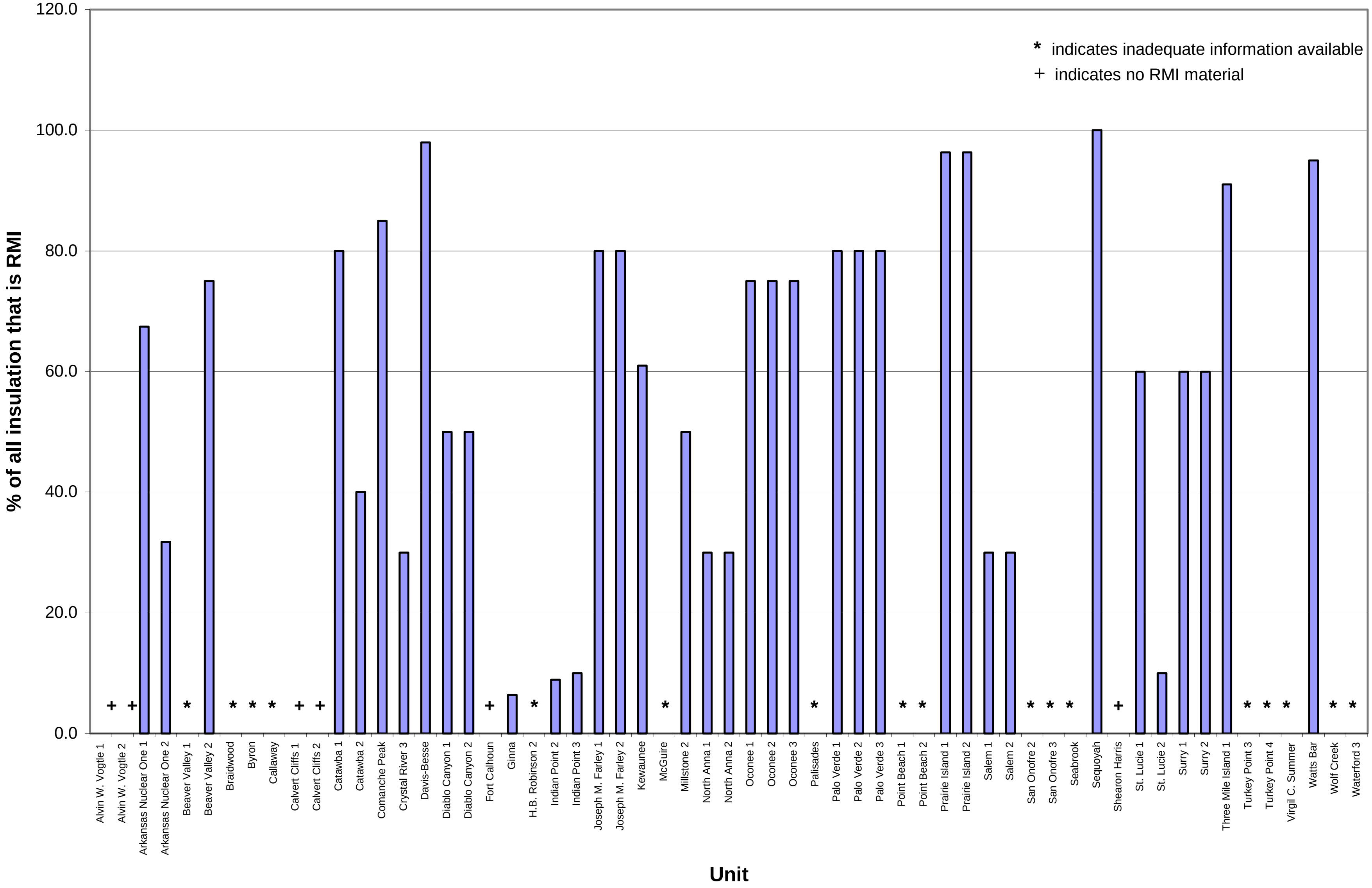


Fig. 2-12. Percentage of all insulation that is RMI insulation.

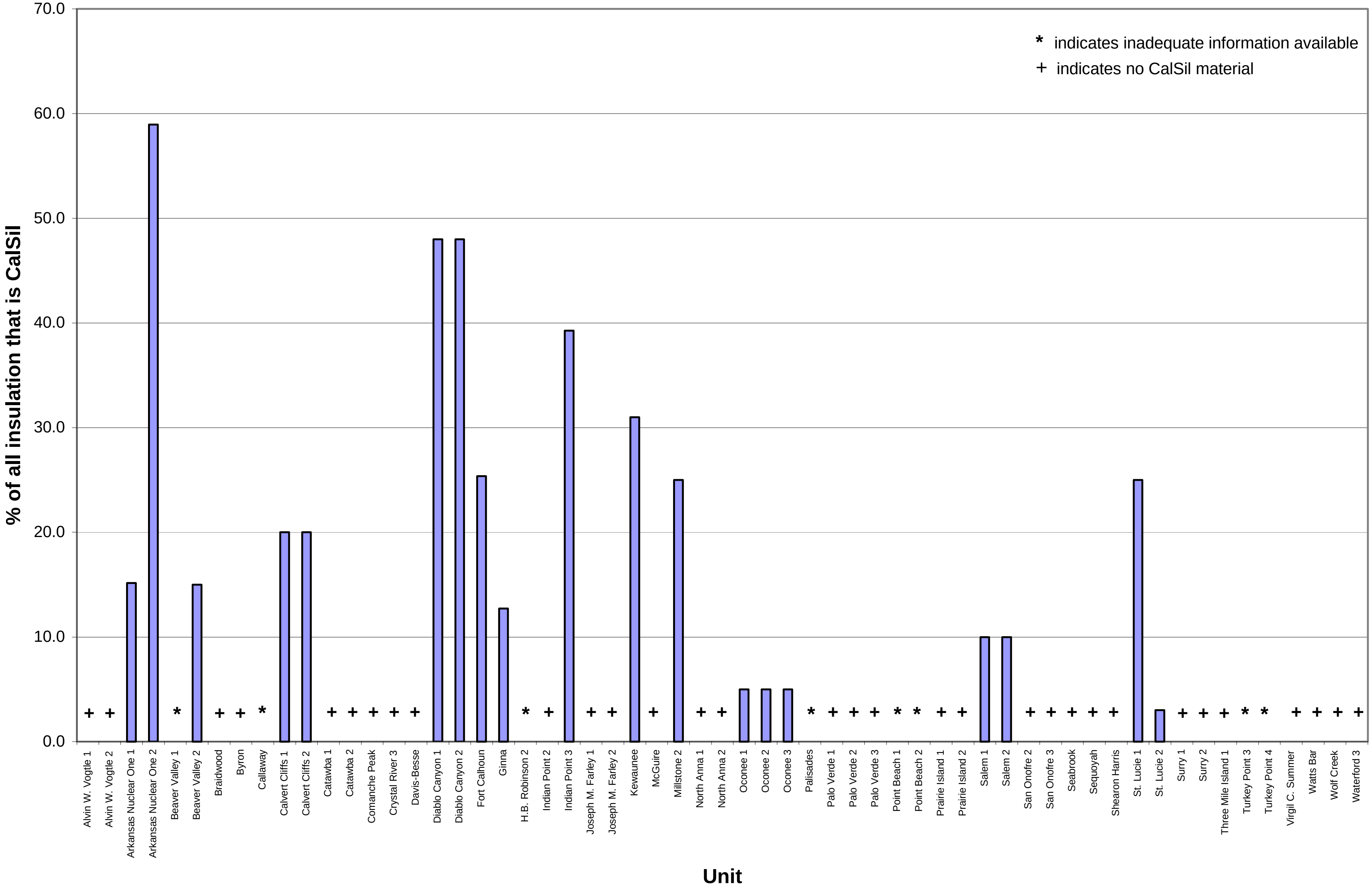


Fig. 2-13. Percentage of all insulation that is calcium-silicate.

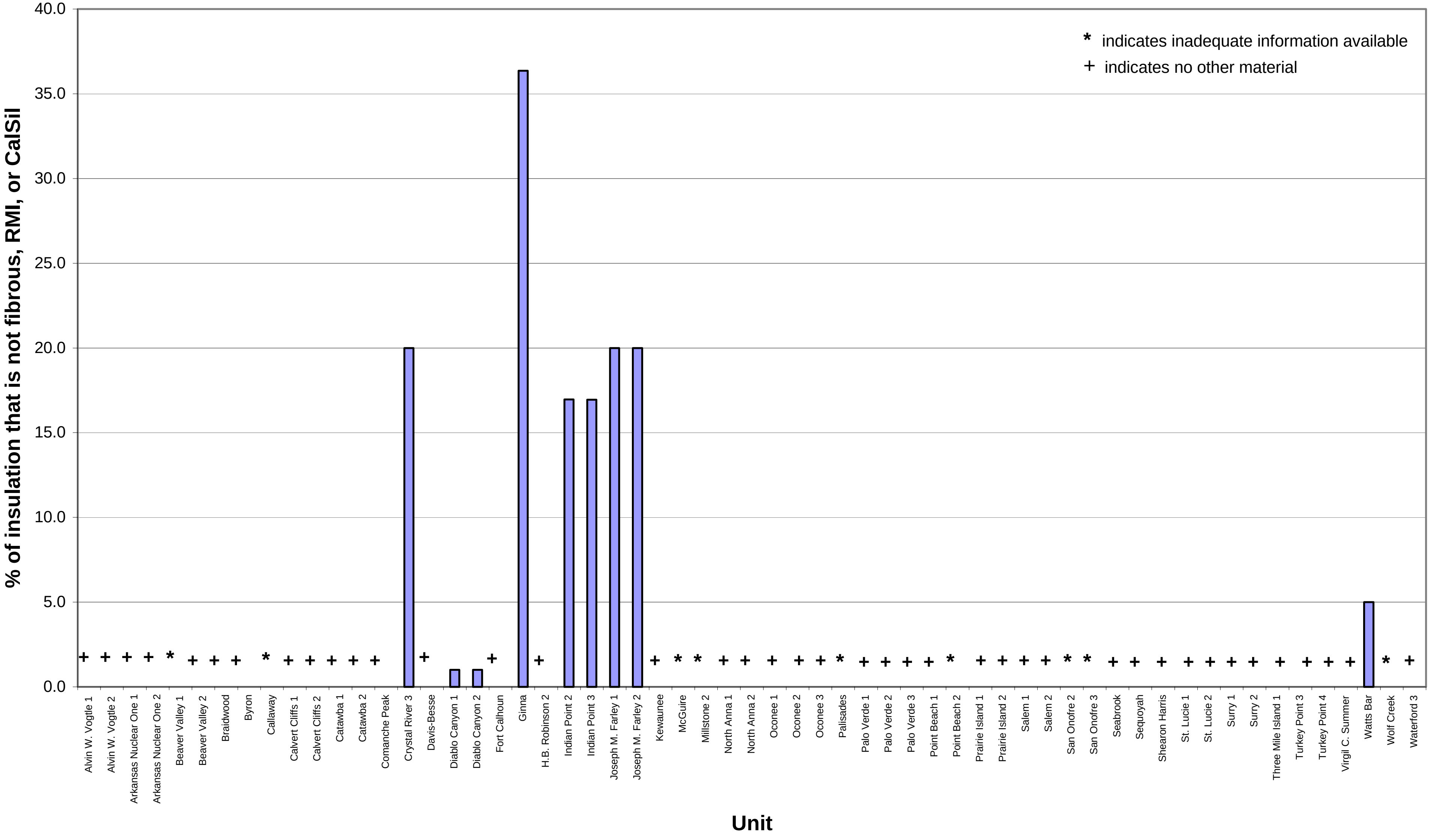
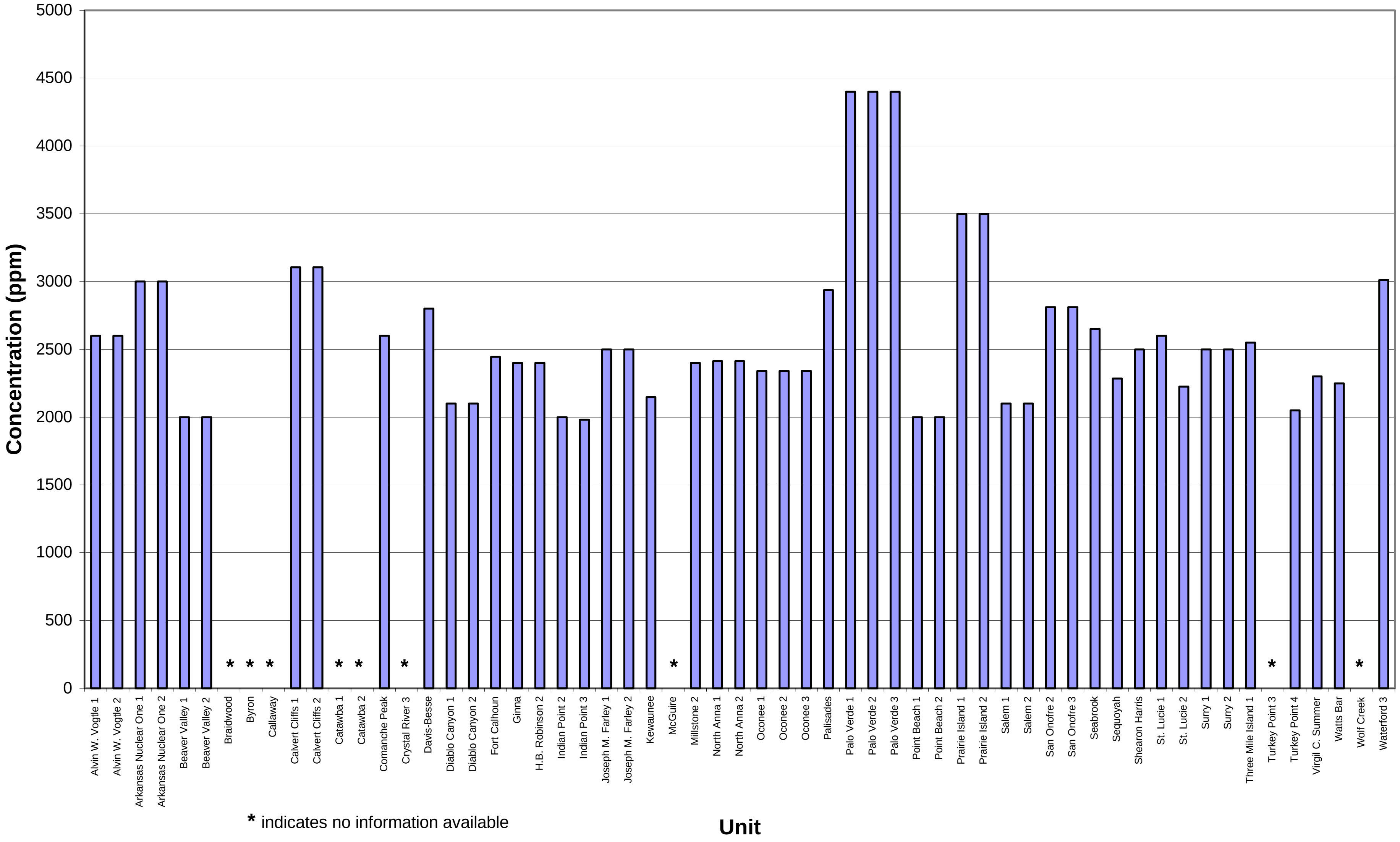


Fig. 2-14. Percentage of all insulation that is other insulation.



* indicates no information available

Fig. 2-15. Pool Boron concentration (ppm) (Questions 5i).

2.2. Analysis of the Industry Responses

2.2.1. LBLOCA Questions

Question 1

Briefly describe the large-break LOCA (LBLOCA) that is the basis for responding to the following questions.

Clear descriptions of the large LOCA scenarios were provided by most of the units that responded. The majority of scenarios were double-ended-guillotine breaks (DEGBs), and most breaks occurred in a cold leg.

Breaks upstream and downstream of a reactor coolant pump were identified. A few of the breaks described were in branch lines (e.g., residual heat removal (RHR) lines, accumulator lines, and pressurizer surge lines). In the branch-line cases, the licensees stated that the appropriate portions are surveilled in accordance with leak-before-break (LBB) considerations. Several units pointed out that their responses to LBLOCA-related survey questions were not unique to a specific large-break scenario.

Question 1a

Following a LBLOCA, what is the containment flood level (i.e., depth of water on the floor) at the time of switchover from the refueling water storage tank (RWST) [or borated water storage tank (BWST)] to the sump? {ft}

The available NPSH at the recirculation pumps depends on the depth of water in the containment pool. The velocities, flow patterns, and turbulence levels (and hence debris transport potential) in the pool depend on pool water depth.

The pool depth depends on (a) credit taken for various water sources in the licensing basis, (b) handling of uncertainties related to the volume of water assumed by the licensee to accumulate in the dead zones, and (c) credit taken for various operator actions and level measurement uncertainties related to RWST switchover. Several units discussed these issues and provided a value that appears to be the minimum water height at switchover. Others seem to have provided a more realistic estimate that may or may not be consistent with the licensing-basis value.

The results of the survey for Question 1a are summarized in Fig. 2-16, where pool depth at switchover is considered to be a normally distributed random variable. As shown in Fig. 2-16, the mean value for water height is 4 ft, with the values ranging between 0.75 and 8 ft. As shown in Fig. 2-1, the pool depth at switchover for North Anna Units 1 and 2, Surry Units 1 and 2, Braidwood, and Byron are less than 1 ft. In the case of North Anna and Surry, these low heights are a reflection of the fact that the inside and outside recirculation pumps start recirculation very early in the accident (5 min) while the ECCS injection is still ongoing. In the case of Braidwood and Byron, the pool height is simply a reflection of the containment/ECCS design.

Question 1b

Following a LBLOCA, when do the low-pressure safety injection (LPSI), RHR, and/or recirculating pumps start to draw suction from the sump? {s}

The timing of switchover to recirculation through the emergency sump is important with regard to debris settling in the containment pool. Longer times to switchover may allow more settling opportunity before the higher pool velocities associated with emergency sump recirculation develop. The time to switchover is affected considerably by (a) the volume of RWST vs the combined flow rates of the ECCS and containment heat removal pumps and (b) the operator response related to ECCS switchover, ECCS/CS throttling, and level indicator uncertainties. The results of the survey for Question 1b are summarized in Fig. 2-17. The mean value for switchover is approximately 20 min, with the actual value ranging from 3 to 60 min. For North Anna Units 1 and 2 and Surry Units 1 and 2, the switchover time is

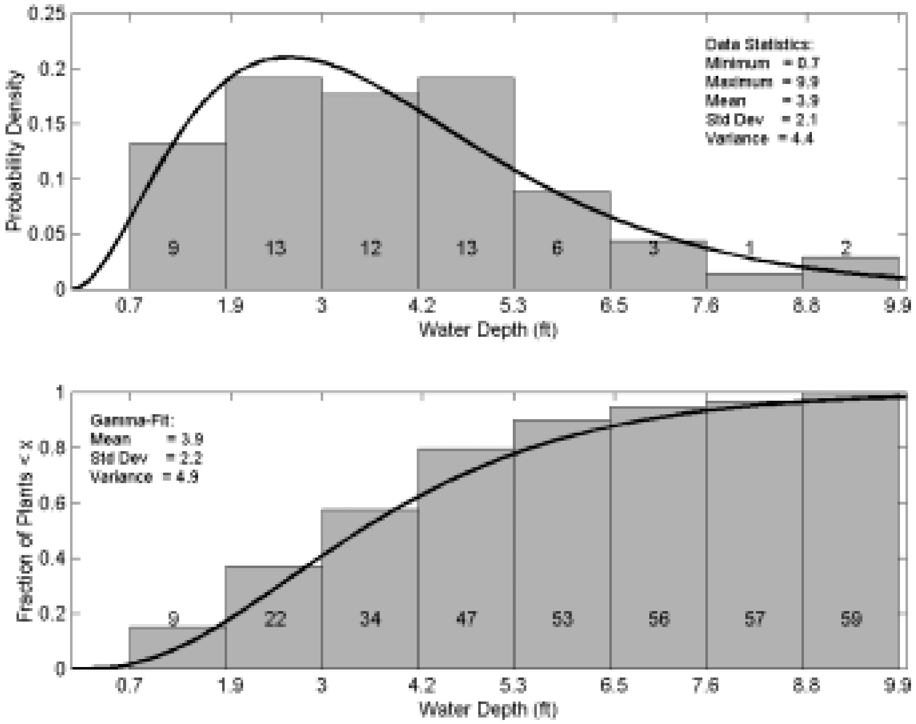


Fig. 2-16. PWR Survey Question 1a. LBLOCA pool depth (above containment floor) at switchover to recirculation through emergency sump.

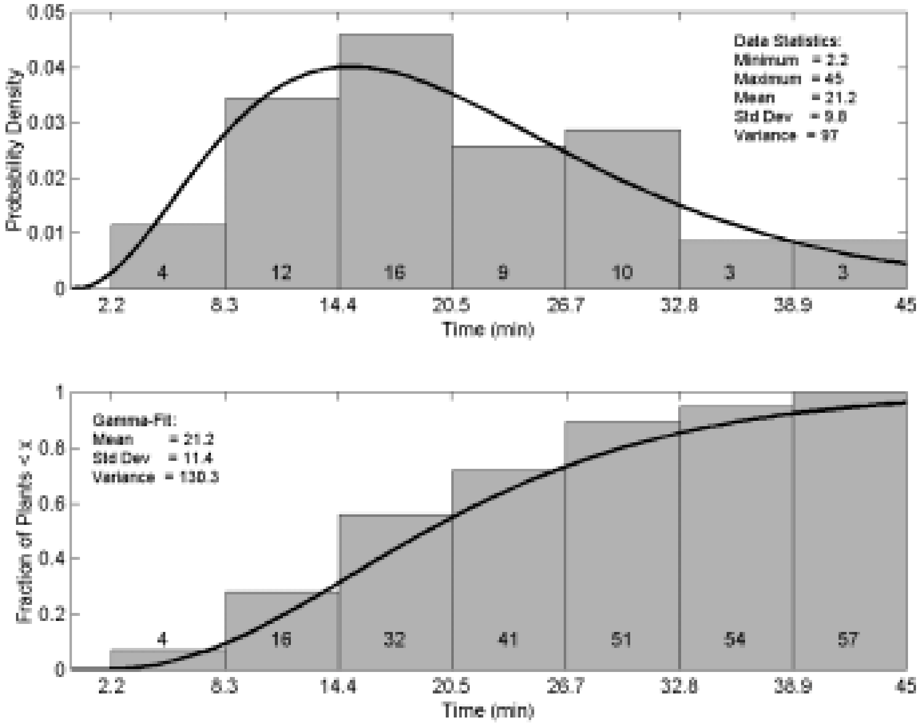


Fig. 2-17. PWR Survey Question 1b. LBLOCA time at switchover to recirculation through emergency sump.

