AEOD/T97-01

DESIGN ERRORS IN NUCLEAR POWER PLANTS

January 1997

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EXECUTIVE SUMMARY

As a followup to address design problems such as those recently uncovered at Millstone, Maine Yankee, and elsewhere, the U.S. Nuclear Regulatory Commission's Office for Analysis and Evaluation of Operational Data (AEOD) has completed a review of operating experience and inspection results to identify potential driving forces for discovery of design errors from 1985 through 1995. The sources of operating experience information included the: (1) Sequence Coding and Search System to identify licensee event reports, (2) Emergency Notification and Safety Related Data system to identify applicable generic communications, (3) Regulatory Information Tracking System to determine direct inspection effort, (4) Electrical Distribution System Functional Inspection database, (5) Service Water System Operational Performance Inspection database, and (6) the Accident Sequence Precursor database. The main source of information included an analysis of 3439 licensee event reports describing design errors that were identified for the 11 year period (1985 through 1995).

This report provides observations about how design errors at operating nuclear facilities have been discovered, and the potential impacts of regulatory or industry actions. The results of the 1985 through 1995 review indicate the following conclusions:

(1) The number of reported design errors has been steadily dropping since the early 1990s even though the number of NRC inspector-hours in performing engineering related inspection modules has increased during the same time period.

(2) The number of reported design errors discovered as a result of design-basis review efforts steadily decreased by 1995, presumably due in part, to diminishing licensing resources allocated to this effort and the lessening number of undiscovered latent design errors.

(3) The number of design errors discovered at any given time was dependent on the extent of initiatives taken by the NRC and the industry. Major NRC initiatives included design-related team inspections which began during the mid-1980's and many design-related generic communications. During this same time period, industry had initiated indepth design-basis reviews which resulted in an increase in the discovery of design problems.

(4) There appeared to be a relation between the number of design-related generic communications issued by the NRC and the number of licensee reported design errors. However, licensee event reports infrequently attributed generic communications as the initiator for the discovery of design errors.

(5) Approximately two percent of the reviewed licensee event reports containing design errors were found significant enough to be evaluated under the Accident Sequence Precursor (ASP) program. Of those design error events that were in the ASP database, the majority had conditional core damage probabilities between 10^{-4} and 10^{-6}.

1 INTRODUCTION

The NRC is examining potential future efforts to address design problems such as those recently uncovered at Millstone, Maine Yankee, and elsewhere. NRC databases were examined to identify the magnitude and trend of design problems as part of this overall effort.

One hypothesis is that, in the late 1980s and early 1990s, the NRC had numerous inspection efforts, generic letters, and other mechanisms that would drive the identification of such problems. Recent emphasis on operational performance and risk may have lessened that pressure on the industry. Furthermore, internal industry trends, such as increased emphasis on economic efficiency, may be inhibiting the identification of problems.

2 DISCUSSION

The NRC Sequence Coding and Search System (SCSS) (Ref. 1) was used to identify licensee event reports (LERs) reporting design errors during 1985 through 1995. The SCSS was also used to categorize these events to identify potential driving forces for discovery of the design errors. The other NRC databases were also relied upon, to the extent feasible, to analyze the causal relationships.

The NRC Emergency Notification and Safety Related Data system (Ref. 2) was searched to identify types and number of generic communications issued during the period, including design related items. The Regulatory Information Tracking System (RITS) (Ref. 3) was used to determine the NRC's direct inspection effort on all design-oriented inspections in operating plants. The NRC databases on Electrical Distribution System Functional Inspection (EDSFI) (Ref. 4) and Service Water System Operational Performance Inspection (SWSOPI) (Ref. 5) were searched to identify the number of such inspections and design-related findings of these inspections over the years.

The trends of the above data were plotted over the 11 year period in an attempt to identify potential relations between the data. The relations of interest were those between the level of the NRC interest or activity in the design arena and the number of design issues identified.

The NRC accident sequence precursor (ASP) database (Ref. 6) was also searched to identify the number of design error events evaluated by the ASP program during the 11 year period and the distribution of their conditional core damage probability (CCDP) values. The NRC's and licensees' efforts contribute to the design error discovery process. The process, including the various contributing factors from both sources and how they feed back, is schematically shown in Figure 1, "Design Error Discovery Process."

3 FINDINGS AND CONCLUSIONS

3.1 Trend of Design Errors

A total of 3439 LERs describing design errors were identified for the 11 year period (1985 through 1995) through the SCSS search, indicating an average of 313 events/year. During this period, there was a significant increase in the number of operating plants as shown in Figure 2, "Number of Operating Plants by Year." The distribution of the design errors over the period (Figure 3, "Trend of Total Design Errors") shows a peak of 450 events in 1988 and a declining trend thereafter with a significant reduction in 1993 through 1995. An explanation of the peaking characteristics and to what extent each contributing factor was responsible for the distribution in Figure 3 is discussed in the following sections, in an attempt to identify potential relations between the data.

3.2 The Effect of Newly Licensed Plants

The distribution of design errors shown in Figure 3 includes the contribution from two groups of plants: "old plants" and "new plants." For the purpose of this analysis, old plants were arbitrarily defined as those licensed before 1980, the new plants being those licensed in 1980 and later. There are 60 old plants and 49 new plants. Further, the new plants were subdivided into two groups: 19 plants licensed during 1980—84 (new plants — group 1) and 30 plants licensed during 1985—95 (new plants — group 2).

The peak in the time dependent distribution in Figure 3 could partly be attributed to the large number of plants licensed around the same time frame (Figure 2). However, the number of design errors on a "per plant" basis (i.e., the number of design errors for each year divided by the number of plants operating during the corresponding year), also shows the same trend (see Figure 4, "Design Errors per Plant for Old and New Plants"). The "per plant" distribution has an average of 3 events/year/plant and a peak of 4.4 events/year/plant in 1988 and fewer events reported in 1993 through 1995.

If the large number of plants licensed around 1988 were the only cause of peaking in Figure 3, expressing the same data on a "per plant" basis should have canceled the effects of number of plants on line at any given year and the resulting "per plant" distribution (Figure 4) should have shown essentially flat characteristics. Therefore, the peaking characteristics in Figure 4 indicate that there are some more factors causing the peaking effect in Figure 3. Although the averages are not significantly different, the peak for new plants is significantly larger and occurs earlier. Also, Figure 4 indicates that the new plants, compared with old plants, have higher per plant errors in the beginning of the 11 year period, but the number drops off rather quickly. As indicated in Figure 4 and noted before, the effect of newly licensed plants alone could not explain the peaking characteristics in Figure 3. This fact implies that there are some more factors causing the peaking effect.

When the design errors for group 2 of newly licensed plants (the 30 plants licensed during 1985—1995) were separated for each year after licensing and then totalled for each year after licensing (i.e., irrespective of the calendar year the errors were reported), the resulting distribution was a unique characteristic curve shown in Figure 5, "Total Design Errors After Licensing for New Plants — Group 2," with maximum contribution of design error discovery in the first year of operation and a gradual exponential-like reduction over the subsequent years.

3.3 The Effect of Design-Basis Reconstitution and Generic Communication Efforts

The effects of factors such as licensees' design-basis reconstitution (DBR) effort and NRC's generic communication process for old and new plants are shown respectively in Figure 6, "Total Design Error Contributors for Old Plants," and Figure 7, "Total Design Error Contributors for New Plants." It is clear that the effects of these factors are relatively small, especially for the generic communication process. However, it is possible that the licensees, while reporting the events, may not have given due credit to the generic communication process, especially when the generic communications helped the discovery indirectly. Therefore, the effect of the generic communication process may be under-represented. The effect of generic communications on new plants is less than for old plants, presumably because some issues were addressed and resolved during the licensing process for the new plants.

Further, it is believed that licensees' effort on the DBR process has been reduced in recent years. Therefore, the resulting rate of discovery attributable to this process is also small. The distribution of various types of NRC generic communications issued, (i.e, bulletins, generic letters, and information notices), is shown in Figure 8, "Generic Communications Issued." Although the total generic communications distribution did not follow the total design error distribution (Figure 3), the distribution of the sum of bulletins and generic letters showed good resemblance, with its peak of 45 in 1988.

The distribution of design-related bulletins and generic letters with actual or potential effect on design, directly or indirectly, is shown in Figure 9, "Design Related Generic Communications Issued." As in the case of the sum of bulletins and generic letters, the distribution of design-related bulletins and generic letters showed good resemblance to the total design error distribution (Figure 3), with a peak of 37 in 1988. There appears to be a relation between the number of design-related generic communications issued and the number of reported design errors.

3.4 The Effect of Other Factors

After deducting the effects of generic communication and DBR efforts, the residual is denoted as "other DEs," meaning other design errors. Because of the inherent limitations of the SCSS with limited cause coding, it was not possible to sort the "other DEs" under all potential cause categories, so as to identify additional driving forces for the error discovery.

However, it is reasonable to assume that the "other DEs" would include NRC's efforts such as design related inspections and licensee's efforts such as other design reviews (other than DBR), audits, self assessments, and inspections (see Figure 1).

The "other DEs" components for old and new plants is shown in Figure 10, "Total Other Design Errors for Old and New Plants," which together constitute the bulk of all design errors (Figure 3). The "other DEs," divided by the number of plants operating during each year, are shown separately for old and new plants in Figure 11, "Other Design Errors per Plant for Old and New Plants." As seen from these figures, after peaking in 1987—88, the "other DEs' have significantly declined over the period 1988—95.

3.5 The Effect of Design Oriented Team Inspections

As in the case of NRC's generic communications, while reporting the events, the licensees may not have indicated that a design error was discovered by or was indirectly found by NRC design-oriented team inspections. Therefore, the effect of these inspections may be under-represented in the SCSS database. The NRC databases such as RITS, EDSFI, and SWSOPI were used for identifying the effect of these inspections, to the extent possible.

Figure 12, "Direct Inspection Effort for NRC Engineering Inspections," shows the distribution of the direct inspection effort that the NRC spent on design or engineering oriented inspections (37000 series Inspection Procedures) for operating plants. Although the trend of the direct inspection hours is increasing over the years, the design error discovery rate has been decreasing over the same period (Figure 3). One possible explanation is that, during recent years, increasing direct inspection hours are being spent on routine engineering inspections which are less effective in discovering design errors and decreasing direct inspection hours are being spent on design-oriented team inspections which are known to be more effective in discovering design problems.

The effect of design-oriented team inspections such as EDSFI and SWSOPI are shown in Figure 13, "EDSFI Findings on System Design," and Figure 14, "SWSOPI Findings on System Design." Each figure shows the number of inspections and the number of design findings during the years the inspections were conducted. There were 71 EDSFIs with a total of 975 design findings; the average man-hours expenditure per EDSFI was 1200. Similarly, there were 25 SWSOPIs with a total of 64 design findings; the average man-hour expenditure per SWSOPI was 1000. The total inspection effort for EDSFIs and SWSOPIs were 41 staff years and 12 staff years respectively.

This analysis made no attempt to compare the relative safety significance of design errors discovered by design based inspections such as EDSFIs or SWSOPIs to those reported in the LERs and documented in the SCSS database.

As these types of inspections directly and intensively look for design errors, they are quite effective in discovering the errors.