200 s for inside/outside recirculation pumps and 3420 s for the LHSI switchover. For these units, the switchover time is controlled by the unique design of the ECCS, which calls for early activation of the inside and outside recirculation pumps to prolong the LHSI injection from the RWST. On the other hand, Beaver Valley Units 1 and 2 and Calvert Cliffs Units 1 and 2 reported switchover times in excess of 45 min, which is primarily a reflection of the assumptions related to containment-spray operation.

Question 1c

Following a LBLOCA, what is the maximum containment flood level? {ft}

The available NPSH at the recirculation pumps depends on the depth of the containment pool. The velocities, flow patterns, and turbulence levels (and hence debris transport potential) in the pool depend on pool depth. The interest here is whether maximum (or terminal) containment pool depth differs from the depth of the containment pool at switchover to recirculation through the emergency sump. Such a difference might be attributable to a holdup of water in the upper containment as a result of spray operation, or prolonged ice melting, or continued operation of containment sprays in the injection mode even after ECCS switchover.

The results of the survey for Question 1c are summarized in Fig. 2-18. The maximum pool height varies between 3 and 18 ft, depending on the containment type and RWST capacity. All of the ice condensers have a maximum height in excess of 10 ft. Several large-dry PWRs also responded that the maximum height would be larger than the minimum height, but the difference is attributed to uncertainties such as:

(1) no leakage to the dead areas (e.g., reactor cavity),
(2) initial RWST inventory at maximum, and
(3) switchover occurring at level later than the set point.

In other words, many PWR licensees used this question to provide what they considered to be the most likely water height vs the licensing-basis water height given in response to Question 1a.

Question 1d

Following a LBLOCA, when is the maximum containment flood level reached? {s}

The time at which terminal pool depth is reached relates to long-term debris transport concerns. Greater depth translates to smaller velocities in the containment pool and hence smaller debris transport potential. Presumably, the sooner terminal pool depth is achieved the better. The results of the survey for Question 1d are summarized in Fig. 2-19.

Question 1e

Which water sources are used to determine flood level [e.g., Reactor Coolant System (RCS) spillage, RWST inventory, containment spray, ice melt, etc.]?

The sources of water identified in the industry responses vary somewhat. Generally, the following were called out:

- RCS spillage,
- Spray additive tank inventory,
- RWST inventory, and
- Accumulator inventories.

Only a few units mentioned accounting for dead-ended compartments where water could become unavailable for recirculation. Two ice-condenser responses identified a portion of the ice bed as being credited in containment pool depth calculations.

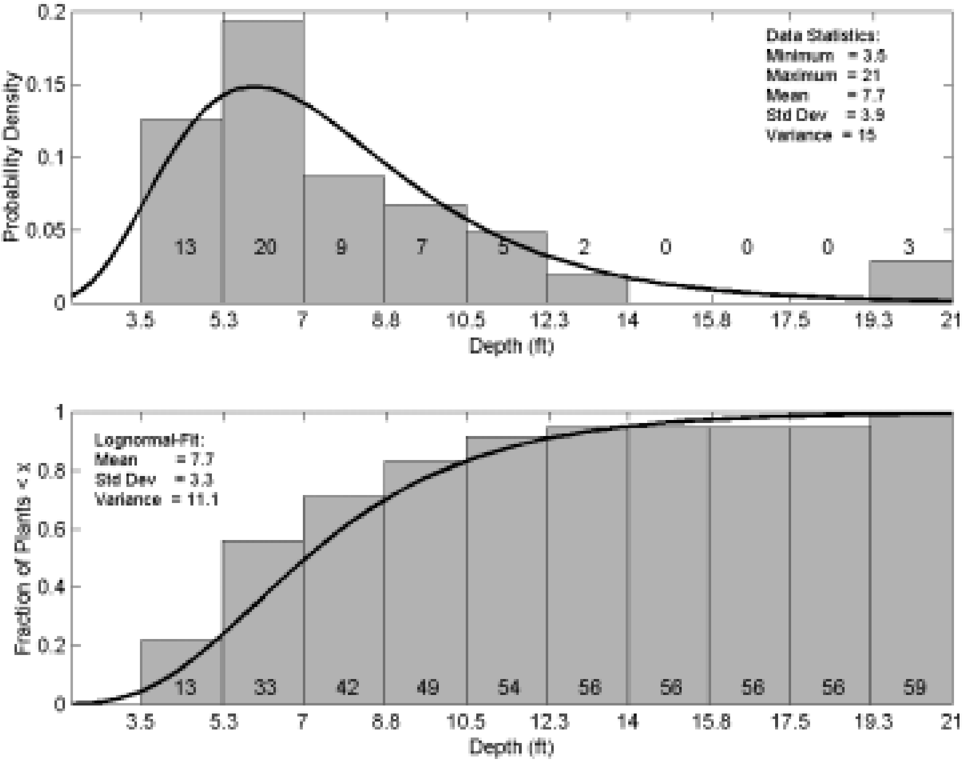


Fig. 2-18. PWR Survey Question 1c: LBLOCA maximum pool depth (above containment floor).

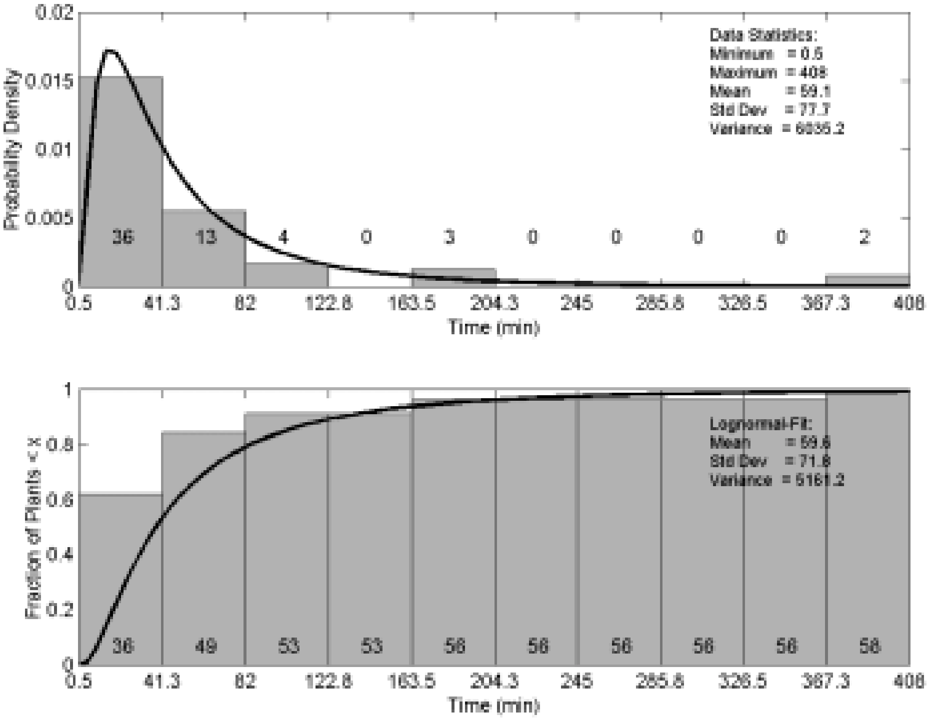


Fig. 2-19. PWR Survey Question 1d: LBLOCA minimum time at which maximum pool depth is reached.

2.2.2. MBLOCA Questions

Question 2

Briefly describe the medium-break LOCA (MBLOCA) or intermediate-break LOCA that is the basis for responding to the following questions.

The responses to Questions 2a–2e were largely incomplete. Many units pointed out that a medium LOCA is not a design-basis condition, and because of this, little attention has been given to predicting medium LOCA progression. Some valuable comments were provided that related medium LOCA expectations relative to large LOCA calculations, but little quantitative information was obtained for these questions. Statistics on the responses are not presented.

2.2.3. Containment Sump Questions

Question 3

Questions 3a through 3o request information regarding various sump geometric design parameters in sketches. Figure 2-20 provides a schematic of an idealized PWR sump and shows the geometric information sought by questions 3a through 3o.

Provide a sketch of the containment sump(s).

How an emergency sump is configured and how its screens and/or trash racks are oriented are important with respect to sump blockage. Forty units responded with drawings of their sumps.

Portions of plant drawings showing sump configurations corresponding to the screen orientations are given in Figs. 2-21 to 2-24.

A review of sketches provided by the responding utilities confirmed that there is no standard sump design. Sumps vary widely in their design, size, and screen arrangement. Figures 2-25 and 2-26 present schematics of some of the idealized sump-screen arrangements (orientations) with respect to the pump suction. Based on this idealization, it is clear that sumps can be divided broadly into five categories.

Box-Type : As shown in Figs. 2-25(d) and 2-25(e), a rectangular box made up of the screen and grating surrounds the suction line. In some designs, the box is below the containment floor level in the sump pit. As shown in Fig. 2-27, 16 units have sumps that closely resembly a box-type sump.

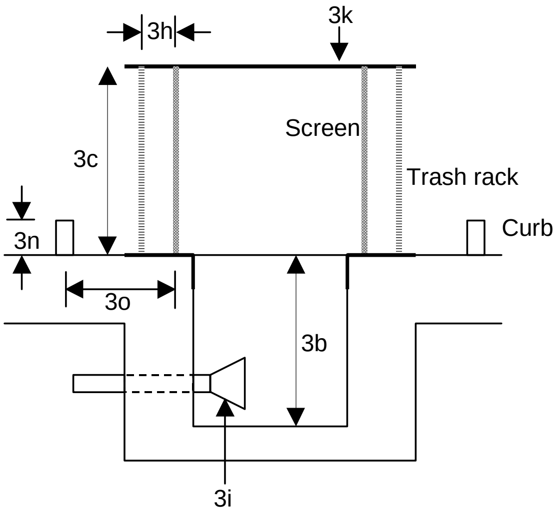
A-Frame. As shown in Fig. 2-25(a), the screen forms an A-frame that surrounds the sump. In many cases, the top of the A-frame is not submerged in water, allowing for free surface dynamics. Typically, A-frames are used to enlarge the screen area available for debris accumulation. About five units currently use A-frame arrangements.

Horizontal. Figure 2-25(f) shows a horizontal screen arrangement. In some extreme cases, a horizontal screen arrangement resembles storm drains, with or without debris curbs. Typically, horizontal screens are used on long trenches that act as drains connecting the containment floor to the sump. About 13 units currently use horizontal screens, with or without curbs.

Lean-To, Inverted Lean-To and Vertical. Examples of lean-to, inverted lean-to and vertical arrangements are shown in Figs. 2-26(a), 2-25(b) and 2-25(c), respectively. In these sumps, the sump screen is basically a semi-vertical flat segment located at the entrance to the sump cavity.

Cylindrical. Some of the newer units used cylindrical screens in lieu of box-type screens. In some cases, the cylinders are located below the floor level [see Fig. 2-26(b)].

Figure 2-27 shows number of each type of sump screen orientation for the population of units responding to the survey.



Question #	Information Type
3a	No. of cont. sumps
3b	Sump depth
3c	Height above floor
3d	Whether it has screen
3e	Screen area
3f	Screen hole size
3g	Trash rack status
3h	Distance between trash rack and screen
3l	Trash rack area
3j	Trash rack hole size
3k	Solid plate
3l	Vortex suppressor
3m	Debris curb
3n	Debris curb height
3o	Distance between debris curb and screen

Fig. 2-20. An idealized PWR sump arrangement.

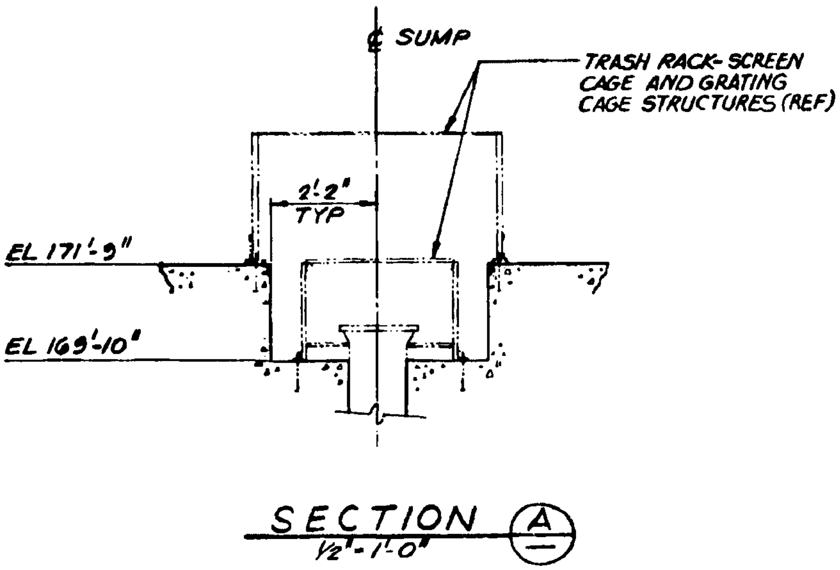


Fig. 2-21. A typical box-type sump with no vortex suppressor.

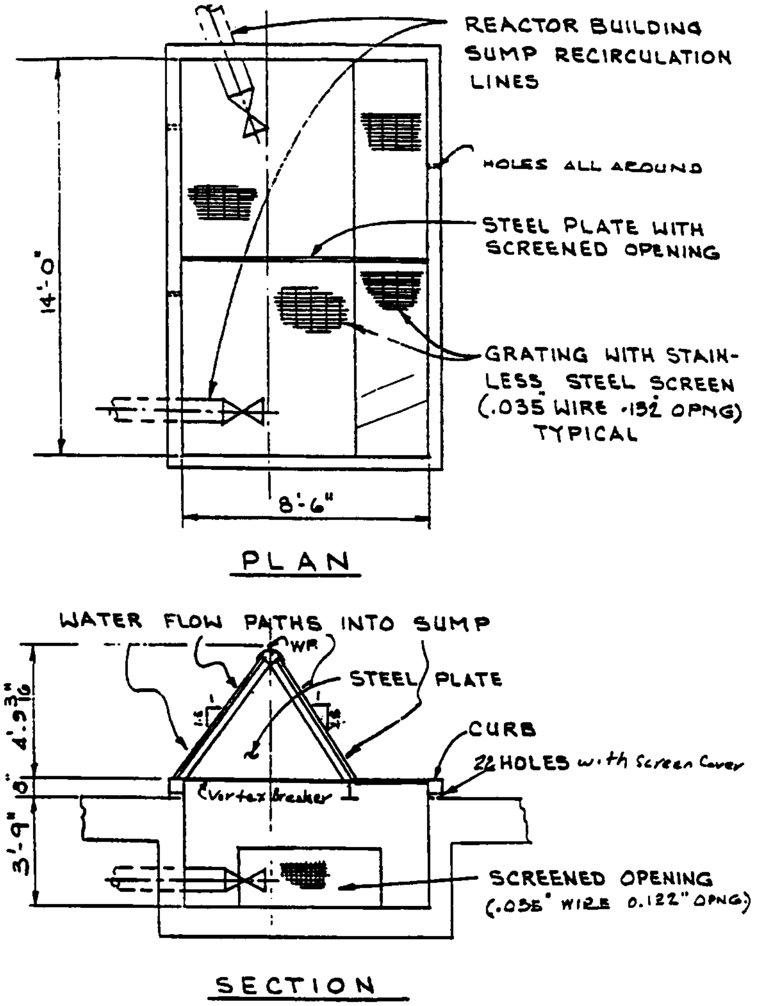


Fig. 2-22. A typical A-frame sump screen arrangement. (This drawing also shows how licensees have used dividers to divide a single sump into two separate compartments to address single-failure considerations.)

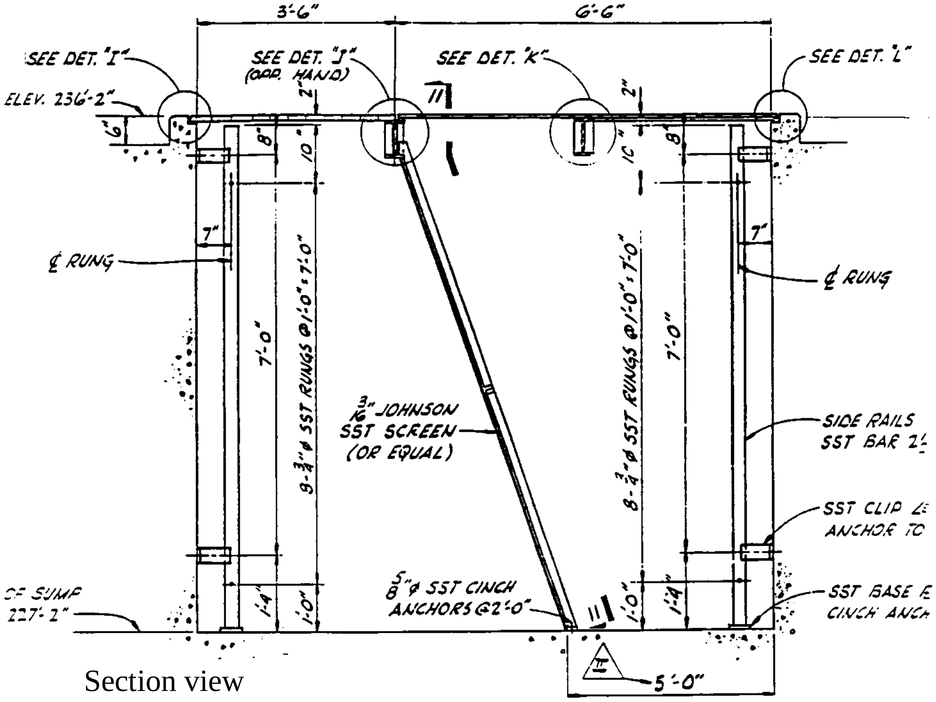


Fig. 2-23. Plant drawing of a sump where the sump screen leans on supporting structures.

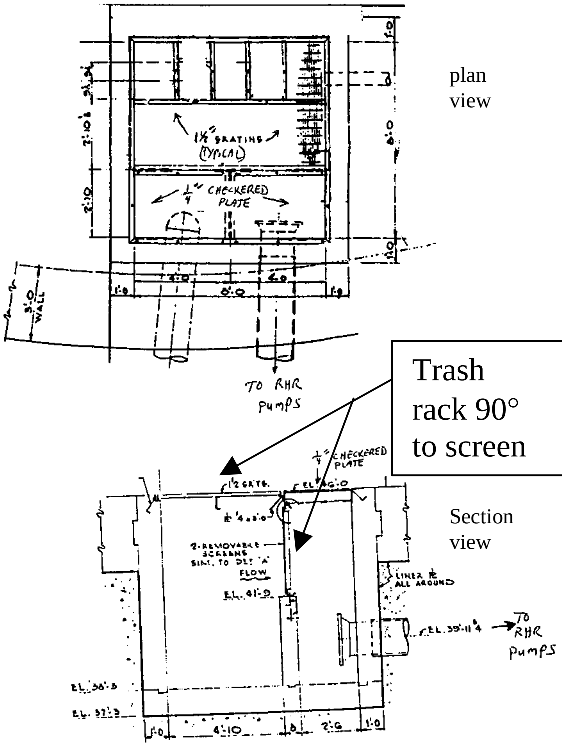
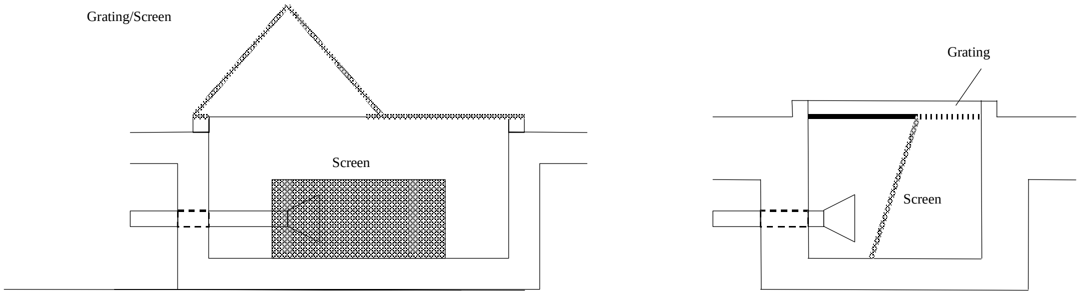
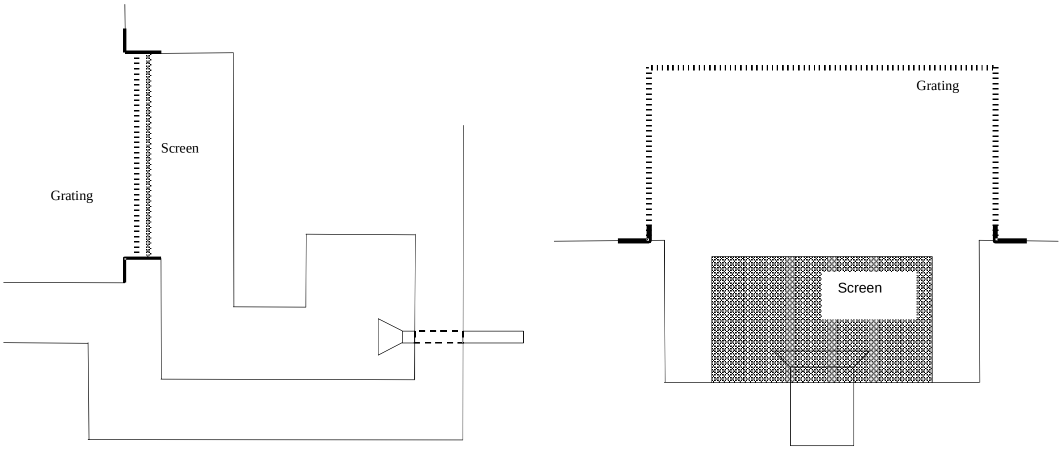


Fig. 2-24. Drawing of the arrangement where the sump screen is below the containment floor level in the pit.



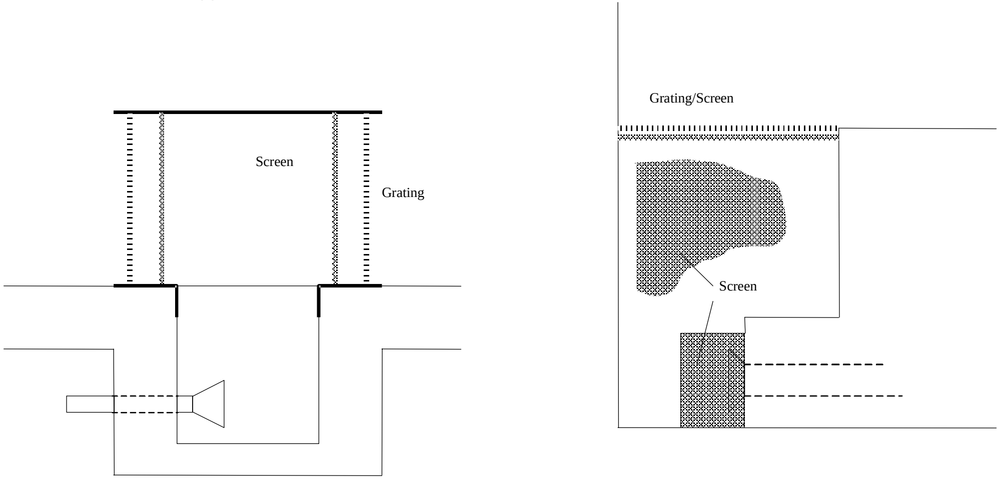
(a) A Frame

(b) Inverted Lean To



(c) Vertical

(d) Box Type



(e) Box Type

(f) Horizontal

Fig. 2-25. Idealized drawings of various sump arrangements at PWRs.