3.6 Relative Safety Significance of Design Errors

A search of the ASP database for the 11 year period identified 61 design-related events with a CCDP range of E-6 to E-2. This represents approximately 25 percent of all events in the ASP database over the same period. The distributions of these events and their CCDP values are shown in Figure 15, "Design Error Events in ASP Database," and Figure 16, "CCDP Distribution of Design Error Events in ASP Database." Out of the 61 events, 42 (approximately 70 percent) had their CCDP value in the E-6 to E-5 range and the remaining 19 (approximately 30 percent) had their CCDP value in the range of E-4 or above, which is considered of relatively high risk significance.

4 CONCLUSIONS

Based on the above analysis and findings, the following conclusions can be made:

(1) The number of reported design errors has been steadily dropping since the early 1990s even though the number of NRC inspector-hours in performing engineering related inspection modules has increased during the same time period.

(2) The number of reported design errors discovered as a result of design-basis review efforts steadily decreased by 1995, presumably due in part, to diminishing licensing resources allocated to this effort and the lessening number of undiscovered latent design errors.

(3) The number of design errors discovered at any given time was dependent on the extent of initiatives taken by the NRC and the industry. Major NRC initiatives included design-related team inspections which began during the mid-1980's and many design-related generic communications. During this same time period, industry had initiated indepth design-basis reviews which resulted in an increase in the discovery of design problems.

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5 REFERENCES

1. U.S. Nuclear Regulatory Commission, Sequence Coding and Search System, Database as of October 1996.

2. U.S. Nuclear Regulatory Commission, Emergency Notification and Safety Related Data System, Database as of October 1996.

3. U.S. Nuclear Regulatory Commission, Regulatory Information Tracking System, Database as of November 1996.

4. U.S. Nuclear Regulatory Commission, Electrical Distribution System Functional Inspection, Database as of October 1996.

5. U.S. Nuclear Regulatory Commission, Service Water System Operational Performance Inspection, Database as of October 1996.

6. U.S. Nuclear Regulatory Commission, Accident Sequence Precursor, Database as of October 1996.

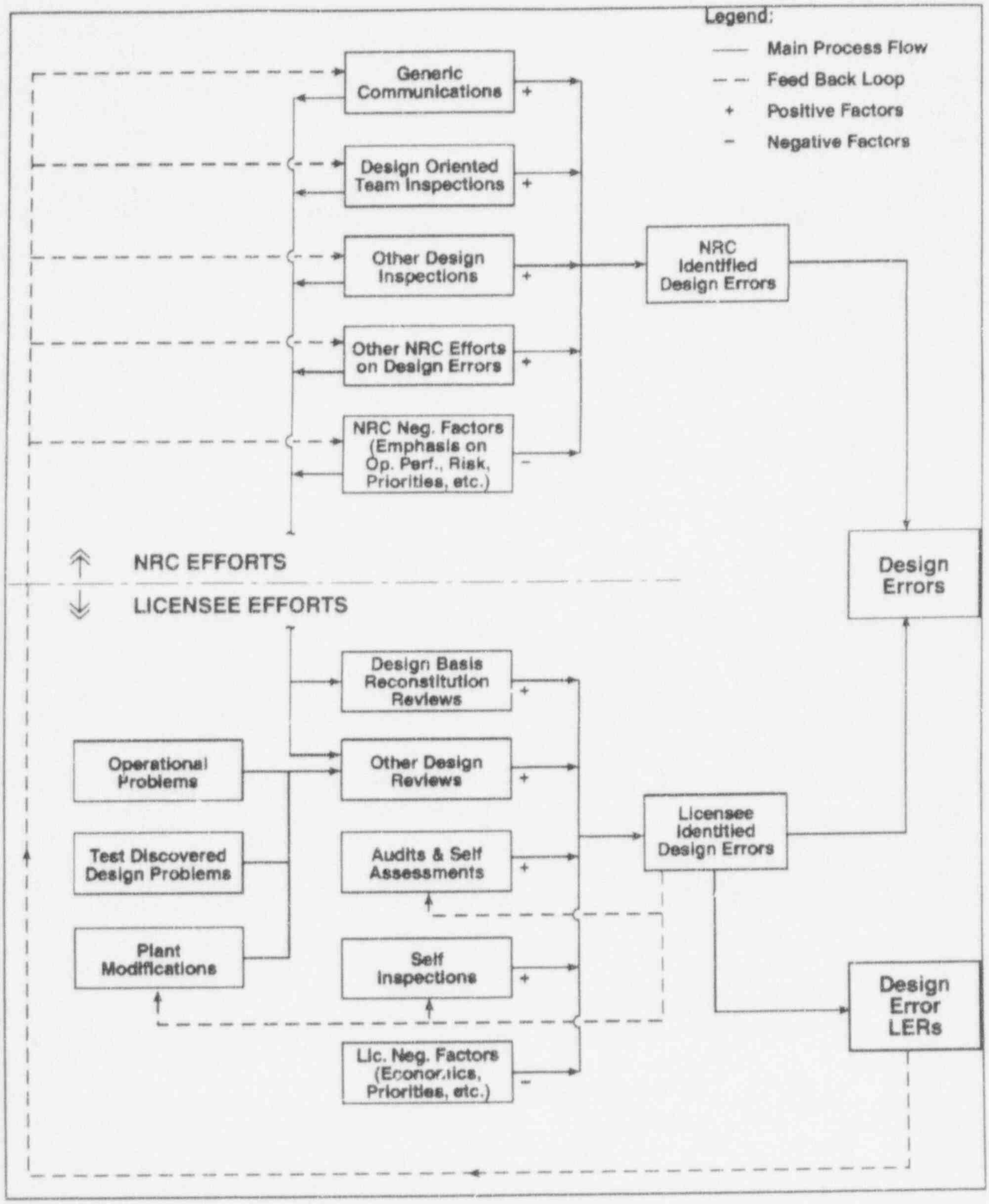
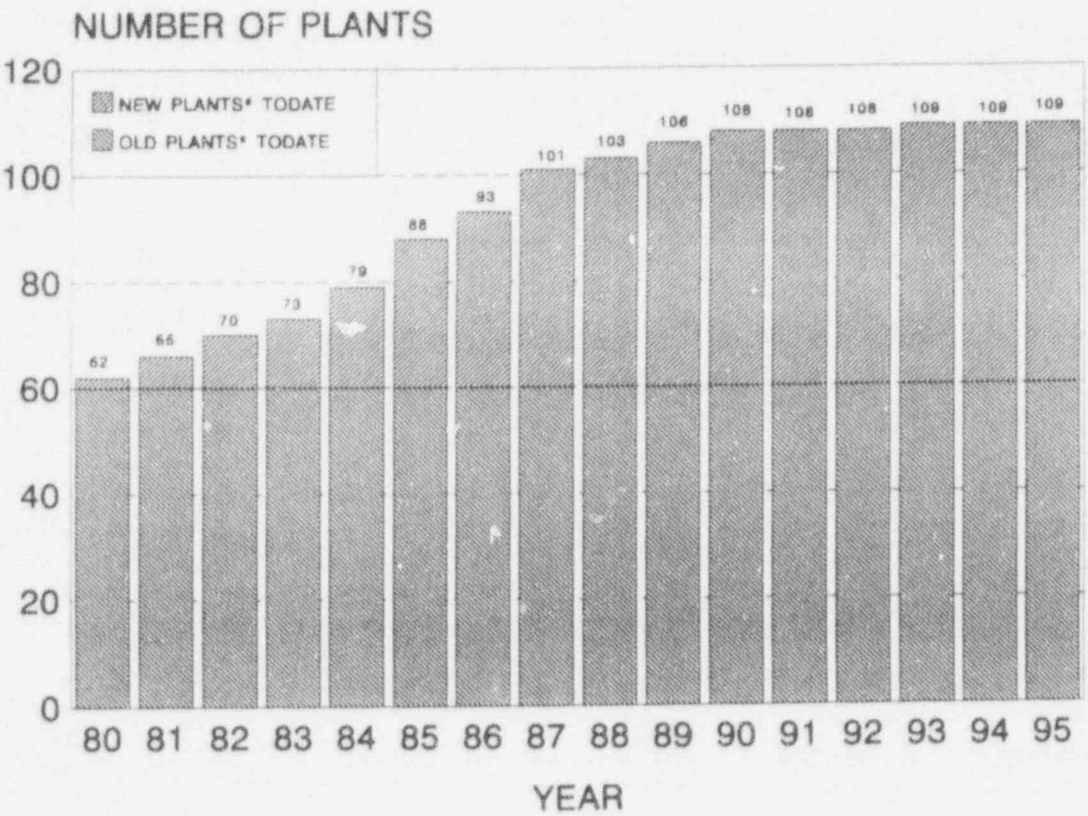


Figure 1 Design Error Discovery Process



* Old Plants: Licensed before 1980; New Plants: 1980 & Later

Figure 2 Number of Operating Plants by Year

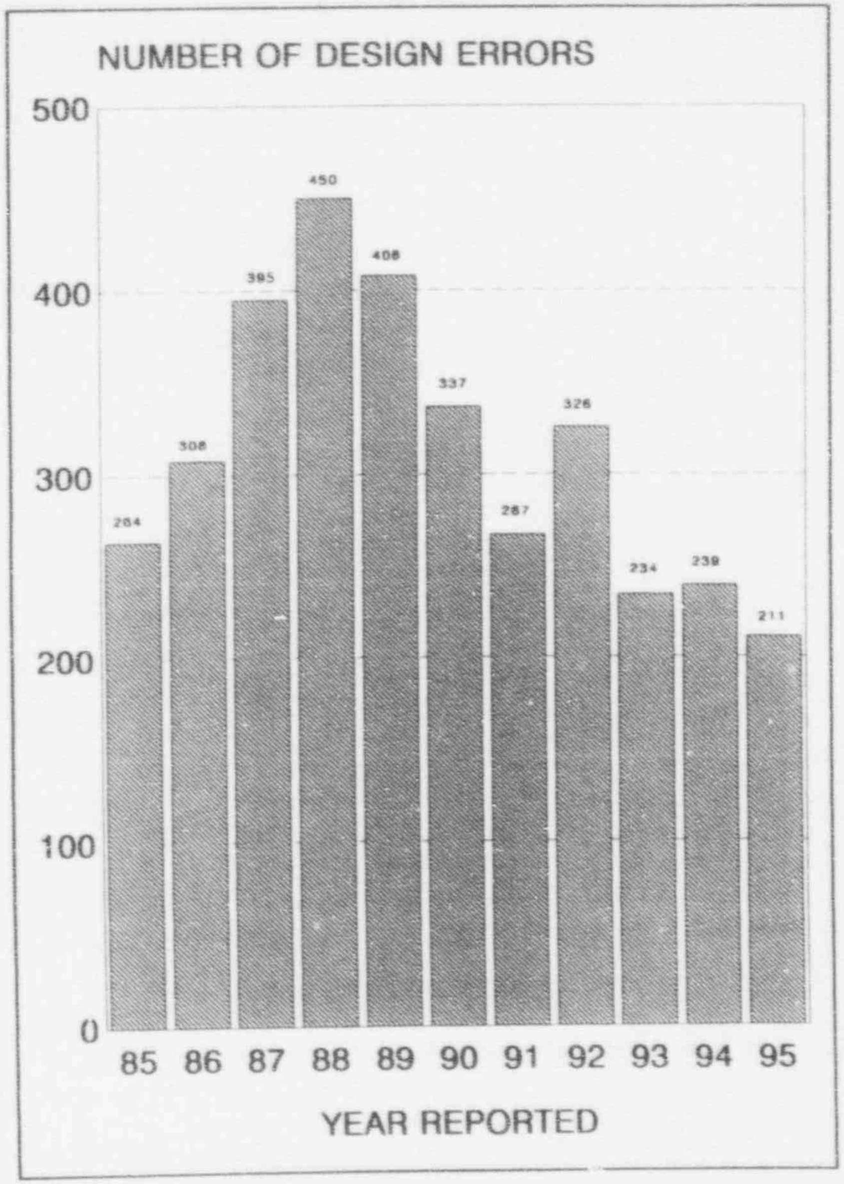


Figure 3 Trend of Total Design Errors

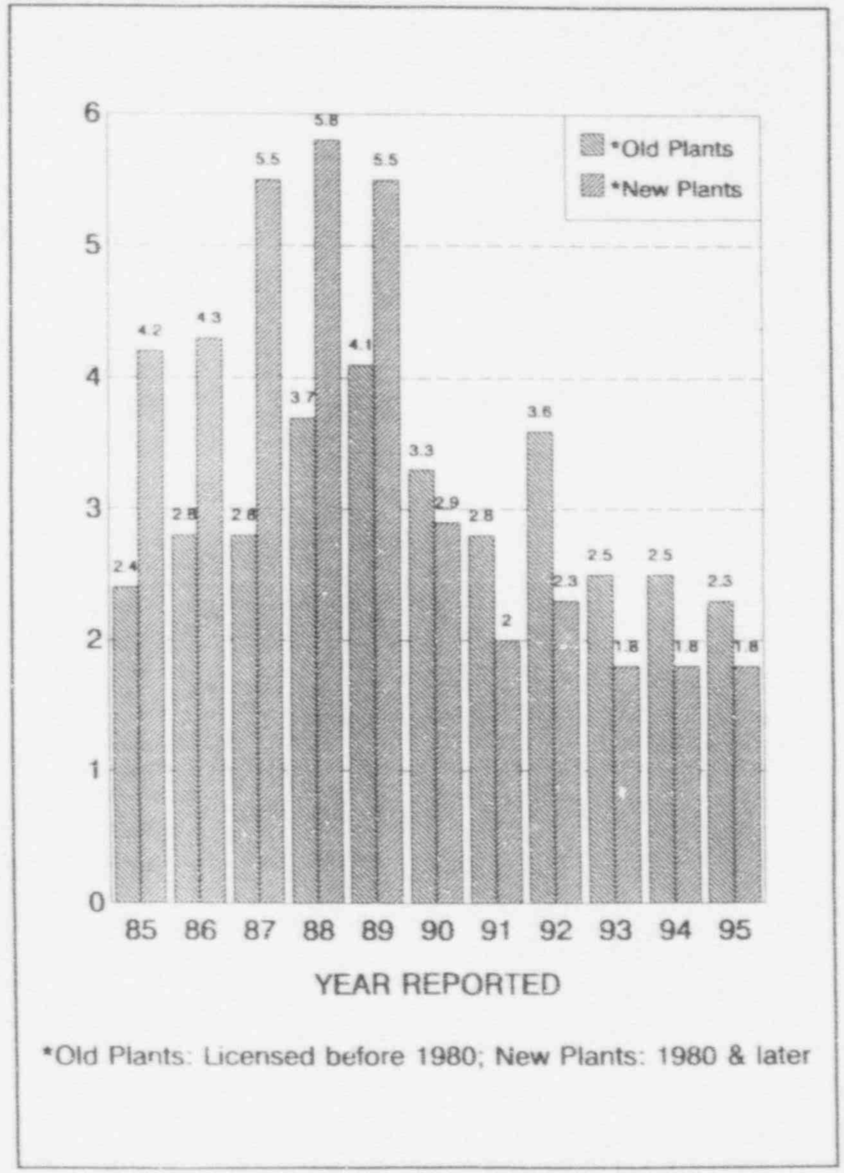


Figure 4 Design Errors per Plant for Old and New Plants