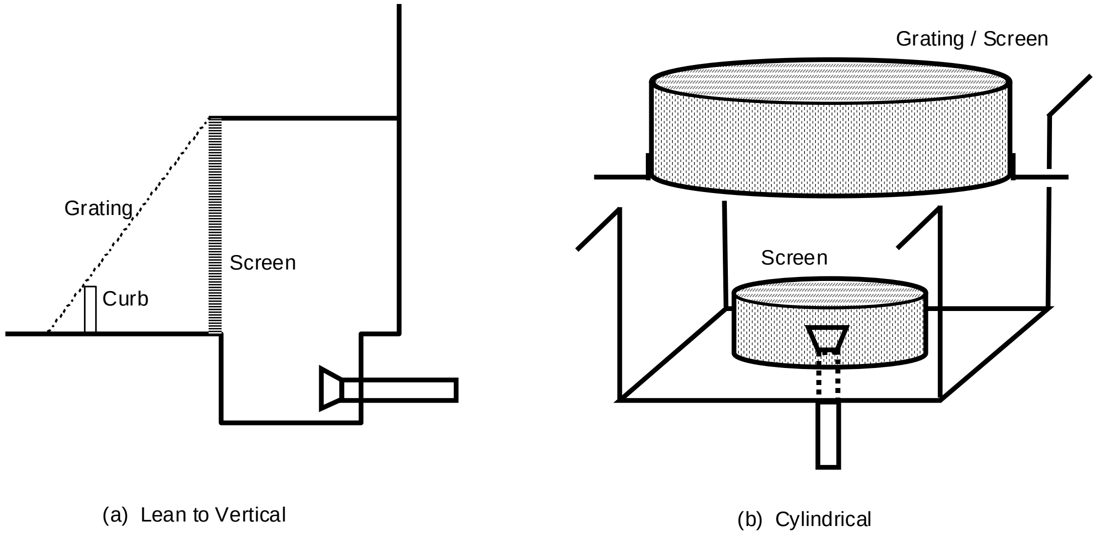


Fig. 2-26. Idealized drawings of various sump arrangements at PWRs.

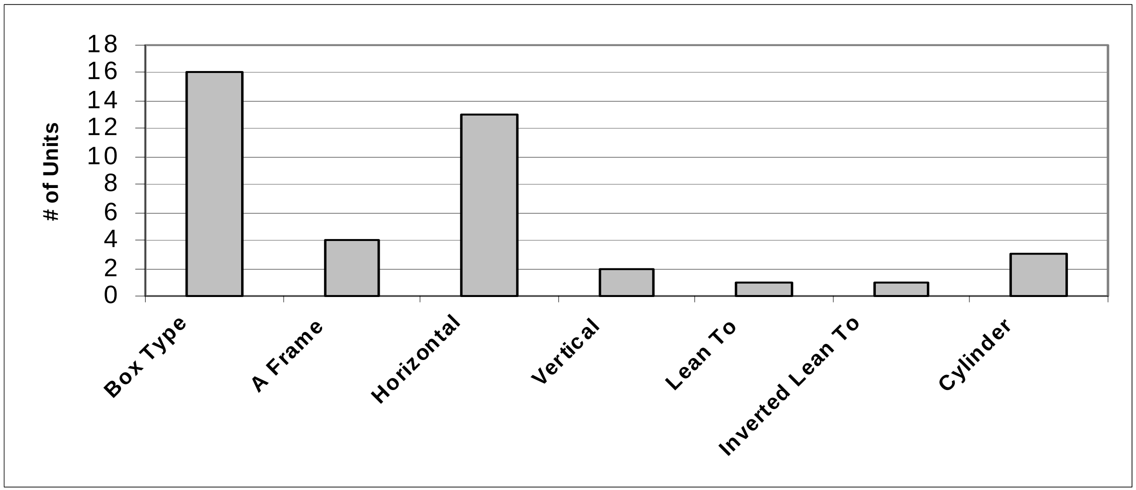


Fig. 2-27. Number of units with each sump screen orientation.

Of unique concern would be horizontal screens or trash racks positioned at or below floor level. Debris that might tumble along the floor of the containment as water moves toward the sump conceivably could accumulate more readily on such screens. (A curb in front of the sump may negate this concern.) No units have been identified that have horizontal fine mesh screens at or below floor level. Two units were identified that have trash racks at floor level with no significant curb in front of them.

Question 3a

How many containment (recirculating) sumps?

Statistics on the number of emergency recirculation sumps that PWR containments have were determined from containment floor layout drawings. Sumps were considered distinct only if they are truly separated spatially and are protected by separate screen arrangements. Sumps having physically separate but adjacent compartments were counted as a single sump. As shown in Fig. 2-22, many units have a single sump protected by a single screen. However, steel plates were placed inside the sump to divide it into “independent sumps” as required to address the single-failure consideration. Forty-two units were identified as having a single sump. Sixteen clearly have two or more spatially separated sumps.

Question 3b

What is the depth below containment floor of containment (recirculating) sumps(s)? {ft}

The results of the survey for Question 3b are summarized in Fig. 2-28. Typically, a sump pit is about 4 ft deep. The very deep sump pits are located in a remote area much below what is considered the containment floor (e.g., Palo Verde).

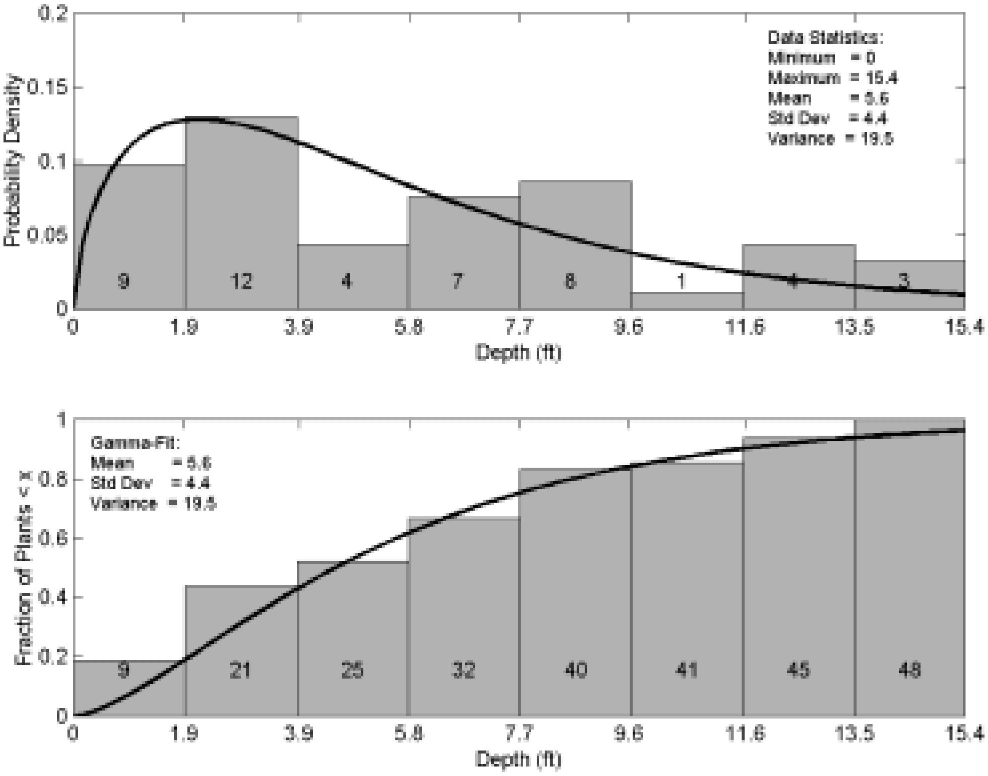


Fig. 2-28. PWR Survey Question 3b: Depth of containment sump.

Question 3c

What is the height above the containment of the containment (recirculating) sump screen(s)? {ft}

Table 2-1 presents the survey responses to Question 3c. As evident from the data presented in this table, most units have sump screens that are above the containment floor. However, a significant number have sump screens at or below the floor level. Figure 2-29 summarizes the data in Table 2-1 in three categories: (a) sump screen above the containment floor, (b) a sump screen at the containment floor level, and (c) sump screen below the containment floor level.

Table 2-1. PWR Survey Question 3c: Sump-Screen Height

Unit Name	Distance of Sump Screen Above Containment Floor (ft)
Alvin W. Vogtle 1 & 2	0
Arkansas Nuclear One 1	4.75
Arkansas Nuclear One 2	7
Beaver Valley 1 & 2	5
Braidwood	Did not answer
Byron	Did not answer
Callaway	Did not answer
Calvert Cliffs 1 & 2	3.5
Catawba 1 & 2	6
Comanche Peak	6.25
Crystal River 3	Below
Davis-Besse	2
Diablo Canyon 1 & 2	5
Fort Calhoun	3.5
Ginna	Below
H.B. Robinson 2	0
Indian Point 2	0
Indian Point 3	Below
Joseph M. Farley 1 & 2	2.5
Kewaunee	5.083
McGuire	Did not answer
Millstone 2	1.6
North Anna 1 & 2	6.25
Oconee 1, 2 & 3	Below
Palisades	0
Palo Verde 1, 2 & 3	4.5
Point Beach 1 & 2	6
Prairie Island 1 & 2	2.75
Salem 1 & 2	3.75
San Onofre 2 & 3	3.5
Seabrook	2.2
Sequoyah	2
Shearon Harris	3.8
St. Lucie 1 & 2	0
Surry 1 & 2	5
Three Mile Island 1	0
Turkey Point 3 & 4	1
Virgil C. Summer	0
Watts Bar	8
Wolf Creek	8.6
Waterford 3	5

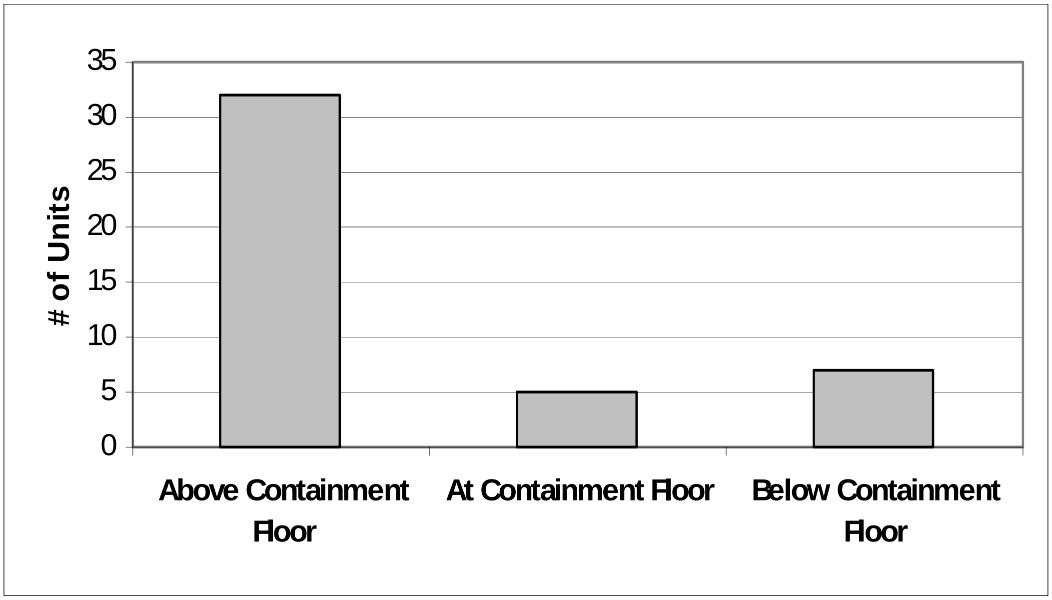


Fig. 2-29. Top of the sump screen with respect to the containment floor.

Responses to this question also can be used to determine whether the sump screen would be completely submerged under water. (This can be done by comparing responses to Question 1a with responses to this question.) This comparison shows that at the time of switchover, about 11 units will have a condition where the screens would not be completely submerged.

Question 3d

Does the sump have a screen?

Of the 58 units responding, only two (Prairie Island 1 and 2) reported not having sump screens. It is not clear if Prairie Island Units 1 and 2 have a licensing basis that allows operation without a sump screen or if the response is simply an error. Prairie Island did not provide answers to any questions related to the sump screen. It appears that Prairie Island Units 1 and 2 rely on a ¾ 4-in. x 3-1/8-in. trash rack for filtration.

Question 3e

How much screen area is available?

The results of the survey for Question 3e are summarized in Fig. 2-30. The sump screen areas ranged from 12 ft^2 to 575 ft^2. There appears to be no correlation between the sump screen area and the plant vintage, insulation type, or ECCS flow rate. The sump-screen area estimates provided by the licensees have the following uncertainties.

1. The sump screens that are not expected to be completely submerged (e.g., St. Lucie) did not reduce the area that would be unavailable for debris deposition.
2. Many licensees have a licensing-basis assumption regarding the fraction of sump area lost to accommodate debris. These fractions were not reflected accurately in the licensee responses.

In spite of these drawbacks, it is clear that PWRs have a large variability in the sump screen area.

Question 3f

What is the hole size in the sump screen? {in.}

The screen hole size may affect debris filtration and accumulation. The results of the survey for Question 3f are summarized in Fig. 2-31.

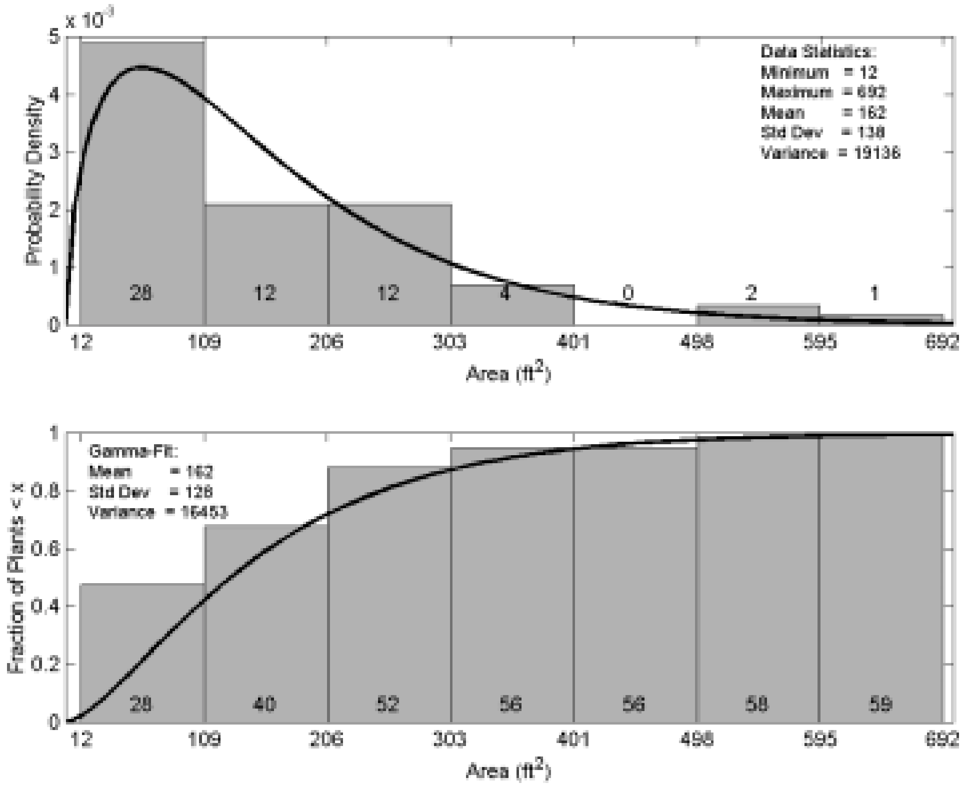


Fig. 2-30. PWR Survey Question 3e: Sump screen area.

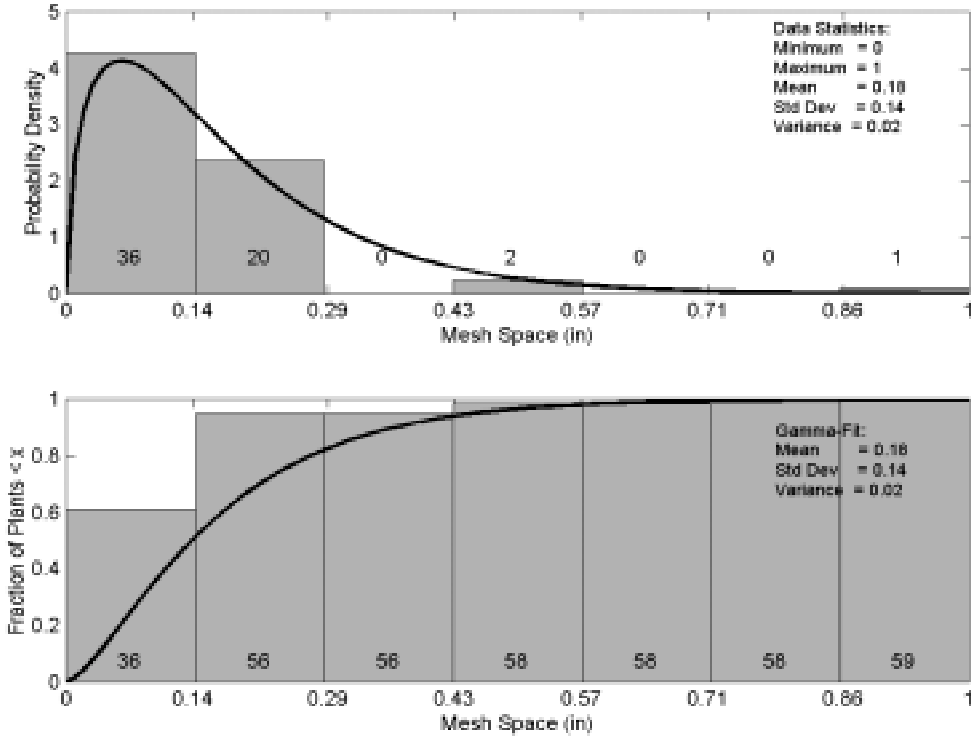


Fig. 2-31. PWR Survey Question 3f: Sump-screen mesh size.

The survey suggests two things.

1. A large number of units (32 out of 58 units that responded) use a 0.125-in. (1/8-in.) or smaller mesh size to screen out particles. The smallest mesh size is 0.078-in. mesh used by Waterford 3.
2. The remaining 26 units use larger mesh [> 0.125 in. (1/8 in.)]. The largest mesh clearance is 0.78 in. used at Surry Units 1 and 2.[6] The trash rack hole size installed at Prairie Island Units 1 and 2 was reported to have a mesh size of 0.75 in. x 3.125 in. The most common mesh size of 0.25 in. is used in 13 units.

This survey result is important because it may have several implications on debris ingestion and its effect on the ECCS performance.

Question 3g

Does the sump have a trash rack?

Of the 58 units that responded, only the 15 listed below reported not having a trash rack in front of their sump. It is possible that some did not distinguish between the trash rack and the fine screen because they are attached to each other.

- Ginna
- Diablo Canyon 1
- Diablo Canyon 2
- Kewaunee
- Palisades
- St. Lucie 1
- TMI-1
- Turkey Point 3
- Turkey Point 4
- ANO-2
- Braidwood
- Byron
- Callaway
- McGuire
- Watts Bar

Question 3h

What is the distance between the sump screen and the trash rack? {in.}

The responses are grouped in Table 2-2. Individual unit values are included in parenthesis. Units not having a trash rack are included as a group, as are those having the trash rack and sump screen oriented at right angles (90°) to each other.

Question 3i

How much trash rack is available? {ft sq.}

The results for Question 3i are summarized in Fig. 2-32. The survey suggests that in many cases, the surface area of the trash racks is smaller than that of the screen. The significance of this finding is not clear, but it may mean that the trash racks may form the limiting case in some units.

---

[6] In June 2001, the authors received an email stating that the 0.78 in. mesh clearance provided for both Surry Units is incorrect. However, the correct value was not provided to the authors or NRC prior to release of this report.

Table 2-2. PWR Survey Question 3h: Separation Between Sump Trash Rack and Screen

No Trash Rack	0–1 in.	1–6 in.	6–12 in.	12+ in.	90°
Ginna	Arkansas 1 (0+)	Fort Calhoun (4+)	Salem 1 (9+)	A .W. Vogtle 1 (32)	Crystal River 3
Palisades	Arkansas 2 (0+)	Joseph M. Farley 1 (6)	Salem 2 (9+)	A. W. Vogtle 2 (32)	Indian Point 2
St. Lucie 1	Calvert Cliffs 1 (0)	Joseph M. Farley 2 (6)	Wolf Creek	Davis-Besse (18)	Indian Point 3
TMI 1	Calvert Cliffs 2 (0)	Palo Verde 1 (3+)		H. B. Robinson 2 (96)	Oconee 1
Turkey Point 3	Catawba 1 (1)	Palo Verde 2 (3+)		North Anna 1 (12+)	Oconee 2
Turkey Point 4	Catawba 2 (1)	Palo Verde 3 (3+)		North Anna 2 (12+)	Oconee 3
Diablo Canyon 1	Millstone 2 (1)	Point Beach 1 (5+)		St. Lucie 2 (32)	Virgil C. Summer
Diablo Canyon 2		Point Beach 2 (5+)		Waterford 3 (24)	
Watts Bar		San Onofre 2 (3+)		Shearon Harris (0+)	
Kewaunee		San Onofre 3 (3+)		Beaver Valley 1 (35)	
ANO2		Surry 1 (2+)		Beaver Valley 2 (16)	
Braidwood		Surry 2 (2+)			
Byron		Seabrook (4.0)			
Callaway		Comanche Peak (5.8)			
McGuire					

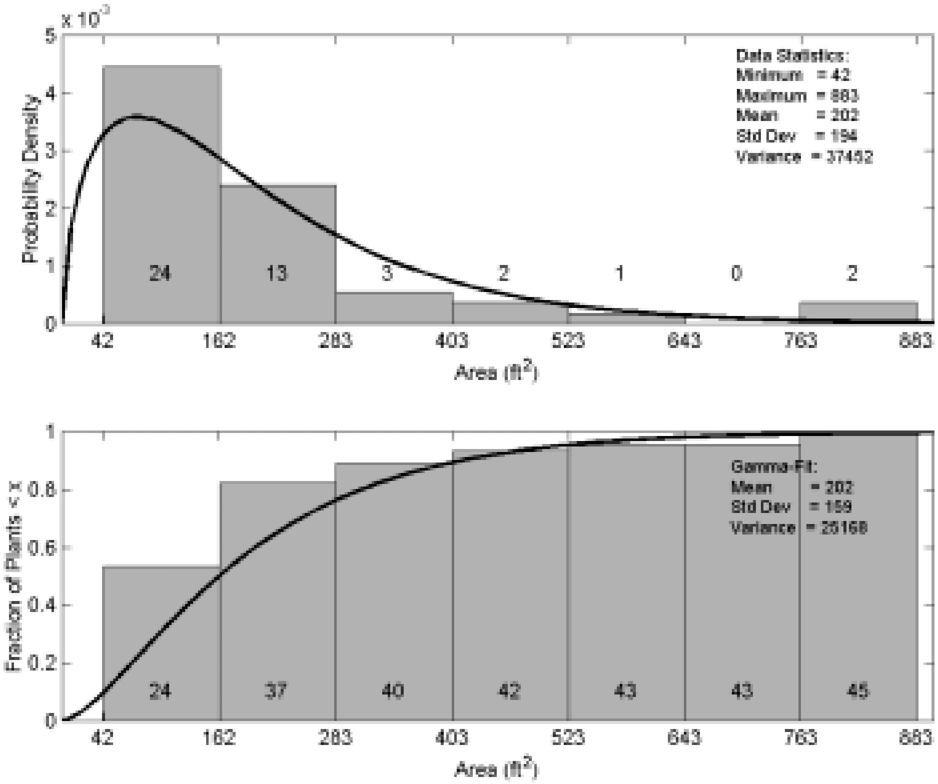


Fig. 2-32. PWR Survey Questions 3i: Emergency sump trash-rack area.