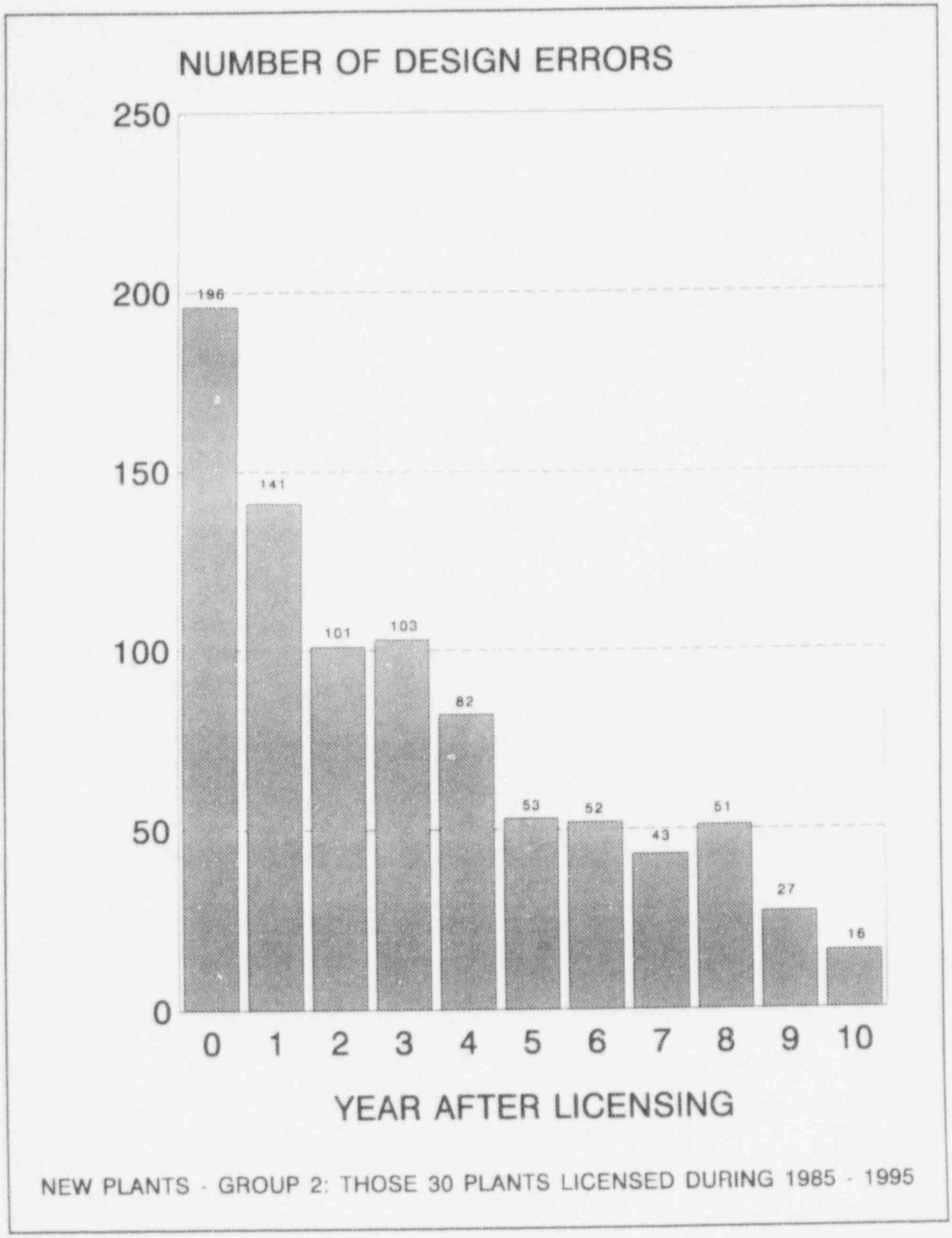


Figure 5 Total Design Errors After Licensing for New Plants — Group 2

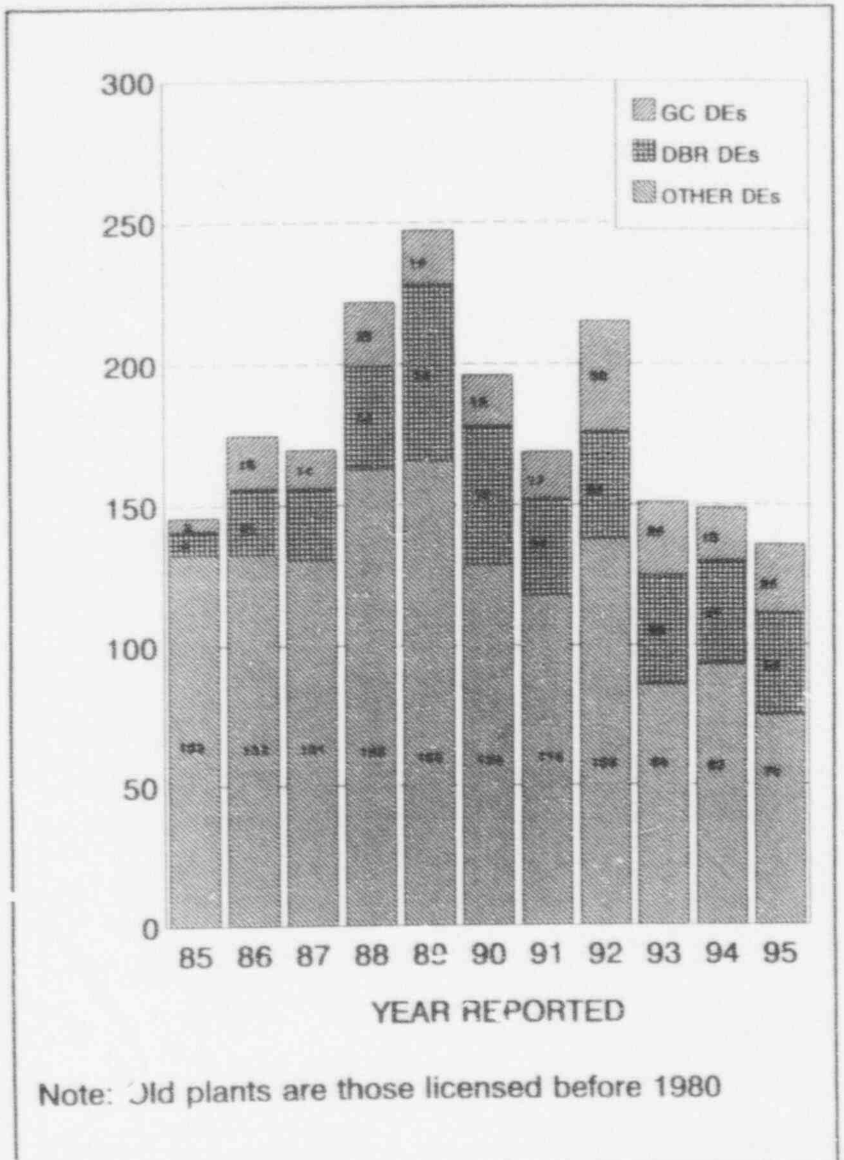


Figure 6 Total Design Error Contributors for Old Plants

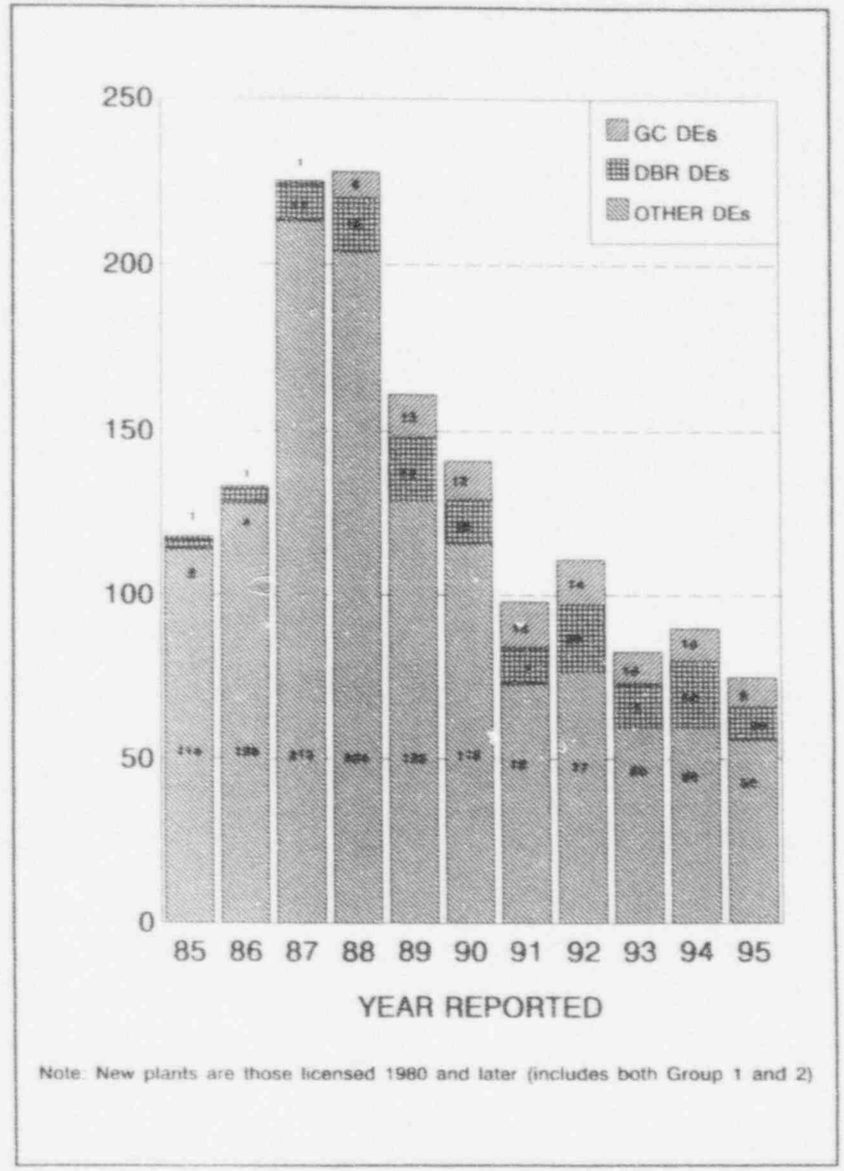
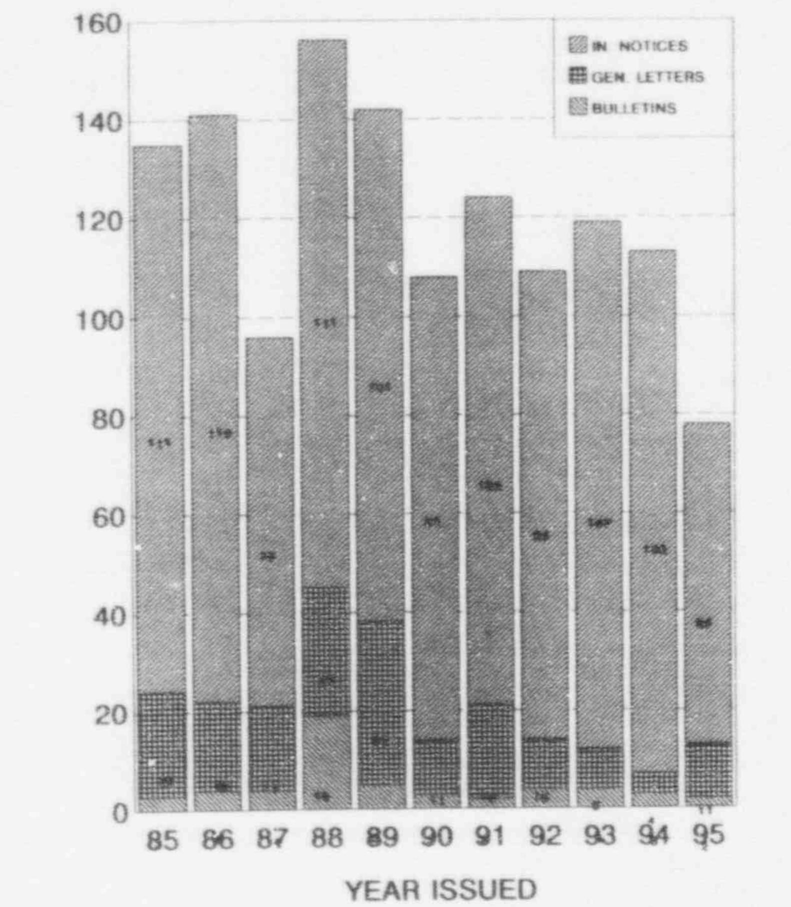
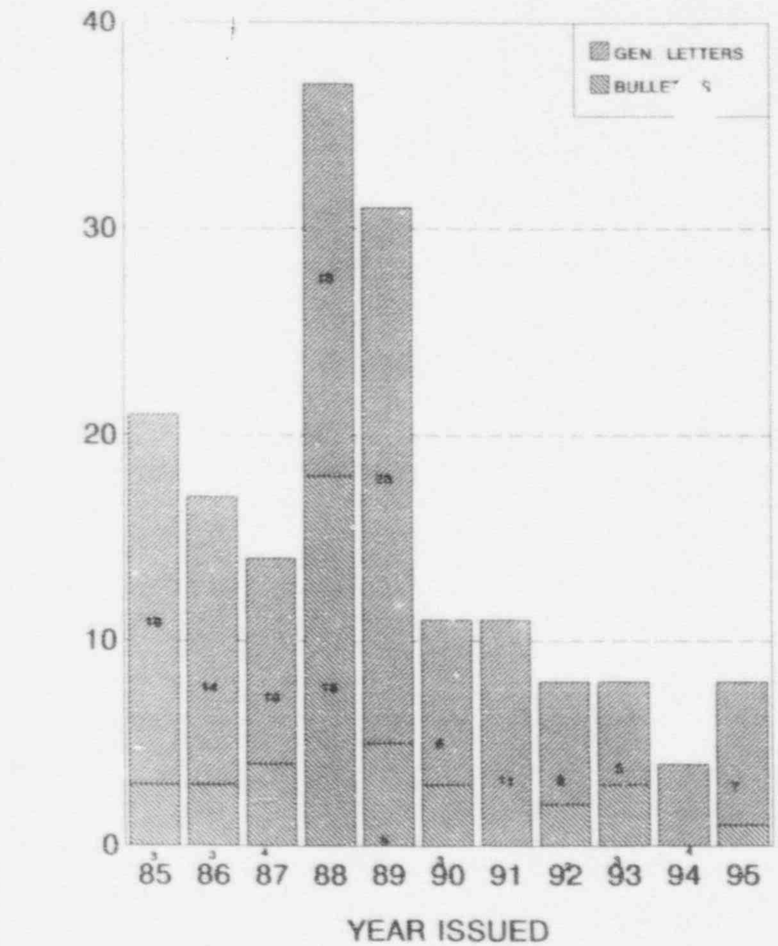