Question 3j

What is the hole size in the trash rack? {in.}

The results of the survey for Question 3j are summarized in Fig. 2-33. Note that the size presented is the open area of a single opening ($in.^2$). Area is presented because trash-rack grids are typically rectangular rather than square, and the actual dimensions vary considerably. The descriptions contained in some of the responses suggest that many units use common industrial gratings as debris trash racks.

Question 3k

Does the sump have a solid or screen cover plate?

Sump covers were identified as being steel plate, steel grating, or screen. Table 2-3 shows which of these sump covers each reporting unit has. Figure 2-34 is an illustration of a sump with a steel-plate cover.

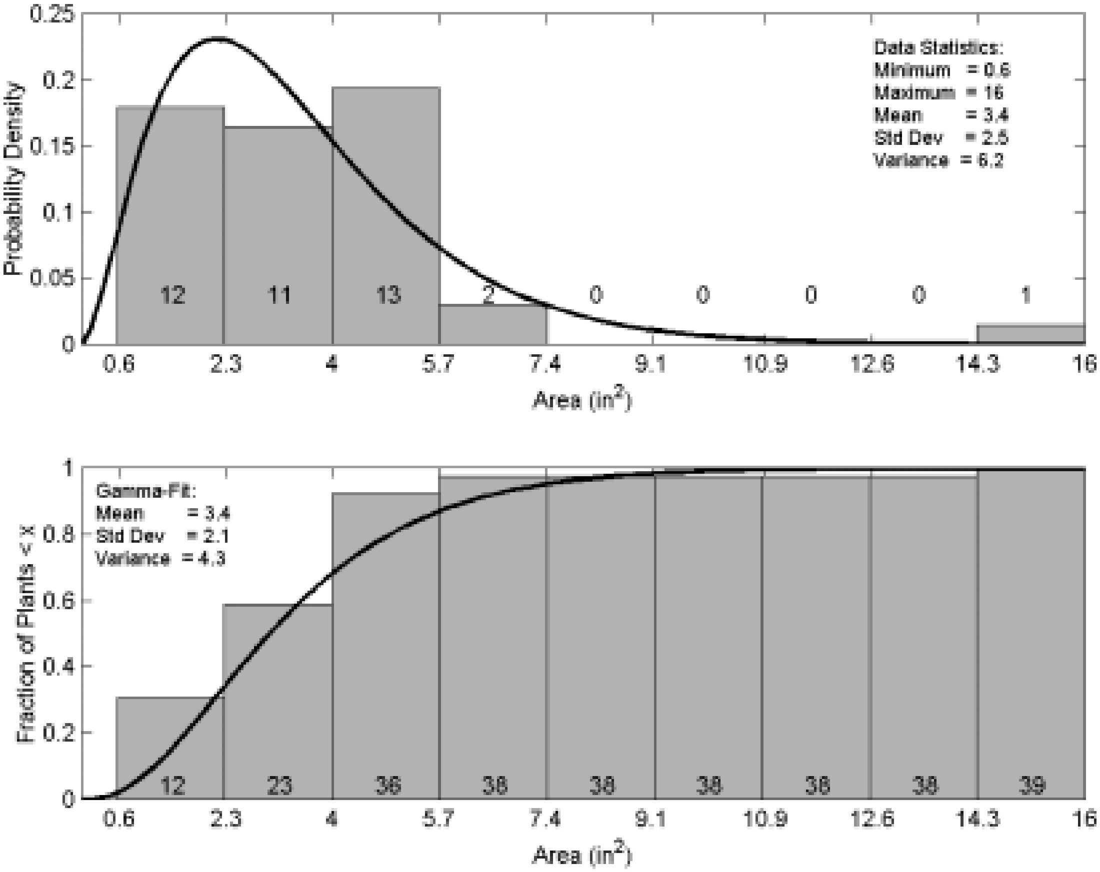


Fig. 2-33. PWR Survey Question 3j: Emergency sump trash rack grid size (open area).

Table 2-3. PWR Survey Question 3k: Sump Cover

Steel Plate	Steel Grating	Screen
A. W. Vogtle 1	Ginna	Arkansas 1
A. W. Vogtle 2	Indian Point 3	Arkansas 2
Catawba 1	Palisades	Calvert Cliffs 1
Catawba 2	Prairie Island 1	Calvert Cliffs 2
Davis-Besse	Prairie Island 2	Crystal River 3
Millstone 2		Fort Calhoun
North Anna 1		H. B. Robinson 2
North Anna 2		Indian Point 2
Oconee 1		Joseph M. Farley 1
Oconee 2		Joseph M. Farley 2
Oconee 3		St. Lucie 1
Palo Verde 1		St. Lucie 2
Palo Verde 2		Turkey Point 3
Palo Verde 3		Turkey Point 4
Point Beach 1		Beaver Valley 1
Point Beach 2		Beaver Valley 2
Salem 1		Diablo Canyon 1
Salem 2		Diablo Canyon
San Onofre 2		Watts Bar
San Onofre 3		Wolf Creek
Shearon Harris		
Surry 1		
Surry 2		
TMI 1		
Virgil C. Summer		
Comanche Peak		
Seabrook		

Question 3l

Inside the sump, do the ECCS pumps draw suction through a vortex suppressor or strainer? If so, provide a sketch.

Configurations inside emergency sump pits at the inlets to ECCS suction piping were reported that have

- a vortex suppressor (solid metal plate),
- a strainer (a screen or perforated plate attached directly to the sump inlet pipe),
- a vortex suppressor with strainer, and
- no vortex suppressing structure.

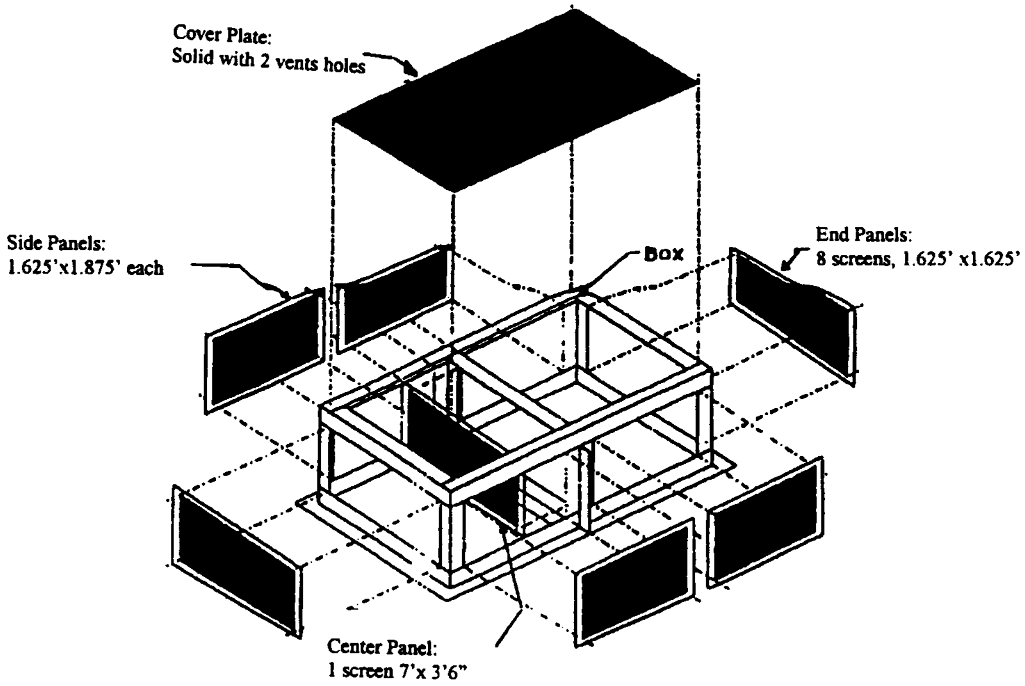


Fig. 2-34. Schematic of a box-type sump with a steel cover plate.

Table 2-4 identifies which of the above configurations each reporting unit has. Figure 2-35 is an illustration of a sump pit with a vortex suppressing structure at the inlets to the ECCS suction piping.

Question 3m

Does the sump have a debris curb?

Figure 2-36 is a portion of a plant drawing showing a sump with a curb. The presence of a curb on the floor of the containment in front of the sump screens could stop tumbling debris from reaching the screens. Of the 54 units responding, all but 18 reported having a curb (or an effective curb) in front of their sump(s). The following units do not have a curb.

- Davis-Besse
- Arkansas Nuclear One 2
- Beaver Valley 2
- Diablo Canyon 1
- Diablo Canyon 2
- Fort Calhoun
- Indian Point 2
- Indian Point 3
- Millstone 2
- North Anna 1
- North Anna 2
- Point Beach 1
- Point Beach 2
- Surry 1
- Surry 2
- Turkey Point 3
- Turkey Point 4
- Seabrook

Table 2-4. PWR Survey Question 3I: Vortex Suppression at ECCS Suction Piping Inlets

Vortex Suppressor	Strainer	Suppressor with Strainer	No Vortex Suppressing Structure
A. W. Vogtle 1	Ginna	Calvert Cliffs 1	Crystal River 3
A. W. Vogtle 2	North Anna 1	Calvert Cliffs 2	H. B. Robinson 2
Arkansas 1	North Anna 2	Catawba 1	Indian Point 2
Arkansas 2	St. Lucie 1	Catawba 2	Oconee 1
Davis-Besse	Surry 1	Salem 1	Oconee 2
Fort Calhoun	Surry 2	Salem 2	Oconee 3
Indian Point 3		San Onofre 2	Palisades
Joseph M. Farley 1		San Onofre 3	Point Beach 1
Joseph M. Farley 2			Point Beach 2
Millstone 2			Prairie Island 1
Palo Verde 1			Prairie Island 2
Palo Verde 2			St. Lucie 2
Palo Verde 3			TMI 1
Shearon Harris			Turkey Point 3
Waterford			Turkey Point 4
Diablo Canyon 1			Beaver Valley 2
Watts Bar			Seabrook
Wolf Creek			
Diablo Canyon 2			
Comanche Peak			
Beaver Valley 1			

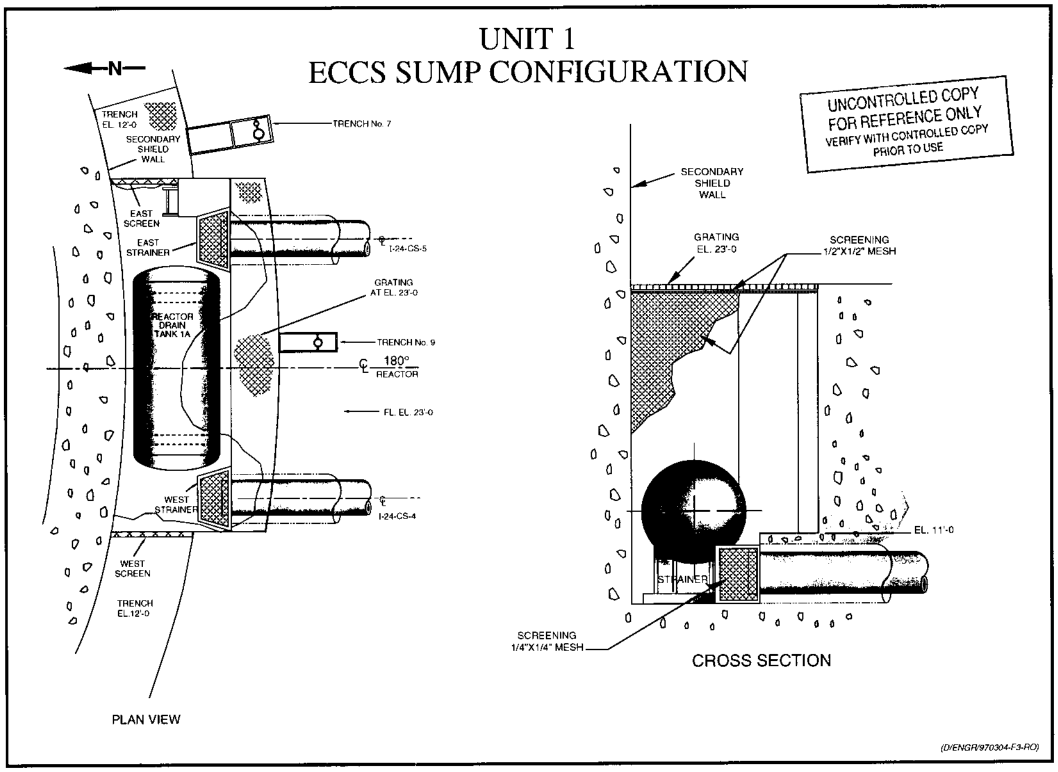
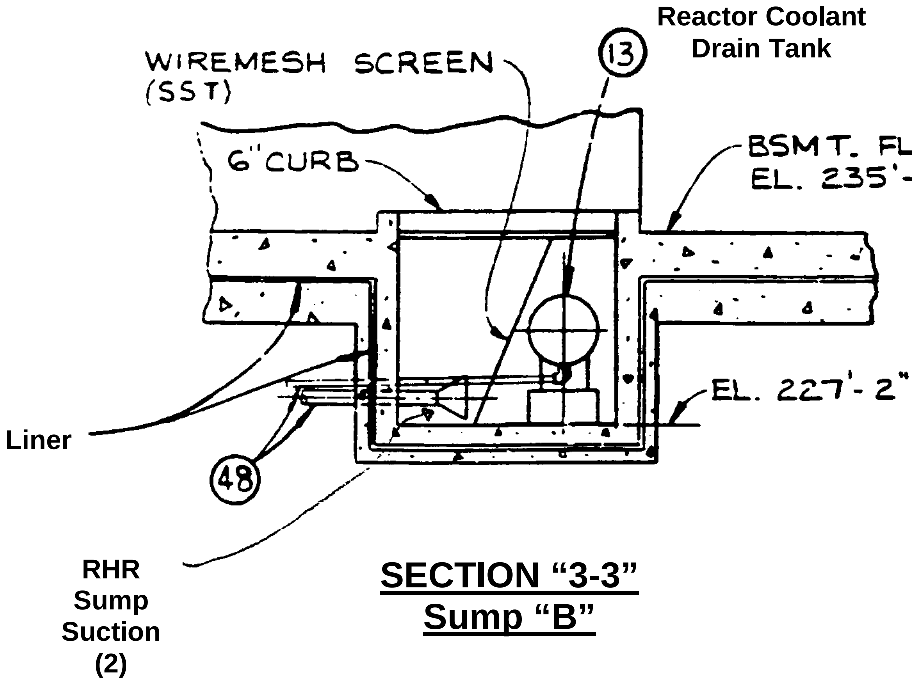


Fig. 2-35. Drawing of a sump pit with a vortex suppressor.



RG&E Dwg 33013-2101

Fig. 2-36. Illustration of a debris curb adjacent to the sump.

Question 3n
What is the height of the debris curb? {ft}

The results of the survey for Question 3n are summarized in Fig. 2-37.

Question 3o
What is the distance between the debris curb and the sump screen?

Figure 2-38 groups the survey responses for Question 3o.

2.2.4. Debris Source Questions

Question 4
Provide a plan-view sketch of the containment elevation that the sumps are located.

40 units responded with drawings.

Question 4a
Containment type?

Debris transport phenomenology would likely differ in some respects, depending on containment type. Of the 60 units contained in Table 2-5,

- 48 reported having a large dry containment,
- 5 reported having an ice-condenser containment (DC Cook Units 1 and 2 did not respond), and
- 7 reported having a large dry subatmospheric containment.

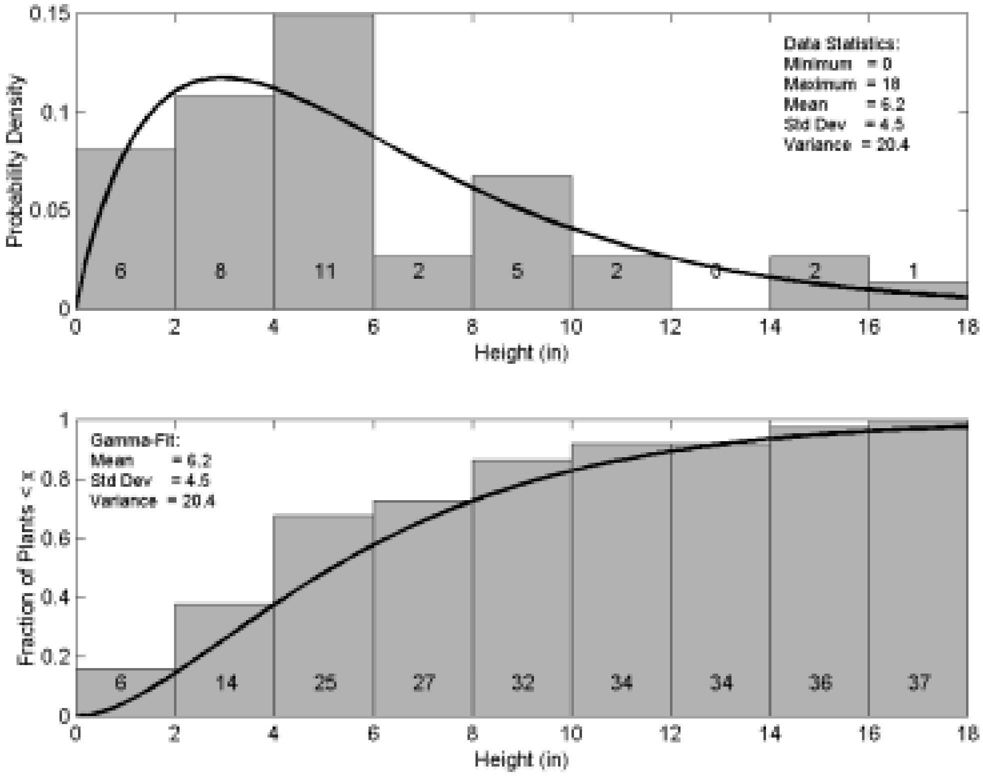


Fig. 2-37. PWR Survey Question 3n: Sump curb height.

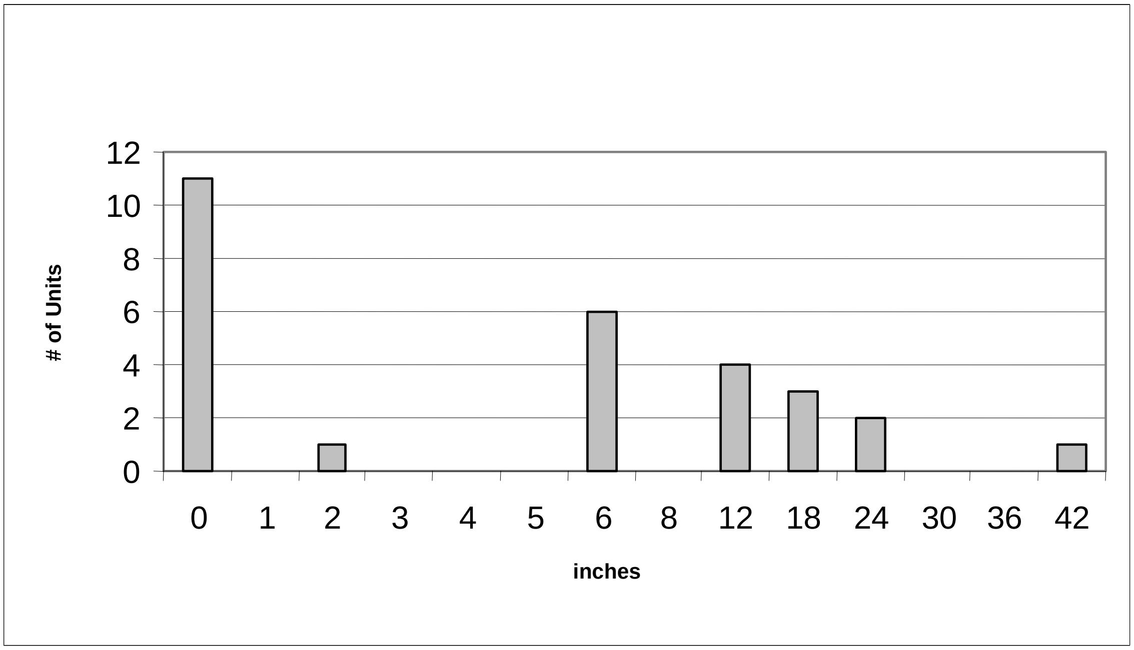


Fig. 2-38. PWR Survey Question 3o: Sump curb offset.

Table 2-5. Containment Types

Large Dry Containment	Ice-Condenser Containment	Subatmospheric Containment
Alvin W. Vogtle 1	Catawba 1	Beaver Valley 1
Alvin W. Vogtle 2	Catawba 2	Beaver Valley 2
Arkansas Nuclear One 1	McGuire	Millstone 3
Arkansas Nuclear One 2	Sequoyah	North Anna 1
Braidwood	Watts Bar	North Anna 2
Byron		Surry 1
Callaway		Surry 2
Calvert Cliffs 1		
Calvert Cliffs 2		
Crystal River 3		
Davis-Besse		
Diablo Canyon		
Fort Calhoun		
Ginna		
H B Robinson 2		
Indian Point 2		
Indian Point 3		
Joseph M Farley 1		
Joseph M Farley 2		
Kewaunee		
Millstone 2		
Oconee 1		
Oconee 2		
Oconee 3		
Palisades		
Palo Verde 1		
Palo Verde 2		
Palo Verde 3		
Point Beach 1		
Point Beach 2		
Prairie Island 1		
Prairie Island 2		
Salem 1		
Salem 2		
San Onofre 2		
San Onofre 3		
Shearon Harris		
South Texas 1		
South Texas 2		
St Lucie 1		
St Lucie 2		
TMI 1		
Turkey Point 3		
Turkey Point 4		
Virgil C Summer		
Waterford 3		

Question 4b

What is the containment floor area (open area only)? {ft sq.}

The depth of the water on the containment floor would depend, among other things, on the area of the floor. The velocities developed in the pool during ECCS recirculation would depend largely on pool depth. Available NPSH at the ECCS pump inlets would vary directly with pool depth.

The results of the survey for Question 4b are summarized in Fig. 2-39. Ice condenser units generally reported the smallest open floor areas; of the other types of containment designs, Diablo Canyon, Kewaunee and Prairie Island reported the smallest areas.

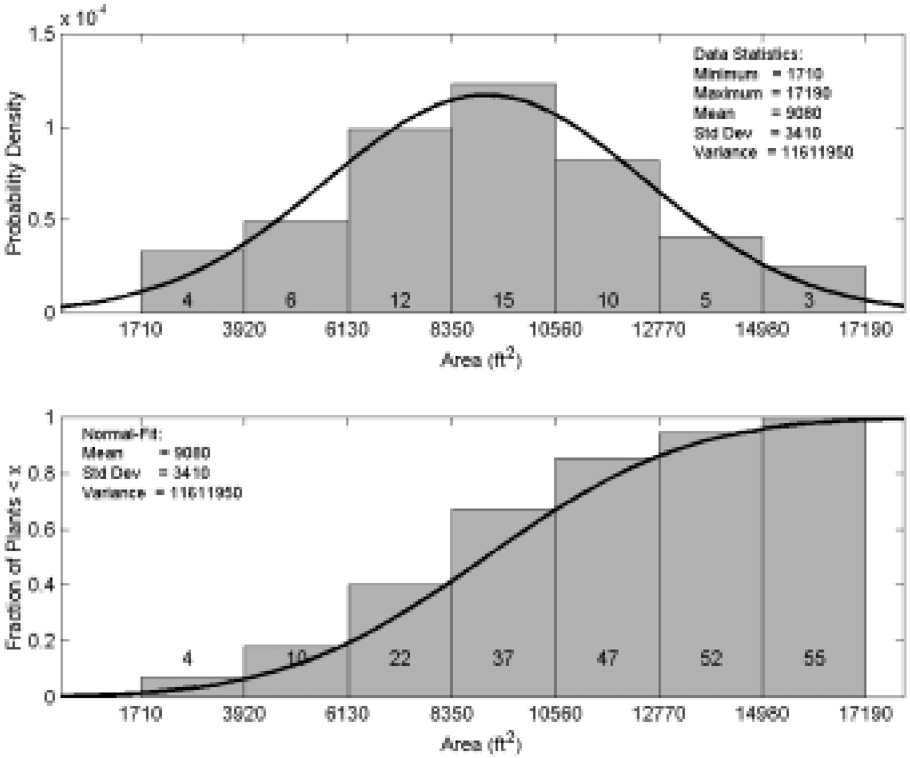


Fig. 2-39. PWR Survey Question 4b: Containment floor open area.

Question 4c

Where are the sumps located?

Containment layout and sump position are thought to strongly influence the potential for debris transport. Sump locations are broadly classified here into three “types” based on the containment layout drawings provided.

1. *Remote Type*
   In the case of a remote sump, flow near the sump would not be influenced by break-flow turbulence or upper containment draining. The floor level of the containment would be typified by contiguous shield walls and sparse openings to a fairly open annulus. The sump would reside in the annulus outside the crane wall.
2. *Exposed Type*
   In the case of an exposed sump, flow near the sump could be influenced by break flow turbulence. For at least some postulated pipe breaks, little (if any) intervening structure would exist between the sump and the break.
3. *Intermediately Exposed Type*
   Not clearly of either above type. Contiguous shield walls might exist but possibly with numerous passages.

Table 2-6 identifies which sump-location type each unit has been associated with. Figure 2-40 shows the number of units having each sump location type. Illustrative containment floor drawings identifying the sump-location types are provided in Figs. 2-41 to 2-43.

Table 2-6. PWR Survey Question 4c: Sump-Location Type

Remote	Intermediately Exposed	Exposed
Arkansas 2	Joseph M Farley 1	Arkansas 1
Fort Calhoun	Joseph M Farley 2	Calvert Cliffs 1
Palo Verde 1	Indian Point 2	Calvert Cliffs 2
Palo Verde 2	Indian Point 3	Ginna
Palo Verde 3	Prairie Island 1	North Anna 1
Salem 1	Prairie Island 2	North Anna 2
Salem 2	San Onofre 2	Oconee 1
Crystal River	San Onofre 3	Oconee 2
TMI 1	Shearon Harris	Oconee 3
A. W. Vogtle 1	St. Lucie 1	Point Beach 1
A. W. Vogtle 2	St. Lucie 2	Point Beach 2
Waterford 3	Turkey Point 3	Millstone 2
Beaver Valley 1	Turkey Point 4	Millstone 3
Beaver Valley 2	Diablo Canyon 1	Surry 1
Comanche Peak	Diablo Canyon 2	Surry 2
Watts Bar	Kewaunee	
Wolf Creek		

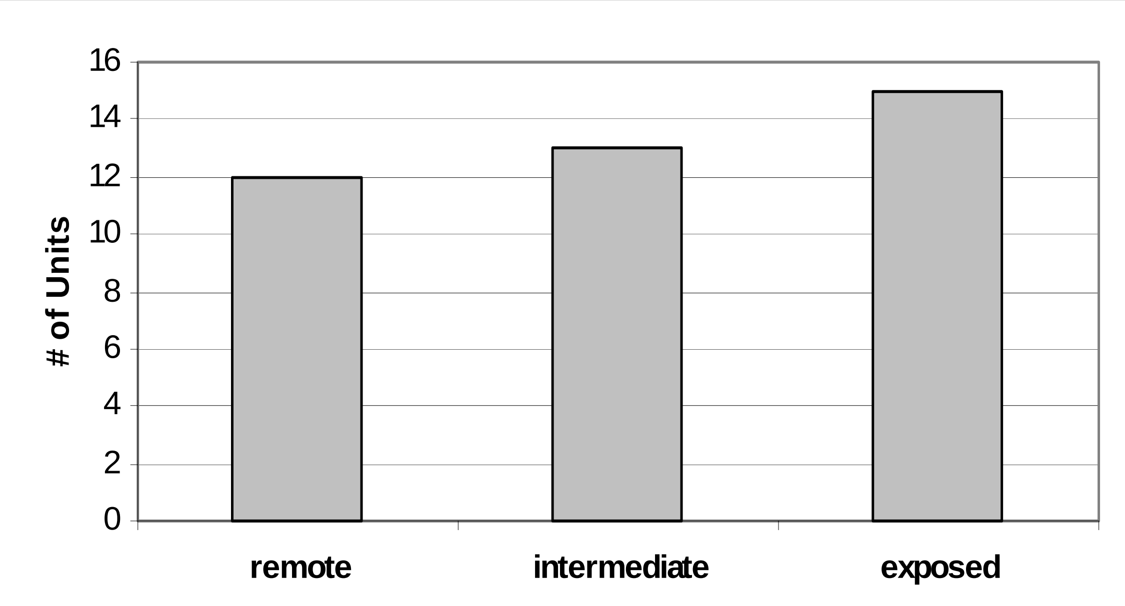


Fig. 2-40. PWR Survey Question 4c: Sump location type.

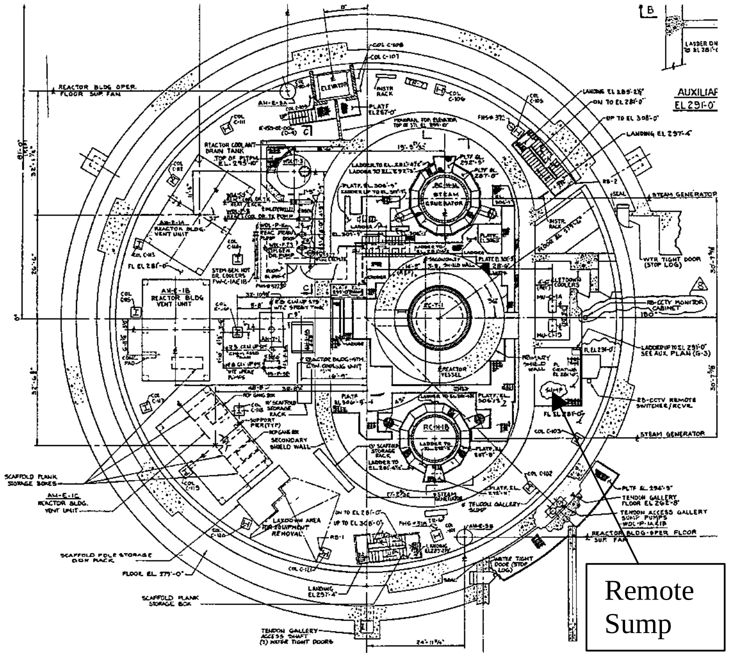


Fig. 2-41. Schematic of a case dry containment with a remote sump.

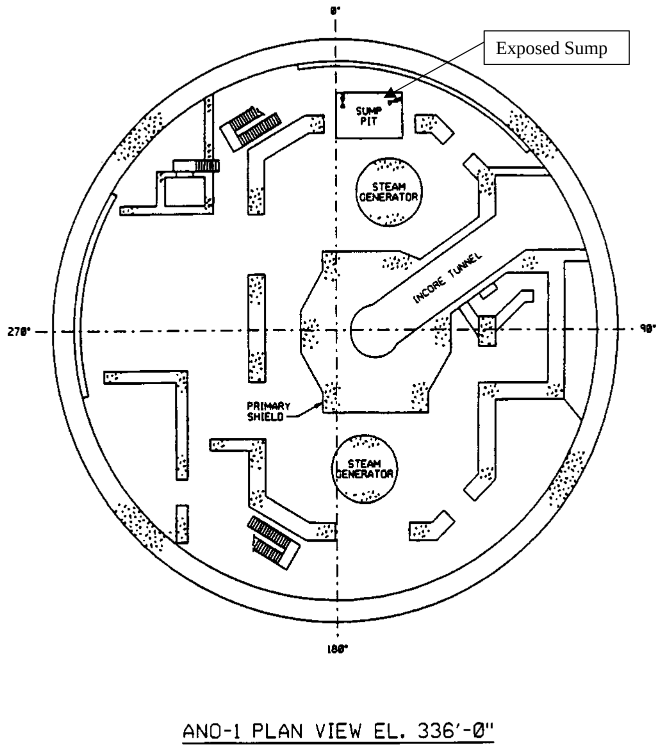


Fig. 2-42. Large dry containment with an exposed sump.

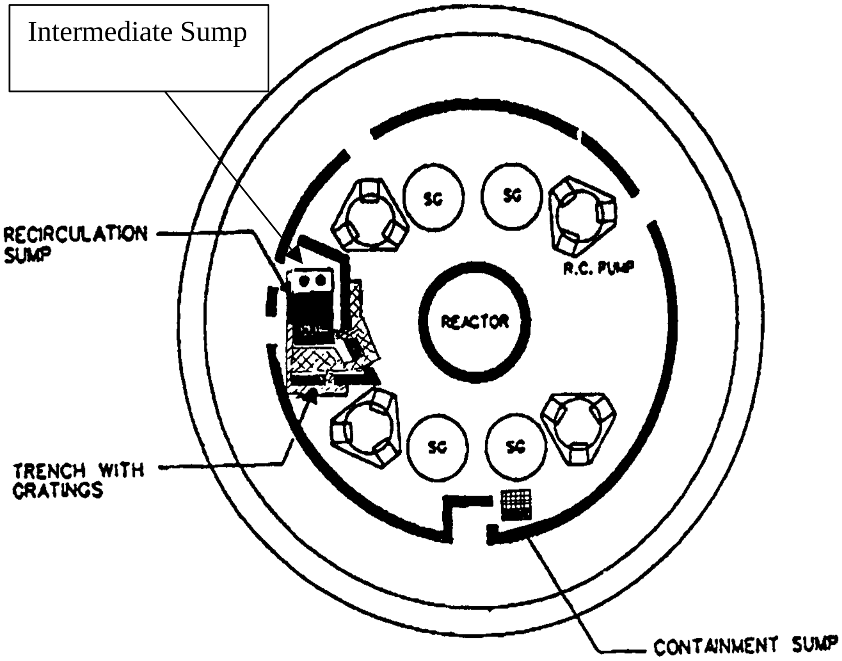


Fig. 2-43. Large dry containment with an intermediate sump.

Question 4d

How many compartments and subcompartments in the containment?

Numerous drawings and written descriptions were provided that identified the different containment configurations existing in US PWRs. The uniqueness of most containments is striking. A primary goal of this question was to determine the relation of the emergency sump to compartments near the containment floor level, which is addressed under Question 4c.

Question 4e

What are the sizes of openings between compartments? {ft}

Numerous drawings and write-ups were provided that describe various openings, walkways, and penetrations joining containment compartments. This information aided in categorizing the responses to Question 4c.

Question 4f

How many openings between compartment?

Numerous drawings and write-ups were provided identifying various openings, walkways, and penetrations joining containment compartments. This information aided in categorizing the responses to Question 4c.

Question 4g

What are the locations of openings between compartments?

Numerous drawings and write-ups were provided identifying various openings, walkways, and penetrations joining containment compartments. This information aided in categorizing the responses to Question 4c.

Question 5

Identify potential debris sources.

The following potential debris sources were identified.

- Failed paint
- Insulation
- Fire barrier materials
- Equipment labels
- Stray pieces of paper
- Tape
- Phenolic tags
- Nylon tie wraps
- Duct tape

Question 5a

List the types of service Level 1 coatings in containment.

The identified Level 1 coatings on concrete and steel are shown in Tables 2-7 and 2-8.

Question 5b

Provide a rough estimate of the amount (square footage) of each type of service Level 1 coating in that is in containment. {%}

Only 18 units provided the amounts of each type of Level 1 coating in the containment. Many units did differentiate between coating applied to concrete and coating applied to steel. Often the amounts reported were percentages rather than square footage. The results of the survey for Question 5b are summarized in Fig. 2-44.

Table 2-7 PWR Survey Question 5a: Level 1 Coatings on Concrete

Number of PWRs That Have Coatings That Fall Within Coating PIRT System Designations			
PIRT ID #	**System Description**	**SRTC ID #**	**# of Units w/**
1	Steel substrate, inorganic zinc primer, epoxy phenolic topcoat	1	19
2	Steel substrate, epoxy phenolic primer, epoxy phenolic topcoat	No match	6
3	Steel substrate, inorganic zinc primer, epoxy topcoat	No match	7
4	Steel substrate, epoxy primer, epoxy topcoat	5	47
5	Concrete substrate, surfacer, epoxy phenolic topcoat	2	6
6	Concrete substrate, surfacer, epoxy topcoat	No match	17
7	Concrete substrate, epoxy phenolic primer, epoxy phenolic topcoat	No match	16
8	Concrete substrate, epoxy primer, epoxy topcoat	No match	12
9	Steel substrate, untopcoated inorganic zinc primer		9

Note 1: Only PWRs that responded to the sump and containment survey are included in this table.
Note 2: Only five systems contained in the survey could not be mapped to one of the nine systems used by the Coating PIRT Panel. These five systems may be in 11 plants different units.
Note 3: This table shows number of units with one of the Coating PIRT systems. It may not be an accurate representation of the quantity of a particular type of coating installed.

Table 2-8. PWR Survey Question 5a: Level 1 Coatings on Steel

Listing of Coatings Installed in PWRs That Fall Within Coating PIRT System Designations	
PIRT ID #	Example of
1	Amercoat 66 with Dimecote 4 on Steel Amercoat 66 with Dimecote 6 on Steel Carbo Phenoline 305 with Carboline Carbo Zinc 11 on Steel Phenoline 305 with Carboline 11 on Steel Phenoline 305 with CZ 11 on Steel
2	Carboline Phenoline 368 with Pheno line Primer on Steel Phenoline 305 on Steel
3	Ameron 90 with Ameron Dimecote on Steel Carboline 801 with Carbozine 11s on Steel Val-Chem Hi Build Epoxy with Mobilzinc 7 on Steel Valspar 76 with Valspar 13-F-12 on Steel Valspar 89W9 with Mobil Zinc MZ-7 on Steel
4	Amercoat 66 on Steel Amercoat 90 on Steel Ameron 90N on Steel Ameron 90 with Ameron 71 on SteelCarboline 801 on Steel Carboline 890 on Steel KE 7107 with KE Polymide 6548 on Steel Keeler & Long E-1-1105 on Steel Keeler & Long E-1-7475 on Steel Keeler & Long E-1-7844 on Steel Keeler & Long E-1-8591 on Steel Keeler & Long KL E-1 with KL 6548/7107 on Steel Keeler & Long PPG HN with Keeler & Long PPG 6548/7107 on Steel Keeler & Long 6548 on Steel Keeler & Longer 7107 on Steel Placite 9009 with 7155 on Steel Polymer Chemical Company Gray Epoxy R274G on Steel Valspar 76 with Valspar 89 on Steel Valspar 78W300 on Steel
5	Amercoat 66 with NU-KLAD 110AA on Concrete Phenoline 305 with Carboline 195 on Concrete
6	89W9 with Valspar 46X29 on Concrete Amercoat 660-Nuklad 1100AA on Concrete Ameron 66 Polymide Epoxy with Ameron 110AA polymide Epoxy Surfacer on Concrete Ameron 66 Polymide Epoxy with Ameron 114 polymide Epoxy Surfacer on Concrete Carboline 890 with Carboline Starglaze 2011 on Concrete Carboline 890 with Carboline Starglaze 2011S on Concrete Carboline 890 with Carboline Starglaze 20115 on Concrete Keeler & Long D-series epoxy with Keeler & Long 4129 on Concrete Keeler & Long PPG HN with Keeler & Long PPG 4500 on Concrete Valspar 76 with Valspar 46-X-29 on Concrete
7	Amercoat 66 on Concrete Carboline 300 on Concrete Carboline Phenolic 300 on Concrete Carboline Phenolic 305 on Concrete Phenoline 305 on Concrete Phenoline 305 with Carboline 295 WB on Concrete
8	Ameron 400NT on Concrete Carboline 890 on Concrete Carboline Starglaze 2011s on Concrete Keller & Long 7475 with Keeler & Long 7107 on Concrete Val-Chem Hi Build Epoxy on Concrete
9	Carboline CZ-11 on Steel CarboZinc11 on Steel Valspar 13G10 on Steel
Note 1: Only PWRs that responded to sump and containment survey are included in this table.	

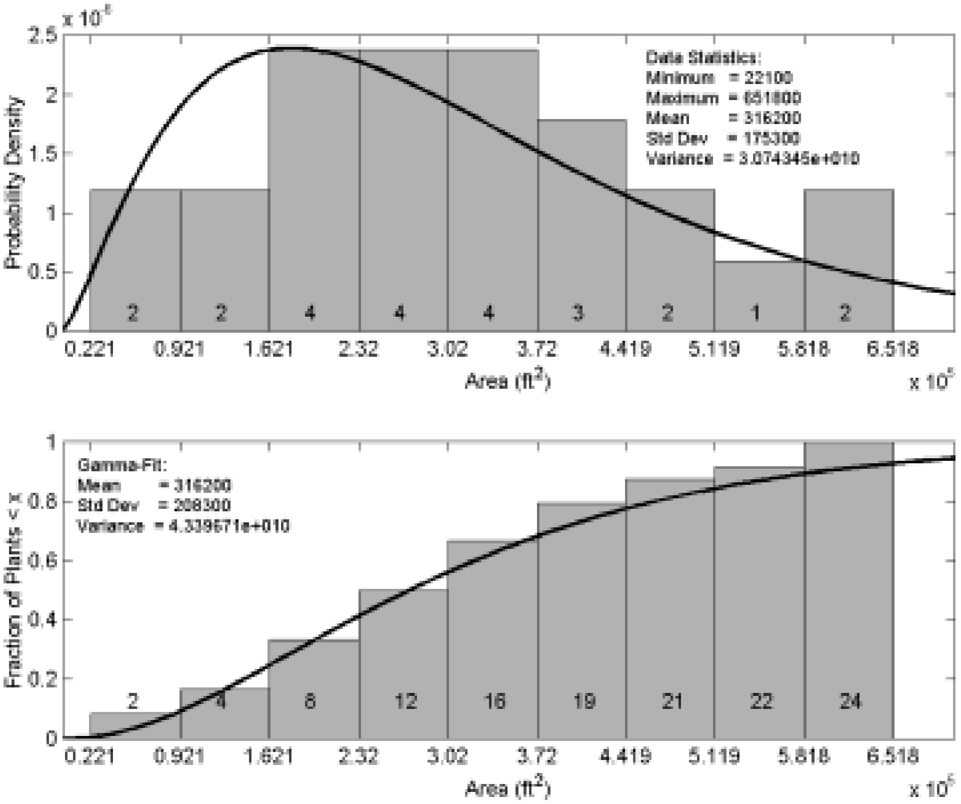


Fig. 2-44. PWR Survey Questions 5b: Amount of level 1 coatings in containment.

Question 5c

List the types of thermal insulation in containment.

Table 2-9 presents various types of thermal insulations used in US PWRs and the number of units using each type. The table divides them into a few broad categories based on their material properties.

Question 5d

Provide a rough estimate of the amount of thermal insulation (by volume or square feet) that is in the containment. {%}

Twenty-nine units responded with quantitative information on the type of thermal insulation in containment. Insulation was predominately of three types (although significant amounts of other types were reported).

- Fibrous
- Reflective metallic
- Calcium-silicate

The units in which insulation amounts were reported were not consistent. Most amounts were given as percentages of total containment insulation. Some amounts were in units of volume (ft^3). A few amounts were in units of area (ft^2). For consistency here, volume and area units have been converted to percentages. The results of the survey for Question 5d are summarized in Figs. 2-45 to 2-48. Note that the total volumes of thermal insulation reported varied from 4410 ft^3 to 9808 ft^3. Total areas varied from 15,000 ft^2 to 21,356 ft^2.

Table 2-9. Number of Units with Each Reported Type of Insulation

Insulation (Type/Description) (Note: Units did not provide very detailed descriptions)	**Number of Units**
Reflective Metallic Insulation (2-mil S/S, 2.5-mil S/S, Al)	
RMI (non-stainless-steel RMI; typically on reactor vessels)	17
Stainless metallic reflective	34
Fibrous: Low-Density Fiberglass	
NUKON fiberglass	12
NUKON jacketed fiberglass	9
NUKON fiberglass blanket with wire mesh outer wrapping	1
Transco fiberglass SS jacketed	1
Transco fiberglass encapsulated	1
Transco fiberglass insulation blankets	1
Transco fiberglass fill wrapped in fiberglass blanket with stainless-steel cover	1
Fibrous: High-Density Fiberglass	
Temp-Mat fiberglass	7
Temp-Mat fiberglass jacketed in stainless steel	1
Temp-Mat fiberglass enclosed in thermoglass covering	2
Temp-Mat fiberglass with silicon cloth	1
Temp-Mat fiberglass and rubberized cloth wrapped in stainless steel	2
Temp-Mat fiberglass blankets	2
Fibrous: Mineral Wool	
Mineral wool	9
Encapsulated mineral wool	5
Encapsulated mineral wool block	2
Mineral wool with stainless-steel jacketing	2
Mineral fiber blanket	1
Fibrous: Fiberglass (indeterminate)	
Fiberglass	7
Fiberglass blanket	9
Fiberglass plastic jacketed	1
Fiberglass steel jacketed	11
Fiberglass metallic jacketed	2
Fiberglass glass cloth jacketed	2
Fiberglass encapsulated	11
Fiberglass wire	1
Fiberglass molded with stainless-steel jacketing	1
Fiberglass vinyl covered	2
Fibrous: Miscellaneous	
Cellular glass jacketed	1
Ceramic fiber enclosed in stainless steel	2
Kaowool enclosed in Thermoglass covering	1
Particulate Insulations (Mass-Type Insulations)	
Calcium-silicate	16
Calcium-silicate jacketed	10
Calcium-silicate encapsulated	1
Asbestos	3
Unibestos	4
Unibestos with stainless-steel jacket	1
Min“”"" enclosed in stainless steel	3
Encapsulated Microtherm	2
Gypsum board with stainless-steel facing	1
Foam Type Insulations	
Vinyl cell covered by stainless-steel sheet	1
Vinyl base rigid foam sheets	1
Armaflex	4
Foamglass	1
Foamglass rigid foam sheets	1
Neoprene	0
Closed-cell neoprene with stainless-steel jacketing	1
Flexible foam anti-sweat	3
Foamed plastic	2

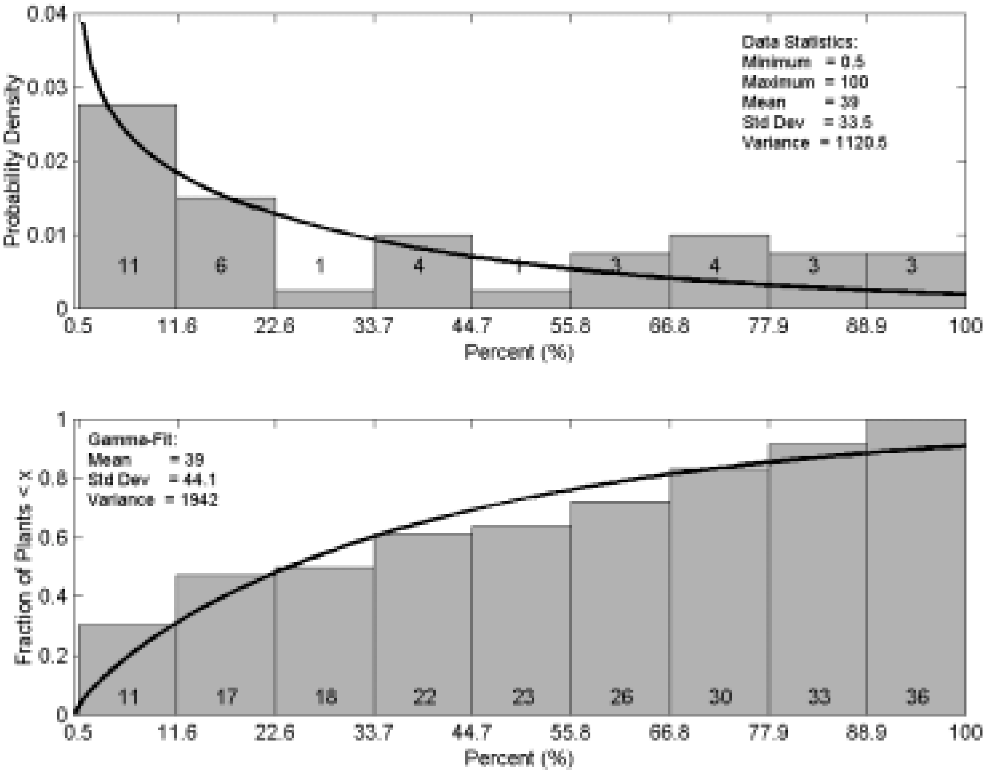


Fig. 2-45. PWR Survey Question 5d: Percentage of containment isulation that is fibrous.

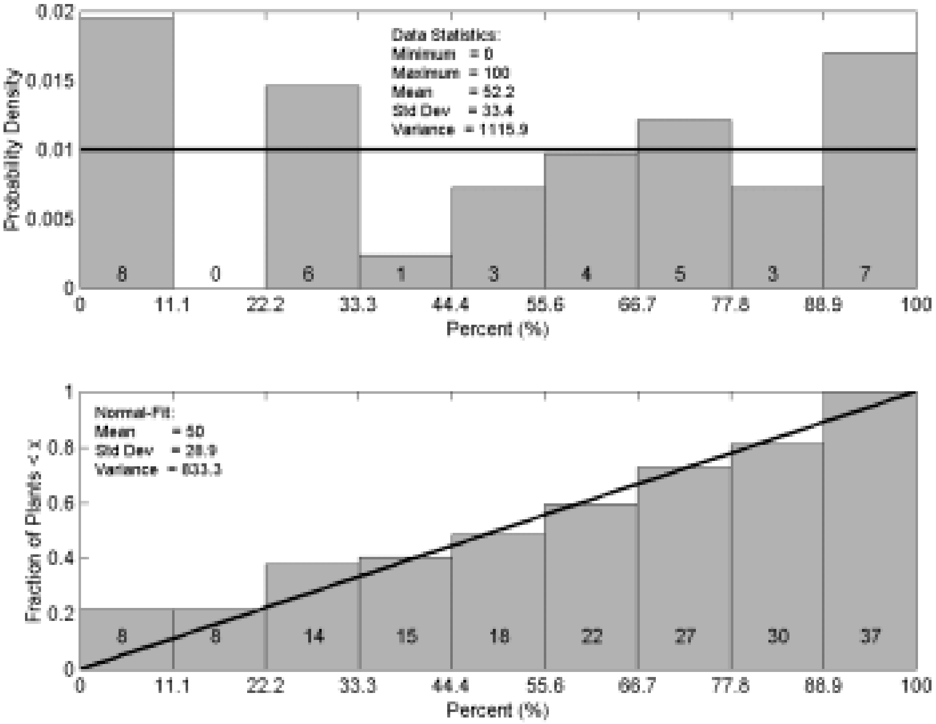


Fig. 2-46. PWR Survey Question 5d: Percentage of containment insulation that is reflective metallic.

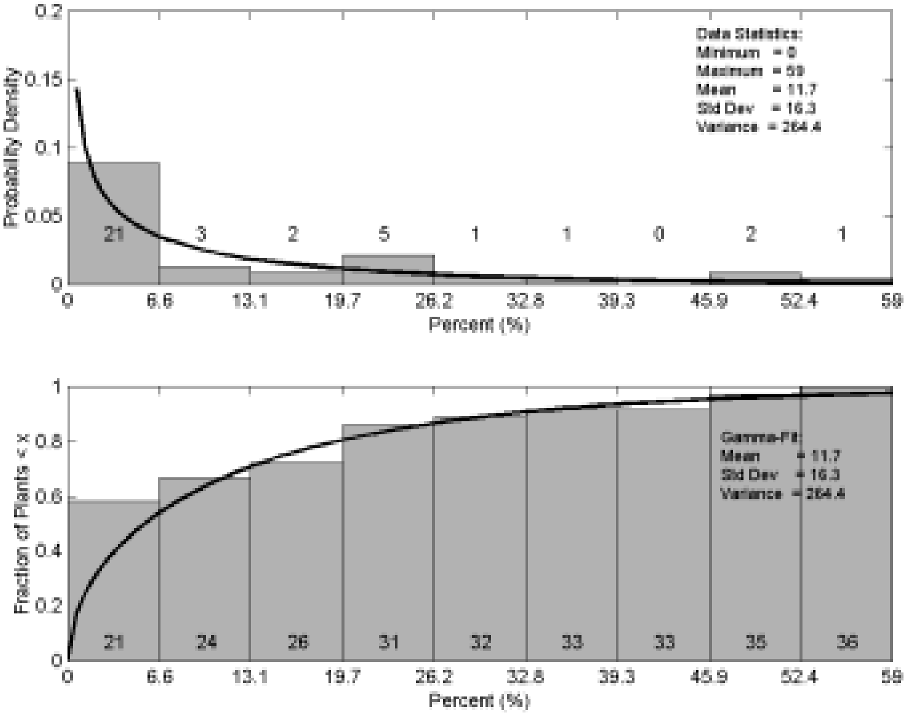


Fig. 2-47. PWR Survey Question 5d: Percentage of containment insulation that is calcium-silicate.

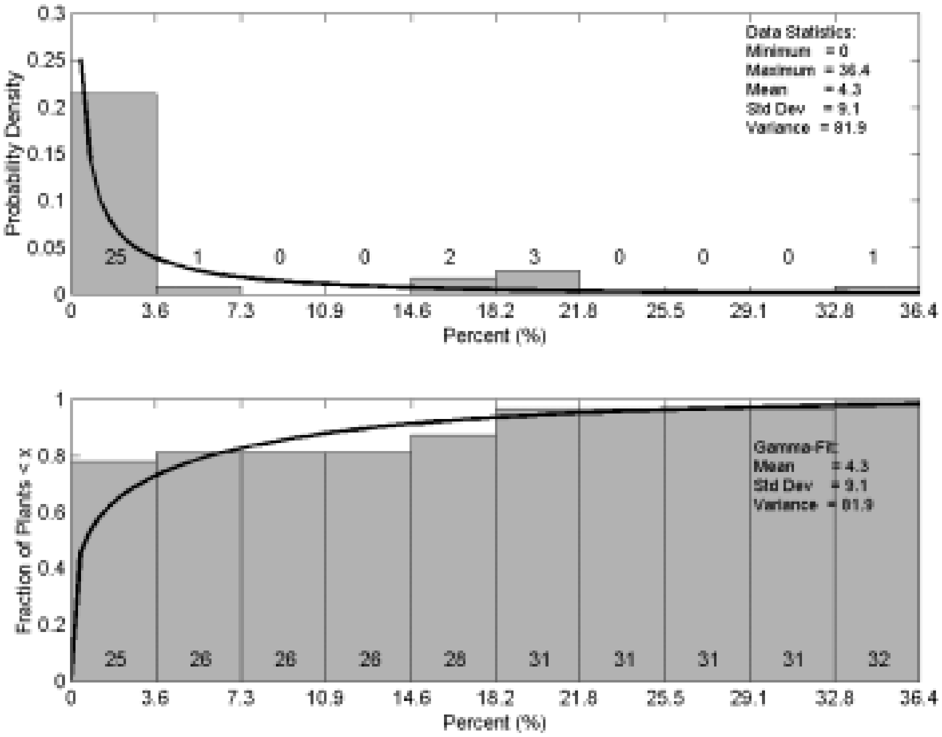


Fig. 2-48. PWR Survey Question 5d: Percentage of containment insulation that is other than fibrous, reflective metallic, or calcium-silicate.

Question 5e

List the types of fire barrier materials in containment.

Table 2-10 identifies each type of fire barrier material and the number of units having each type.

Question 5f

Provide a rough estimate of the amount of fire barrier material (by volume or square feet) that is in the containment. {%}

Reported amounts of fire barrier material varied from 0 ft^3 to 1500 ft^3. Twelve units reported having no fire barrier materials in containment. A total of 31 units responded to Question 5f with actual values.

Question 5g

List the types of filter materials in the containment.

The types of materials reported were as follows.

- Filter paper
- Fiberglass
- HEPA
- Charcoal

Several units responded that no filter materials are present in their containment. There were no filters identified as susceptible to being dislodged or dismantled and transported to the emergency sumps. The majority of the responses included statements to the effect of

- the filters are enclosed in metal casing,
- the filters are not in the proximity to the RCS,
- all filter materials are qualified to function in a post-LOCA environment, and/or
- the filters would not be exposed to containment sprays and would always be above containment flood level.

Table 2-10. Number of Units with Each Reported Type of Fire Barrier

Fire Barrier Materials (Type/Description) (Note: Plants did not provide very detailed descriptions)		**Number of Units**
	3M Interam TM E50 Series Fire Wrap	5
	3M Interam E54 sheet material	1
	3M M20C	1
	Cerafiber	3
	Kaowool	6
	Marinite board	14
	Thermolag (TSI)	7
	Thermo-Lag 330-1 in conduit and panel form	5
	Low density foam	1
	Pabco rigid panel	1
	Hemyc wrap	1
	Fiberglass blanket	3
	Transit board	1
	Silicone foam	5
	Fire retardant (Flamastic)	2
	Promatec—Hymac	1
	Mineral wool	2
	Fire-resistant caulk	1
	Silicone elastomer	1
	Fire-resistant boot seal material	1

Question 5h

Provide a rough estimate of the amount of filter material (by volume or square feet) that is in the containment. {%}

As much as 12,985 ft^2 of filter material was reported. Two units reported this amount.

Question 5i

Following a LBLOCA, what is the boron concentration in the water on the containment floor? {ppm}

Basic or acidic tendencies in recirculating water may change the corrosion, dissolution, or precipitation characteristics of metal- or degraded-metal-based paints in containment. A specific concern is the possible precipitation of ZnOH formed from chemical interaction between Zn (in the zinc-based paints) and water at high temperature. The dissolution/precipitation of ZnOH in water is influenced by the degree of boration. The results of the survey for Question 5i are summarized in Fig. 2-49.

2.2.5. Alternate Water Source Question

Question 6

Are there procedures available providing instruction on switching to an alternate water source if the sump is unavailable? What is the water source?

The following units responded that no alternate water source exists.

- A. W. Vogtle 1
- A. W. Vogtle 2
- Arkansas 1
- Arkansas 2
- Calvert Cliffs 1
- Calvert Cliffs 2
- Davis-Besse
- Fort Calhoun
- Millstone 2
- Palo Verde 1
- Palo Verde 2
- Palo Verde 3
- San Onofre 2
- San Onofre 3
- TMI-1
- Waterford 3

Table 2-11 calls out the units that identified an alternate water source and what that source would be. Those identifying an alternate source typically identified having emergency operating procedures or severe accident management guidelines that addressed using it.

The following units did not respond to Survey Question 6.

- Catawba 1
- Catawba 2
- Shearon Harris

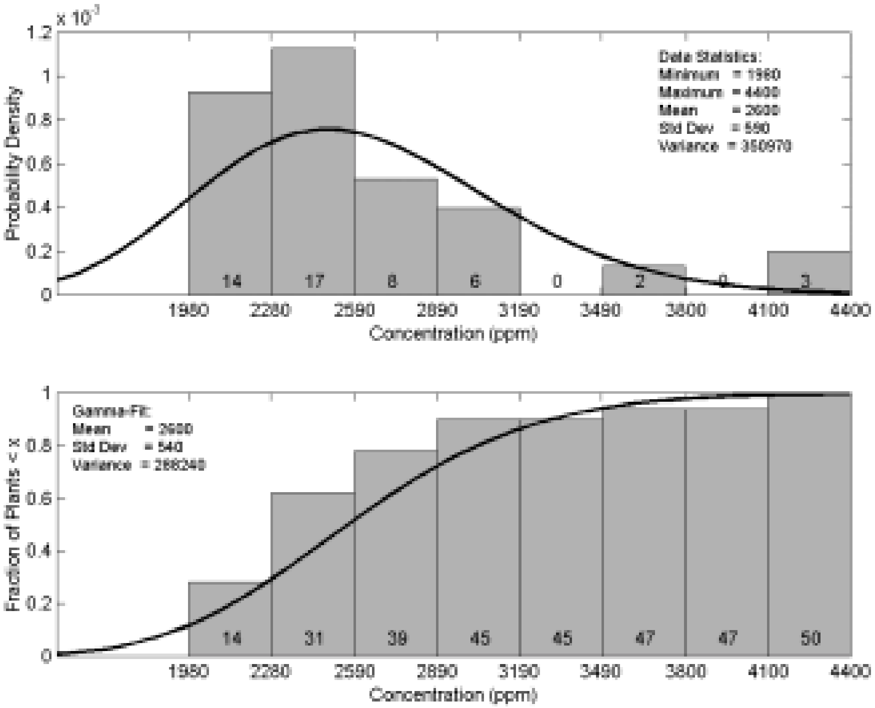


Fig. 2-49. PWR Survey Question 5i: Maximum containment pool boron concentration following a LBLOCA.

Table 2-11. PWR Survey Question 6: Alternate Water Source Availability

Unit	Alternate Water Source
Crystal River 3	RB penetrations or refill the BWST from unidentified source
Ginna	Refill of the RWST from boric acid blender
H. B. Robinson 2	Refill the RWST—no source identified
Indian Point 2	External RHR pumps water source from unidentified source
Indian Point 3	Alternate sump and RHR pumps
Joseph M. Farley 1	Refill RWST from unidentified source
Joseph M. Farley 2	Refill RWST from unidentified source
North Anna 1	Refill RWST from boric acid blender
North Anna 2	Refill RWST from boric acid blender
Oconee 1	Fill BWST from boric acid mix tank
Oconee 2	Fill BWST from boric acid mix tank
Oconee 3	Fill BWST from boric acid mix tank
Palisades	Refill RWST from unidentified source
Point Beach 1	Refill RWST from primary
Point Beach 2	Refill RWST from primary
Prairie Island 1	6 sources listed
Prairie Island 2	6 sources listed
Salem 1	Refill RWST from borated water makeup
Salem 2	Refill RWST from borated water makeup
St. Lucie 1	Refill RWT from 6 possible sources
St. Lucie 2	Refill RWT from 6 possible sources
Surry 1	Refill RWST from boric acid blender or spent fuel pool
Surry 2	Refill RWST from boric acid blender or spent fuel pool
Turkey Point 3	Refill RWST from borated primary source
Turkey Point 3	Refill RWST from borated primary source
Virgil C Summer	From spent fuel pool

3.0. ADDITIONAL PARAMETERS AFFECTING SUMP PERFORMANCE

A complete assessment of ECCS recirculation performance requires information beyond that obtained through the survey. In particular, one needs to examine the total recirculation flow rate, the velocity of water entering the sump screen (i.e., approach velocity), containment spray setpoint and NPSH margin for the recirculation pumps. Total recirculation flow establishes the net flow rate of water across the containment floor, and therefore affects the efficiency with which debris can be transported toward the sump. The sump screen approach velocity strongly affects head loss across debris that accumulates on the screen. The containment spray setpoint indicates whether spray flow would be anticipated during a LOCA. When sprays operate, water cascades downward across containment piping and other structures, increasing the amount of debris transported to the containment floor. NPSH margin represents the maximum head loss that can be tolerated across a debris-laden sump screen.

Although these parameters were not elicited in the industry survey, they can be examined from industry responses to GL 97-04: "*Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps*." Results are summarized in this section.

***ECCS Flow Rate and Screen Velocity**.* The GL 97-04 responses (and, in a few cases, plant FSARs and system notebooks) were used to compile total ECCS recirculation flow rates for each PWR unit. Results are shown in Fig. 3-1. The flow rate information was coupled with containment floor area information and industry survey responses to compute (a) the containment annulus flow velocities (in the case of units with remote sumps), and (b) the sump screen approach velocities. Figure 3-2 shows the resulting sump screen approach velocities. The flow rates and sump screen velocities credited in the licensing basis analyses for some of the units might differ slightly from the values listed in Figs. 3-1 and 3-2 because of differences in assumptions regarding throttling and manual termination of containment sprays[7]. It is worth noting that the sump screen approach velocities for many units are below 0.2 ft/s (i.e., the minimum velocity needed to draw and hold RMI foils on a sump screen). Consequently, RMI debris generation and transport might not be important contributors to sump performance for these units. In contrast, a few units have approach velocities in excess of 1.0 ft/s. Transport and accumulation of all types of debris in these units could be substantial.

Steady state ECCS flow rates were also estimated for a small break (2-in. diameter) LOCA in each PWR unit. Results are summarized in Table 3-1. The steady-state break flow for each unit was estimated by estimating ECCS pump flow for a pressure steady RCS pressure of 500 psig. This stable pressure was used based on analysis results presented in "Pressurized Water Reactor Sump Screen Blockage Issue (GSI-191)." For the centrifugal ECCS pumps (charging, HPSI), it was determined (from inspection of pump curves on the NRC's website) that maximum (runout) pump flow would occur. Some units also have positive displacement charging pumps - the capacity of these pumps was included in the break flow total.

Most of the data below (except pump runout flow data) were gathered from Table 4.5-3 in "Overview and Comparison of U.S. Commercial Nuclear Power Plants," NUREG/CR-5640. The pump runout flow data and some information on positive displacement (PD) pumps was found on the NRC's website.

The ECCS flow range from 1830 gpm (Ginna) to 4,835 gpm (South Texas). However, the majority of the units have flow rates of approximately 2,500 gpm.

---

[7] This may not be a major issue because the flow rates for a majority of the units were obtained from their responses to GL 97-04. Most units provided licensing basis flow rates in those responses.

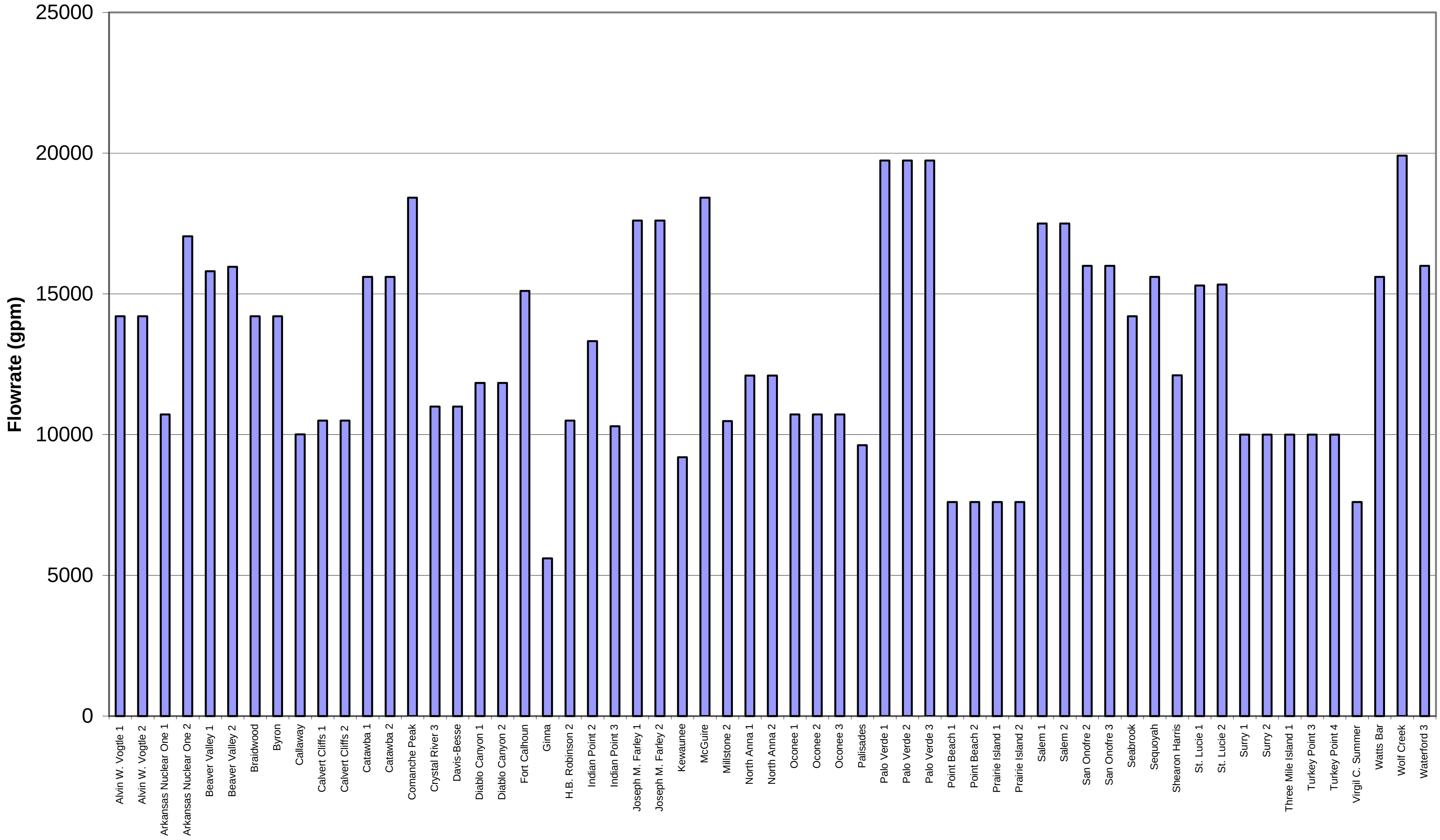


Fig. 3-1. Total recirculation flow rate (gpm). [Licensee GL 97-04 responses and UFSARs]

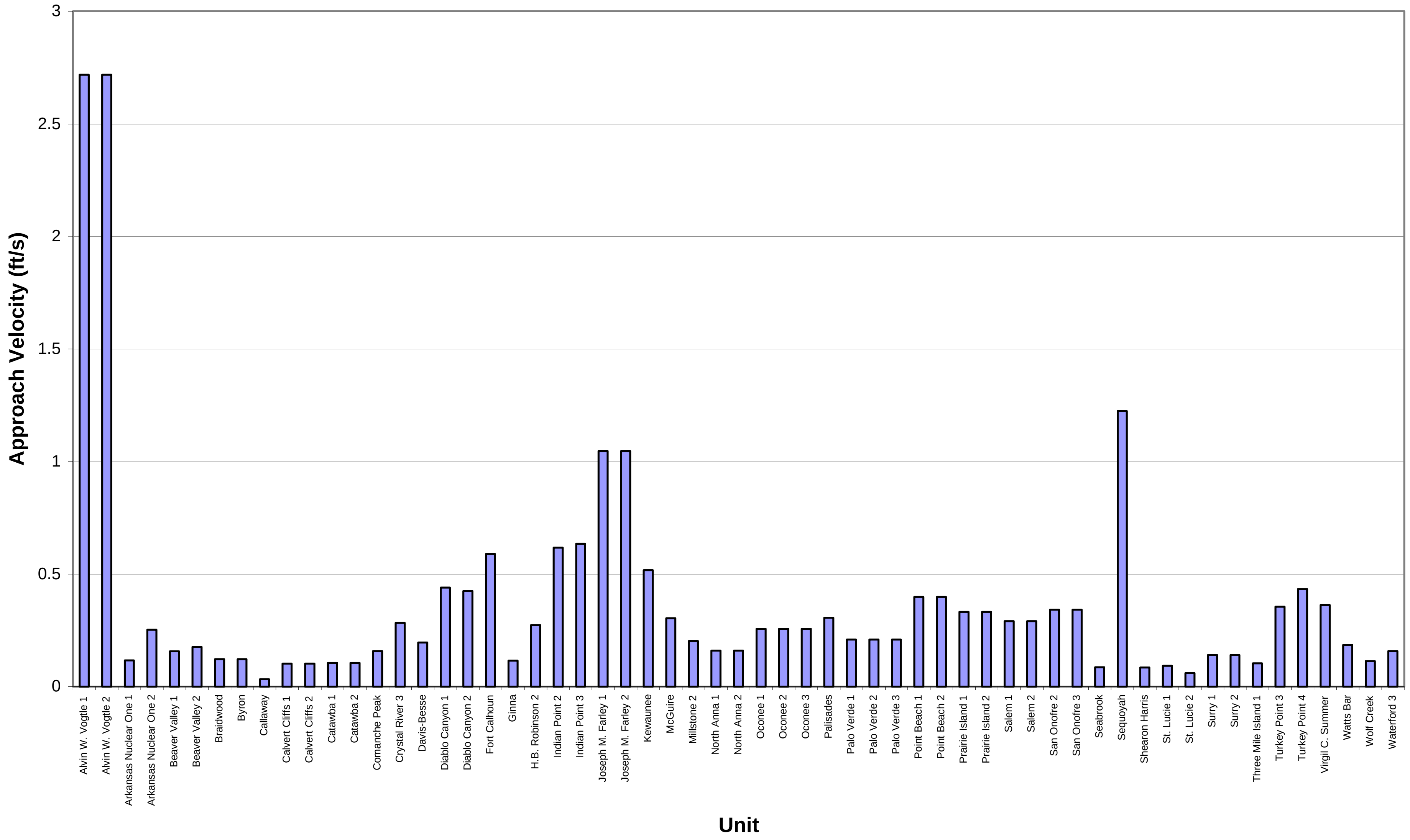


Fig. 3-2. Sump screen approach velocities (ft/s). [LANL estimate from GL 97-04/ survey values]

Table 3-1. Small Break LOCA ECCS (HPSI + Charging) Flow Rates

Unit	No. of Centrifugal Pumps	Centrifugal Pump Flow Rate at Pressure Listed at Right-Hand Column (gpm)	Centrifugal Pump Pressure (psig)	Centrifugal Pump Flow at 500 psig (per pump, runout flow)	No. of PD Pumps	PD Pump Capacity (gpm)	No. of HPSI Pumps	HPSI Pump Flow Rate at Pressure Listed at Right-Hand Column (gpm)	HPSI Pressure (psig)	HPSI Pump Flow at 500 psig (per pump, runout flow)	Total ECCS Flow at 500 psig
Arkansas Nuclear One 2					3	44	3	320	1214	825	2607
Beaver Valley 1 & 2	3	150	2514				Note 1				?
Braidwood 1 & 2	2	150	2526		1	98	2	400	1106		?
Byron 1 & 2	2	150	2526		1	98	2	400	1106		?
Callaway	2	150		550	1	98	2	425	1162	650	2498
Calvert Cliffs 1 & 2					3	44	3	345	1084	740	2352
Catawba 1 & 2	2	150	2800		1	98	2	400	1750		?
Comanche Peak 1 & 2	2			550	1	unknown	2			650	2400
DC Cook 1	2	150	2800	550	1	98	2	400	1700	650	2498
DC Cook 2	2	150	2800	550	1	98	2	400	1700	650	2498
Diablo Canyon 1 & 2	2	150	2514	550	1	98	2	425	1084	650	2498
Farley 1 & 2	3	150	2800	700			Note 1				2100
Ft. Calhoun					3	40	3	150	1214	400	1320
Ginna					3	60	3	300	1170	550	1830
Indian Point 2	3			650	3	98			1180		2244
Indian Point 3	3			650	3	98			1180		2244
Kewaunee					3	60.5	2	700	1082	850	1881.5
McGuire 1 & 2	2	150	2514		1	55	2	400	1106		?
Millstone 2					3	44	3	315	1084	640	2052
Millstone 3	3	150	2800				2	425	1500		?
North Anna 1 & 2	3	150	2500	650			Note 1				1950
Palisades					3	40-44	2	300	1084	600	1324
Palo Verde 1, 2 & 3					3	44	2	815	1233	1130	2392
Point Beach 1 & 2					3	60.5	2	700	1750	1100	2381.5
Prairie Island 1 & 2					3	60.5	2	700	1082	850	1881.5
Robinson					3	77	3	375	1750		?
Salem 1 & 2	2	150	2800	600	1	98	2			650	2598
San Onofre 2 & 3					3	44	3	415	1227	1000	3132
Seabrook	2	150	2800	550	1	98	2	425	1750	650	2498
Sequoyah 1 & 2	2	150	2514	550	1	55	2	425	1084	650	2455
Shearon Harris 1	3	150	2514				Note 1				?
South Texas 1 & 2	2	150	2513	?	1	35	3	800	1235	1600	4835 (Note 2)
St. Lucie 1 & 2					3	44	2	345	1084	640	1412
Summer	3	150		650	3	150	Note 1				2400
Surry 1 & 2	3	150	2485				Note 1				?
Turkey Point 3 & 4					3	77	2	300	1750		?
Vogtle 1 & 2	2	150	2514	550	1	98	2	425	1162	650	2498
Waterford 3					3	44	3	380	1227	910	2862
Watts Bar 1 & 2	2	150	2514		1	98	2				?
Wolf Creek	2	150	2514	550	1	98	2	425	1161	650	2498

Notes:

1. Same as charging pumps.
2. Does not include contribution from charging pumps.

***Containment Spray Setpoint**.* Containment spray setpoints are typically defined based on large LOCA considerations. Consequently, sprays may not (automatically) actuate during medium or small LOCAs, because peak containment pressures are lower. If sprays do not actuate during such events, debris transport to the containment floor would be reduced. Setpoints for each PWR unit are shown in Fig. 3-3. Values are found to span a wide range: 2.8 to 30 psig[8]. Consistently lower values are observed in sub-atmospheric and ice condenser containment designs, as would be expected. Nevertheless, values at or below 5 psig are observed for several units, including Calvert Cliffs, Fort Calhoun, Palisades and Waterford.

***NPSH Margin**.* PWR licensee responses to GL 97-04 were used to compile values for NPSH margin as shown in Fig. 3-4. This figure suggests approximately 20 PWR units have a margin of 2 ft of water or less. The lower margins are not necessarily a reflection of the assumptions used in ECCS design (e.g., 50% screen blockage). Rather, low margins are a result of other factors that influence NPSH-available, such as higher pool water temperature (without taking credit for containment overpressure). So far, only two PWR licensees have taken credit for containment pressures in excess of Regulatory Guide (RG) 1.1.

4.0. IMPLICATIONS OF SURVEY FINDINGS

The intent of the industry survey was to gather information that can be used in the GSI-191 Program. This information has two immediate applications. First, it facilitates NRC staff review of a particular unit's ECCS recirculation sump design and potential debris sources, and provides a preliminary means of evaluating the extent to which these characteristics favor or preclude degradation of ECCS recirculation flow. Findings with regard to this subject are described in Section 4.1. Second, it aids in the design and conduct of experiments and analysis that will provide a technical basis for full resolution of the issue. Findings of interest to GSI-191 research efforts are described in Section 4.2.

4.1. Plant Characteristics Affecting Recirculation Sump Performance

As postulated in the GSI-191 program plan, degradation or failure of ECCS recirculation can occur in one of three ways:

- The channels connecting the containment region within the missile shield to the sump (if located in the annulus) may be blocked by large debris;
- The head loss across the sump screen resulting from debris accumulation may exceed the static head available for driving the flow through the screen; and
- The NPSH margin is exceeded.

Results of the industry survey confirm all three mechanisms to be credible. That is, design characteristics can be identified in at least some units that support the possibility of each of these mechanisms. Note, however, that the units with characteristics supporting one failure mechanism are not necessarily the same units with design characteristics supporting other mechanisms. Conversely, many units have design features that likely preclude any of the postulated failure mechanisms. Which of these groups any particular unit resides in requires a thorough plant-specific review.

The survey results provide useful information for a qualitative assessment of each of these mechanisms on a unit-specific basis. For example, a unit with a sump located in the annulus, and multiple or large openings in the base of the missile shield or crane wall, are probably not susceptible to the first failure mechanism. Units with a large submerged sump screen area, small quantities of fibrous insulation and minimal sources of particulate debris (e.g., calcium silicate) are not likely to be susceptible to the second failure mechanism.

---

[8] Values were not available for several units including St. Lucie 1&2, Summer and Turkey Point 1&2.

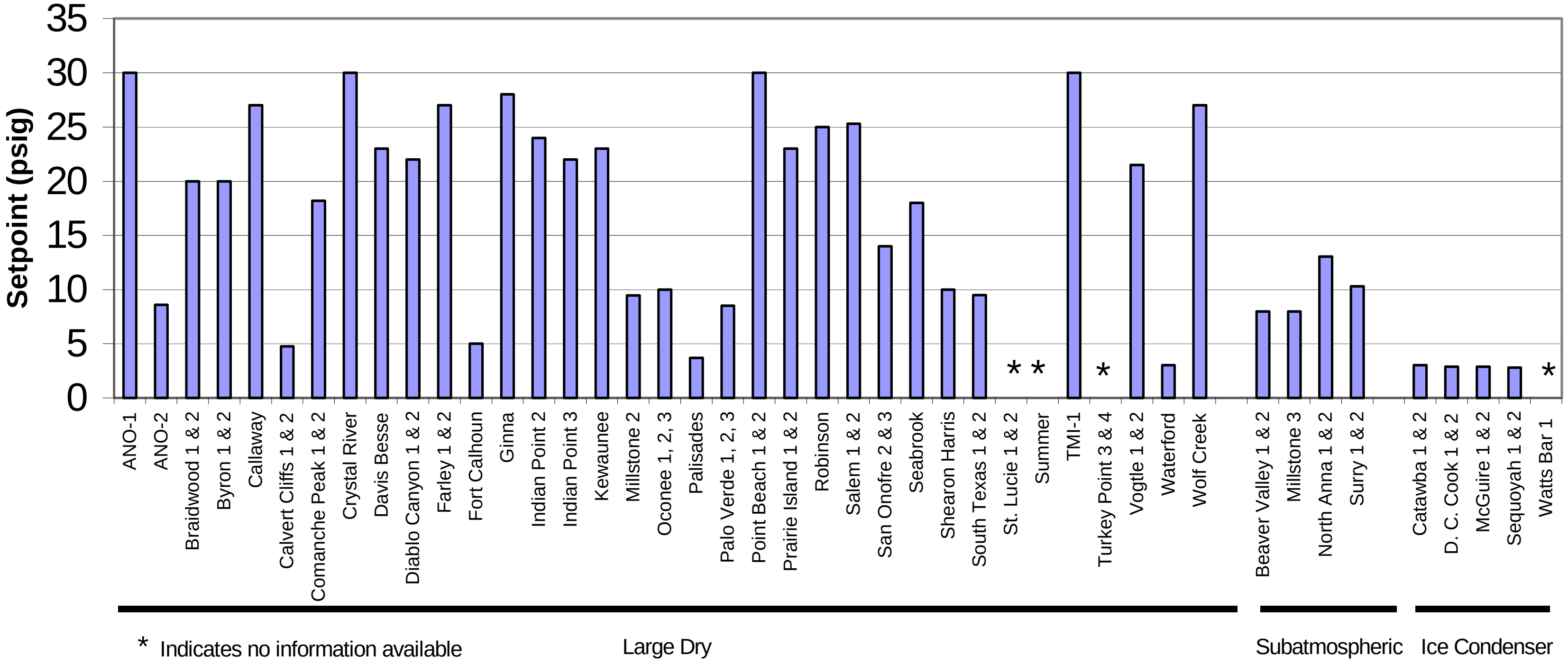


Fig. 3-3. Containment spray setpoints.

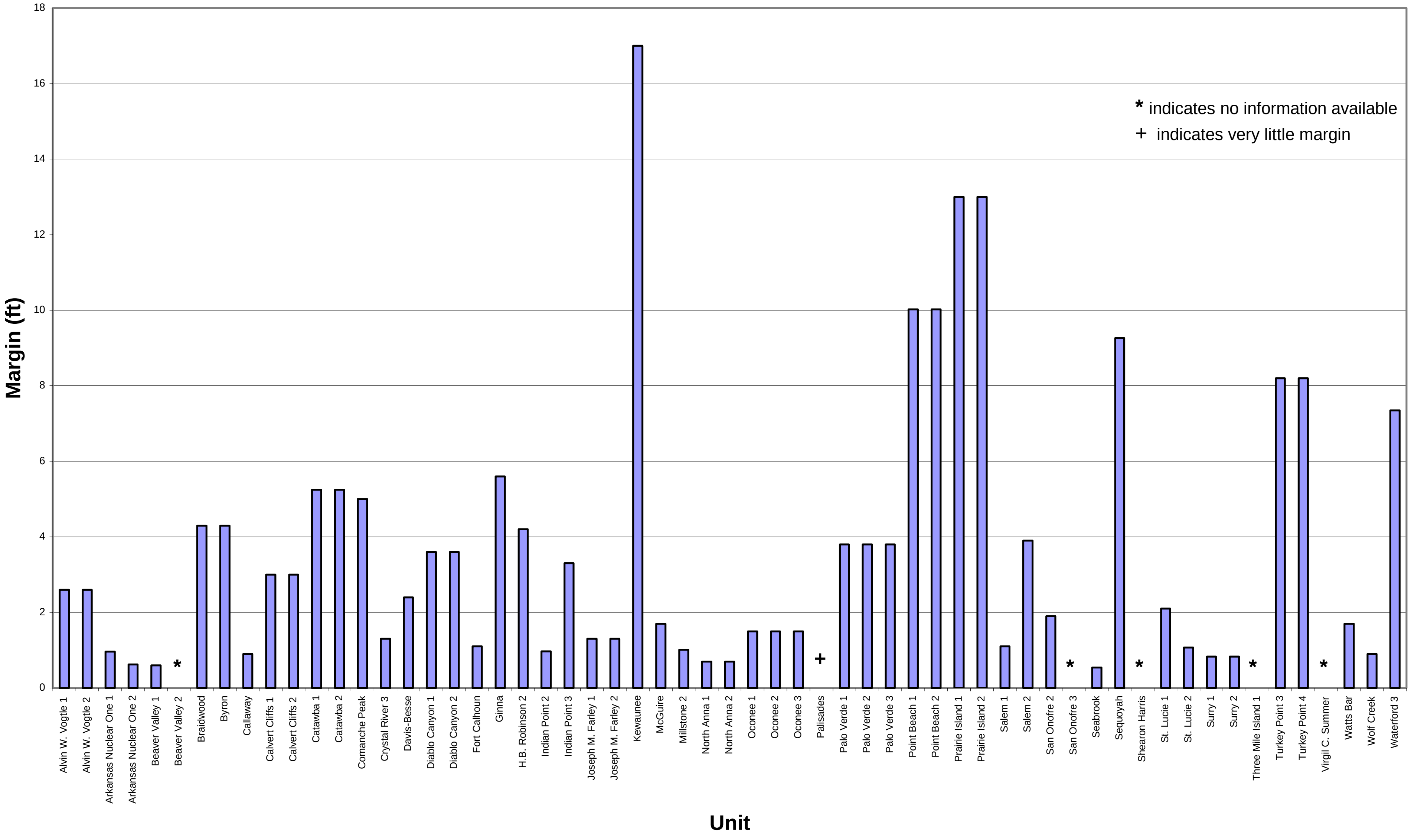


Fig. 3-4. NPSH margin (ft). [From Licensee GL 97-04 responses]

In all cases, the terms such as “small,” “large,” or “minimal” cannot be quantitatively measured from the results of the survey alone. Ongoing research activities endeavor to provide the additional information needed to establish quantitative failure criteria. However, a qualitative assessment of the susceptibility of a particular unit relative to the overall population of U.S. PWRs can be made from the data listed in Table 4-1.

The survey also identified several specific design characteristics that need to be considered in an evaluation of any particular unit’s ECCS design. These characteristics broadly fall under the topics of debris generation and debris transport.

Debris Generation

The survey clearly demonstrated that PWRs use a wider variety of insulation than BWRs. Therefore, data collected from the Boiling Water Reactor Owners’ Group (BWROG) air jet impingement test (AJIT) program does not address many types of insulation currently in service on PWRs. This issue remains to be resolved either as part of a generic issue or through plant-specific evaluations.

The survey results confirm the dominant application of RMI on primary system piping, the reactor pressure vessel, and steam generator surfaces; but significant quantities of non-metallic insulation are used on secondary coolant system piping (e.g., steam lines), instrumentation lines, and associated components (e.g., pipe-whip restraints). It is likely that these lines would be within the zone of influence (ZOI) formed by breaks in primary system piping at some locations. Close proximity of primary and secondary system piping is particularly applicable to B&W plants because of the unique configuration of the once-through steam generators.

Table 4-1. Summary of Key Survey Results

Parameter	Median Value	Standard Deviation	Lowest Value	Highest Value	Comments
Pool Height at Switchover (ft)	3.87	2.10	0.7	9.9	Lowest for containments with inside recirculation sumps
Time at Switchover (min)	21.19	9.84	2.2	45.	Lowest for containments with inside recirculation sumps
Number of Containment Sumps	1		1	4	Sump with steel plate to compartmentalize is counted as one sump.
Sump Screen Area (ft^2)	162	138	12	692	
Sump Screen Clearance (in)	0.17	0.14	0.07	1.0	Five units have >0.75 in. clearance
Trash Rack Area (ft^2)	201	193	42.2	883	
Trash Rack Clearance (in^2)	3.4	2.5	0.56	16	
Curb Height (in)	6.2	4.5	0.	18	
Fibrous Insulation (%)	39	--	0.5	100	
RMI Insulation (%)	12	--	0.0	100	
Cal-Sil Insulation (%)	12	--	0.0	59	
Sump Screen Approach Velocity @ Switchover (ft/s)*	0.21	0.29	0.03	1.36	
NPSH Margin (ft-water)*	3.9	3.8	0.0	17	

* Additional information obtained from GL 97-04 responses.

Further, the survey results indicate a significant number of PWRs use fibrous or particulate fire barrier materials (amounting up to 1500 ft^3) in the containment. Not much information was provided in the survey responses to indicate whether these materials would be protected from the destructive forces of a pipe break (e.g., cable-trays or other structures). Additional information would be required to dismiss these items as potential debris sources.

Debris Transport

A considerable fraction of the responding PWRs provided containment floor layout drawings. The following observations could be made from these drawings.

A large fraction of the PWR ECCS sumps are “exposed” to the pool dynamics influenced by the water that would spill from broken pipes. Turbulence levels and complex fluid dynamics near the sump makes the estimation of debris transport in these cases challenging. Applying or extrapolating results of quiescent pool transport experiments to such conditions is questionable at best.

The pathways connecting remote sumps to the main containment floor vary considerably. In most cases, large doorways fitted with a grating-door are used to screen out very large pieces of debris. There are no noticeable curbs or structural impediments in front of these doors; hence, debris accumulation on these doors (if sufficiently dense) could impede the flow of water to the piping annulus where the sumps are located. This could, in turn, affect (i.e., decrease) the height of water over the sump and the available NPSH. A closer examination of the potential for and effects of plugging these pathways may be warranted.

Some units have narrow channels (e.g., 1 ft diameter labyrinths) that connect the region inside the missile shield (or crane wall) to the piping annulus where the recirculation sumps are located. In such cases, the entrances to the labyrinths are protected by trash racks and/or fine screens. The potential for plugging of these labyrinths should be examined carefully.

Finally, units that may require careful attention are those in which the sump screen is not expected to be fully submerged at the time ECCS suction switches over to the containment sump. A listing of these units is given in Table 4-2. In such cases, ‘head loss’ is not an appropriate metric for evaluating the effects of debris accumulation on the sump screen. Rather, changes in pool water level due to reduced flow through the lower portion of the screen may upset the balance of water flow into the sump and pump suction from the sump.

4.2. Implications for Related Research Activities

A major finding of this survey is the high degree of variability in ECCS recirculation sump design features and characteristics of potential debris sources. Based on the results of the survey, it is difficult, if not impossible, to described a “prototypic” recirculation sump design for the purposes of planning research activities. At least 6 major categories of sump design were identified, each distinguished by a unique geometric configuration. The total amount and type of debris the sump screens would encounter in the event of a LOCA also appear to span a very wide range.

If experimental or analytical studies are to properly examine ECCS recirculation sump performance for even a sample of “representative” U.S. plants, this variability must be taken into account. Statistical analysis of the survey results reveals useful quantitative information on the range and distribution of values for parameters that affect sump performance. A summary of this information was given in Table 4-1, which lists the median, standard deviation and extreme values for surveyed parameters.

Values for the velocity of water entering the sump screen and the ECCS recirculation pump NPSH margin at the time of switchover are also given at the bottom of the Table 4-1. These two parameters were not included in the GSI-191 survey, but can be obtained or computed from the submittals for GL-97-04.

Table 4-2. List of Units with Partially Submerged Sump Designs

Unit Name	Pool Height (ft)	Screen Height Above the Floor (ft)	NPSH Margin (ft)
Wolf Creek	2.1	8.7	0.9
St. Lucie 1	5.5	11.5	2.1
St. Lucie 2	5.5	11.5	1.07
North Anna 1	0.9	6.25	0.7
North Anna 2	0.9	6.25	0.7
Beaver Valley 1	4.1	5.0	0.6
Beaver Valley 2	4.1	5.0	0.6
Surry 1	0.7	5.0	0.83
Surry 2	0.7	5.0	0.83
Comanche Peak	2.24	6.25	5.0
Diablo Canyon 1	2.73	5.0	3.6
Diablo Canyon 2	2.73	5.0	3.6
Three Mile Island 1	1.74	4.0	N/A
San Onofre 3	1.92	4.0	N/A
Point Beach 1	5.3	6.0	10.02
Point Beach 2	5.3	6.0	10.02

In addition to these measurable parameters, variations in the overall configuration of recirculation sumps should also be considered in planning future studies. Research performed to date in support of GSI-191, has focused on the fluid mechanics of water on the containment floor and the attendant transport of suspended debris toward the recirculation sump screen. Variability in the quantitative parameters listed in Table 4-1 has been addressed in this work. However, to apply results of this research to a quantitative evaluation of sump screen performance (i.e., a comparison of head loss to NPSH margin), major differences in sump screen configurations would also need to be considered.

Scaled hydraulic experiments to simulate debris transport to the recirculation sump(s), therefore, should consider the full range of possibilities as far as the location of the water spill from the break relative to the location of the sump. Further, the survey results do not support screening out the possibility of debris accumulation and flow impediment at locations other than the sump screen. Consequently, the potential for blockage of passageways between the inner containment floor and the location of the sump should also be examined in the experimental program.

Appendix A

Industry Survey on PWR Sump Design and Operation

Question	Unit	Explanatory Notes
Unit Name: xxxx	n/a	A separate response is needed for each PWR unit.
1. Briefly describe the large-break LOCA (LBLOCA) that is the basis for responding to the following questions.	n/a	Use: This information will be used to establish the conditions in containment that may affect debris generation, transport, accumulation, and head loss. Content of Response: Include system, location, diameter of break, and type of break (e.g., DEGB). If a description of the LBLOCA is contained in the FSAR, please, identify which postulated accident is the basis for responding to the following questions (e.g., LOCA-6). Sample Response: Double-ended main-steam-line break at containment wall.
a. Following a LBLOCA, what is the containment flood level (i.e., depth of water on floor) at time switch over from refueling water storage tank (or borated water storage tank) to sump?	ft	Use: This information will be used to estimate debris transport (e.g., amount of debris settling, transport rate of debris to sump).
b. Following a LBLOCA, when does the low-pressure safety injection (LPSI), residual heat removal (RHR), and/or recirculating pumps start to draw suction from the sump?	s	Use: This information will be used to estimate debris transport (i.e., amount of debris settling).
c. Following a LBLOCA, what is the maximum containment flood level?	ft	Use: This information will be used to estimate debris transport.
d. Following a LBLOCA, when is the maximum containment flood level reached?	s	Use: This information will be used to estimate debris transport.
e. Which water sources are used to determine flood level [e.g., Reactor Coolant System (RCS) spillage, Refueling Water Storage Tank (RWST) inventory, containment spray, ice melt, etc.)?	n/a	Some plant FSARs do not inventory water from the molten ice or one of four accumulator tanks. This is treated as an additional margin of safety in the FSAR. In risk assessment and debris transportation estimates, such knowledge may vary some of the results. Use: This information will be used to estimate debris transport.
2. Briefly describe the medium-break LOCA (MBLOCA) or intermediate-break LOCA that is the basis for responding to the following questions.	n/a	See Question 1 and its explanatory notes.
a. Following a MBLOCA, what is the containment flood level (depth of water on floor) at the time of switchover from the RWST (borated water storage tank)?	ft	See Question 1 and its explanatory notes.
b. Following a MBLOCA, when does the LPSI, RHR, and/or recirculating pumps start to draw suction from the sump?	s	See Question 1 and its explanatory notes.

Question	Unit	Explanatory Notes
c. Following a MBLOCA, what is the maximum containment flood level?	ft	See Question 1 and its explanatory notes.
d. Following a MBLOCA, when is the maximum containment flood level reached?	s	See Question 1 and its explanatory notes.
e. Which water sources are used to determine flood level (e.g., RCS spillage, RWST inventory, containment spray, ice melt, etc.)?	n/a	See Question 1 and its explanatory notes.
3. Provide a sketch of the containment sump(s).	n/a	A detailed response to this set of questions is very important. Small features such as curbs may significantly influence debris transport. Use: This information (and the following sump information) will be used to estimate debris transport, accumulation, and head loss. This information also will be used to design any experimental facility that may be needed.
a. How many containment (recirculating) sumps?	n/a	Use: This information will be used in estimating debris transport, debris accumulation, and head loss associated with the accumulation of debris. The information also will be factored into risk assessment.
b. What is the depth below containment floor of containment (recirculating) sump(s)?	ft	
c. What is the height above the containment floor of the containment (recirculating) sump screen(s)?	ft	
d. Does the sump have a screen?	n/a	Use: Responses to this question will be used to calculate debris transport, accumulation and head loss.
e. How much screen area is available?	ft^2	Use: Estimation of head loss across debris bed and design of experiments.
f. What is the hole size in the sump screen?	In.	Use: Estimation of head loss across debris bed and design of experiments. Sample Responses: ¼4-in.-diam perforations at 5/16 in. center to center, #4 mesh with 3/16-in. openings, mesh with 0.187-in. openings, etc.
g. Does the sump have a trash rack?	n/a	See Question 3d and its explanatory notes.
h. What is the distance between the sump screen and the trash rack?	in.	
i. How much trash rack is available?	ft^2	See Question 3e and its explanatory notes.
j. What is the hole size in the trash rack?	in.	See Question 3f and its explanatory notes. Sample Responses: Stainless-steel grating with 4-in. by 1/3-in. spacing, mesh with 4-in. by 4-in. openings, 1-in. by ¼ 4-in. grating, etc.
k. Does the sump have a solid or screen cover plate?	n/a	
l. Inside the sump do the ECCS pumps draw suction through a vortex suppressor or strainer, if so provide a sketch?	n/a	See Question 3d and its explanatory note.

Question	Unit	Explanatory Notes
m. Does the sump have a debris curb?	n/a	Use: The responses to this question will be used to estimate debris transport and accumulation.
n. What is the height of the debris curb?	ft	
o. What is the distance between the debris curb and sump screen?	ft	
4. Provide a plan view sketch of the containment elevation that the sumps are located.	n/a	Containment features, such as compartmentalization, can significantly influence debris transport. Use: Responses to this question will be used to estimate debris transport and accumulation. Also, responses will be used to design experiments.
a. Containment type?	n/a	This information is needed if plant names are not included with the collected data. Examples of Responses: Large dry, subatmospheric, or ice condenser
b. What is the containment floor area (open area only)?	ft^2	Use: Responses to this question will be used to estimate the volume of water on the containment floor, to calculate bulk flow rates, and to design experiments.
c. Where are the sumps located?	n/a	Content of Response: It is preferable if sump locations were shown on the plan-view sketch of the containment.
d. How many compartments and subcompartments in containment?	n/a	Content of Response: It is preferable if sump locations were shown on the plan-view sketch of the containment. Provide a list of the compartments.
e. What are the size of openings between compartments?	ft	Content of Response: Response should not include openings that are not expected to be open during a postulated accident. Indicate on list of compartments. Sample Response: 4-ft x 8-ft to 6-in.-diam openings.
f. How many openings between compartments?	n/a	Content of Response: It is preferable if sump locations were shown on the plan-view sketch of the containment. Indicate on list of compartments or sketch.
g. What are the locations of openings between compartments?	n/a	Content of Response: It is preferable if sump locations were shown on the plan view sketch of the containment.
5. Identify potential debris sources.		Use: Different debris types (e.g., insulation) behave differently following a LOCA. Therefore, the staff needs to understand what types of debris sources are in PWRs. This information also will be used to design experiments and in all analyses.
a. List the types of service level 1 coatings in containment.	n/a	Sample Responses: Epoxy phenolic on steel surfaces, epoxy mastic on steel and concrete surfaces (e.g., carbomastic 15, Amerlock 400NT), inorganic zinc on steel surfaces (e.g., Dimetcote 6 (D6), Carboline CZ-11), epoxy polyamide on steel or concrete surfaces (e.g., Val-Chem 89 series, Carboline 2191, Starglaze 2011S), phenolines on steel or concrete surfaces (e.g., Phenoline 368 WG, Carboline 890), vinyl on steel surfaces, etc.
b. Provide a rough estimate of the amount (square footage) of each type of service level 1 coating that is in containment.	%	Sample Response: Epoxy phenolic on steel surface (35%), vinyl on steel surface (5%), phenolines on concrete surfaces (60%).

Question	Unit	Explanatory Notes
c. List the types of thermal insulation in containment.	n/a	Sample Responses: Aluminum reflective metallic insulation, stainless-steel reflective metallic insulation (e.g., MIRROR), fiberglass blanket, jacketed fiberglass (e.g., NUKON®, Thermal-Wrap®), mineral wool blankets, calcium silicate, jacketed calcium silicate, min-k blanket, k-wool blanket, etc.
d. Provide a rough estimate of the amount of thermal insulation (by volume or square feet) that is in containment.	%	Sample Response: Reflective metallic insulation (80%), calcium silicate (10%), encapsulated fiberglass (10%).
e. List the types of fire barrier materials in containment.	n/a	Some fire barriers are made with fibrous material.
f. Provide a rough estimate of the amount of fire barrier material (by volume or square feet) that is in containment.	%	See Question 5d and its explanatory note.
g. List the types of filter materials in containment.	n/a	It has been postulated that filter materials disintegrate following a LOCA and would generate fine fibrous debris. Use: This information will be used to assess the potential for debris to be generated from filter materials.
h. Provide a rough estimate of the amount of filter material (by volume or square feet) that is in containment.	%	See Question 5d and its explanatory note.
i. Following a LBLOCA, what is the boron concentration in water on the containment floor?	ppm	It has been postulated that boron in sump water reacts with zinc from the paint chips and precipitates small zinc-hydroxide particles, which is an additional source of debris. However, this reaction is very slow at the low boron concentrations that are typical of many US PWRs. Staff wants to get a good understanding of this potential. Use: This information will be used to make a determination whether the formation of boron precipitates is a credible particulate debris source.
j. Following a MBLOCA, what is the boron concentration in water on the containment floor?	ppm	See Question 5i and its explanatory note.
6. Are there procedures available providing instruction on switching to an alternate water source if the sump is unavailable? What is the water source?	n/a	Assumptions regarding recovery actions would substantially alter risk estimates, and thus the overall outcome of this issue. Use: Responses to this question will be used in the risk assessment. Sample Response: Yes, RWST that has been refilled from . . .

APPENDIX B

Nuclear Plant Units Responding to Survey

Alvin W. Vogtle 1
Alvin W. Vogtle 2
Arkansas Nuclear One 1
Arkansas Nuclear One 2
Beaver Valley 1
Beaver Valley 2
Calvert Cliffs 1
Calvert Cliffs 2
Catawba 1
Catawba 2
Comanche Peak
Crystal River 3
Davis-Besse
Diablo Canyon 1
Diablo Canyon 2
Fort Calhoun
Ginna
H.B. Robinson 2
Indian Point 2
Indian Point 3
Joseph M. Farley 1
Joseph M. Farley 2
Kewaunee
Millstone 2
North Anna 1
North Anna 2
Oconee 1
Oconee 2
Oconee 3
Palisades
Palo Verde 1
Palo Verde 2
Palo Verde 3
Point Beach 1
Point Beach 2
Prairie Island 1
Prairie Island 2
Salem 1
Salem 2
San Onofre 2
San Onofre 3
Seabrook
Sequoyah
Shearon Harris
St. Lucie 1
St. Lucie 2
Surry 1
Surry 2
Three Mile Island 1
Turkey Point 3
Turkey Point 4
Virgil C. Summer
Watts Bar
Wolf Creek
Waterford 3

APPENDIX C

Survey Limitations

This section summarizes general problems (or uncertainties) associated with the responses, followed by additional questions that may be helpful in resolving some of the problems.

General Survey Response Troubles/Uncertainties

Question 1c / 1d

Following a LBLOCA, what is the maximum containment flood level {ft}, and when does it occur{sec}?

The intent of these questions was to find out whether containment pool depth would differ from containment pool depth at switchover to recirculation. The industry responses did not provide enough information to fully resolve this question and more explanation may be needed. (Such a difference might be attributable to prolonged ice melting or a holdup of water in upper containment as a result of spray operation.) What the responses identify is how high the containment pool could get given uncertainties such as no leakage to the reactor cavity or instrument tunnel, initial RWST inventory at maximum, and switchover to recirculation through the emergency sump failing to take place as it should before the RWST was completely drained.

It appears that many licensees responded to Question 1a using licensing-basis assumptions and to Question 1c using best-estimate assumptions. Unless additional information is provided, it appears that the licensee responses to 1c will not be used in any of our analyses.

Questions 2 and 2a-2e

Medium LOCA questions.

Responses to Questions 2 and 2a-2e were largely incomplete. Many units pointed out that a medium LOCA is not a design-basis condition and that because of this, little attention has been given to predicting medium LOCA progression. Some valuable comments were provided that related medium LOCA expectations relative to large LOCA calculations, but little quantitative information was obtained for Questions 2 and 2a-2e.

Question 3e

What is the sump screen area? {ft^2}

The intent of this question was to gather information regarding the amount of surface area available to accommodate debris. Most of the units provided the total physical area of the screen. However, in some, the entire sump screen will not be submerged in water, and the exposed area would not be available for accommodating debris. Based on our review, this concern seems to apply to 16 units.

Question 3n

What is the height of the debris curb? {ft}

The beneficial effects of a debris curb are becoming evident in the linear flume testing. The “dead transport zone” created by the curb in the Millstone 2 tank tests lends more credence to the importance of this feature. Many units reported having no curb. The clarification of what constitutes a curb may eliminate some of these responses. Any solid obstruction at the containment floor level in front of or under the sump screen can be considered a curb. A good example of this would be the angle iron or channel used to fasten the screens to the floor. These fasteners actually provide a 1- to 2-in. curb.

Question 5b

Provide a rough estimate of the amount (square footage) of each type of service level 1 coating that is in containment. {%}

Only a few units provided amounts of each type of level 1 coating in containment. The typical response identified the total amount of level 1 coatings applied to concrete and the total amount applied to steel. Some units reported percentages and some provided in ft^2.

Responses to this question would benefit the ongoing paint study considerably.

Question 5d

Provide a rough estimate of the amount of thermal insulation (by volume or square feet) that is in containment. {%}

The units in which insulation amounts were reported were inconsistent. Most amounts were given as percentages of total containment insulation. Some amounts were in units of volume (ft^3). A few amounts were in units of area (ft^2). This question was answered in three or four different ways and really needs to be answered in a consistent manner. The question should read "*Provide a rough estimate of the amount of thermal insulation by volume in cubic feet for each type of insulation present in containment.*"

Missing Responses

Question 1a

Following a LBLOCA, what is the containment flood level (i.e., depth of water on the floor) at the time of switchover from the refueling water storage tank (or borated water storage tank) to the sump? {ft}

The following units did not respond to this question.

- Beaver Valley Units 1 and 2
- Salem, Farley Units 1 and 2, and St. Lucie Units 1 and 2 (LANL estimated the actual height from the flood levels (e.g., +581 ft) provided by the licensees)

Question 3b

What is the depth below containment floor of containment (recirculating) sumps(s)? {ft}

The following units did not respond to this question.

- Indian Point 3
- Prairie Island 1
- Prairie Island 2
- Shearon Harris

Question 3e

How much screen area is available?

The following units did not respond to this question.

- ANO-2
- Indian Point 3
- Joseph M. Farley 1
- Joseph M. Farley 2
- Prairie Island 1
- Prairie Island 2

LANL estimated the values in these units using drawings provided by the licensee.

Question 3f

What is the hole size in the sump screen? {in.}

The following units did not respond to this question.

- Prairie Island 1
- Prairie Island 2
- Shearon Harris
- Surry 1
- Surry 2

Prairie Island Units 1 and 2 and Surry Units 1 and 2 seem to have 0.75-in. trash racks and no sump screens.

Question 3i

How much trash rack is available? {ft sq.}

The following units did not respond to this question.

- ANO-2
- Ginna
- Indian Point 2
- Indian Point 3
- North Anna 1
- North Anna 2
- Palisades
- St. Lucie 1
- St. Lucie 2
- Surry 1
- Surry 2
- Turkey Point 3
- Turkey Point 4
- Waterford 3

Question 3j

What is the hole size in the trash rack? {in.}

The following units did not respond to this question.

- Alvin W. Vogtle 1
- Alvin W. Vogtle 2
- ANO-1
- ANO-2
- Catawba 1
- Catawba 2
- Ginna
- Indian Point 3
- Palisades
- Palo Verde 1
- Palo Verde 2
- Palo Verde 3
- St. Lucie 1
- St. Lucie 2
- Turkey Point 3
- Turkey Point 4

Question 3n

What is the height of the debris curb? {ft}

The following units did not respond to this question.

- ANO-2
- Davis-Besse
- Fort Calhoun
- Indian Point 2
- Indian Point 3
- Joseph M. Farley 1
- Joseph M. Farley 2
- Millstone 2
- North Anna 1
- North Anna 2
- Point Beach 1
- Point Beach 2
- Surry 1
- Surry 2
- Turkey Point 3
- Turkey Point 4

Question 4b

What is the containment floor area (open area only)? {ft sq.}

The following units did not respond to this question.

- H. B. Robinson 2
- Indian Point 3
- Point Beach 1
- Point Beach 2
- St. Lucie 1
- St. Lucie 2
- Waterford 3

Question 5b

Provide a rough estimate of the amount (square footage) of each type of service level 1 coating that is in containment. {%}

The following units did not respond to this question.

- Calvert Cliffs 1
- Calvert Cliffs 2
- Davis-Besse
- Ginna
- H. B. Robinson 2
- Indian Point 2
- Joseph M. Farley 1
- Joseph M. Farley 2
- Oconee 1
- Oconee 2
- Oconee 3
- Palisades
- Palo Verde 1
- Palo Verde 2
- Palo Verde 3
- Prairie Island 1
- Prairie Island 2
- Salem 1
- Salem 2
- San Onofre 2
- San Onofre 3
- Shearon Harris
- St. Lucie 1
- St. Lucie 2
- Turkey Point 3
- Turkey Point 4
- Waterford 3

Question 5d

Provide a rough estimate of the amount of thermal insulation (by volume or square feet) that is in containment. {%}

The following units did not respond to this question.

- Calvert Cliffs 1
- Calvert Cliffs 2
- H. B. Robinson 2
- Millstone 2
- Palisades
- Palo Verde 1
- Palo Verde 2
- Palo Verde 3
- Point Beach 1
- Point Beach 2
- San Onofre 2
- San Onofre 3
- Turkey Point 3
- Turkey Point 4
- Virgil C. Summer
- Waterford 3

Question 5i

Following a LBLOCA, what is the boron concentration in water on the containment floor? {ppm}

The following units did not respond to this question.

- Catawba 1
- Catawba 2
- Crystal River 3
- Turkey Point 3

3.3. Additional Questions that could be Helpful

Regarding containment sprays (given a large LOCA):

- When would the sprays actuate and how long would they be on?
- What would spray flow rate be?
- How would spray water make its way to the containment pool?

Velocity at Sump Screen

This was not a question specifically asked in the survey. The values presented in this report are calculated by LANL based on the screen area provided and the sump flow rates taken from a separate report. These values should be confirmed by the units to ensure accuracy.