Figure 7 Total Design Error Contributors for New Plants



Note: Circulars and Administrative Letters are not included

Figure 8 Generic Communications Issued



Note: Only power reactor GCs with actual or potential effect on design, directly or indirectly are included. Only Generic Letters and Bulletins are included (other GC types have negligible effect)

Figure 9 Design Related Generic Communications Issued

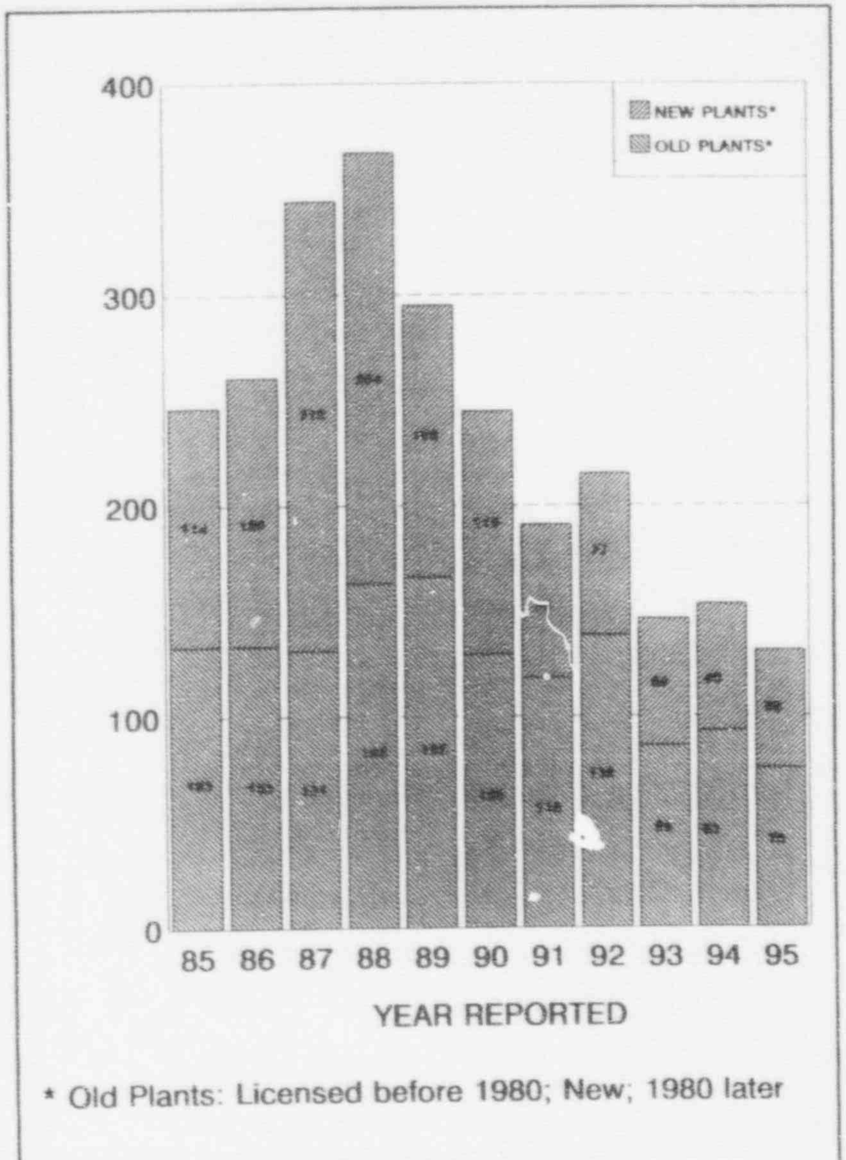


Figure 10 Total Other Design Errors for Old and New Plants

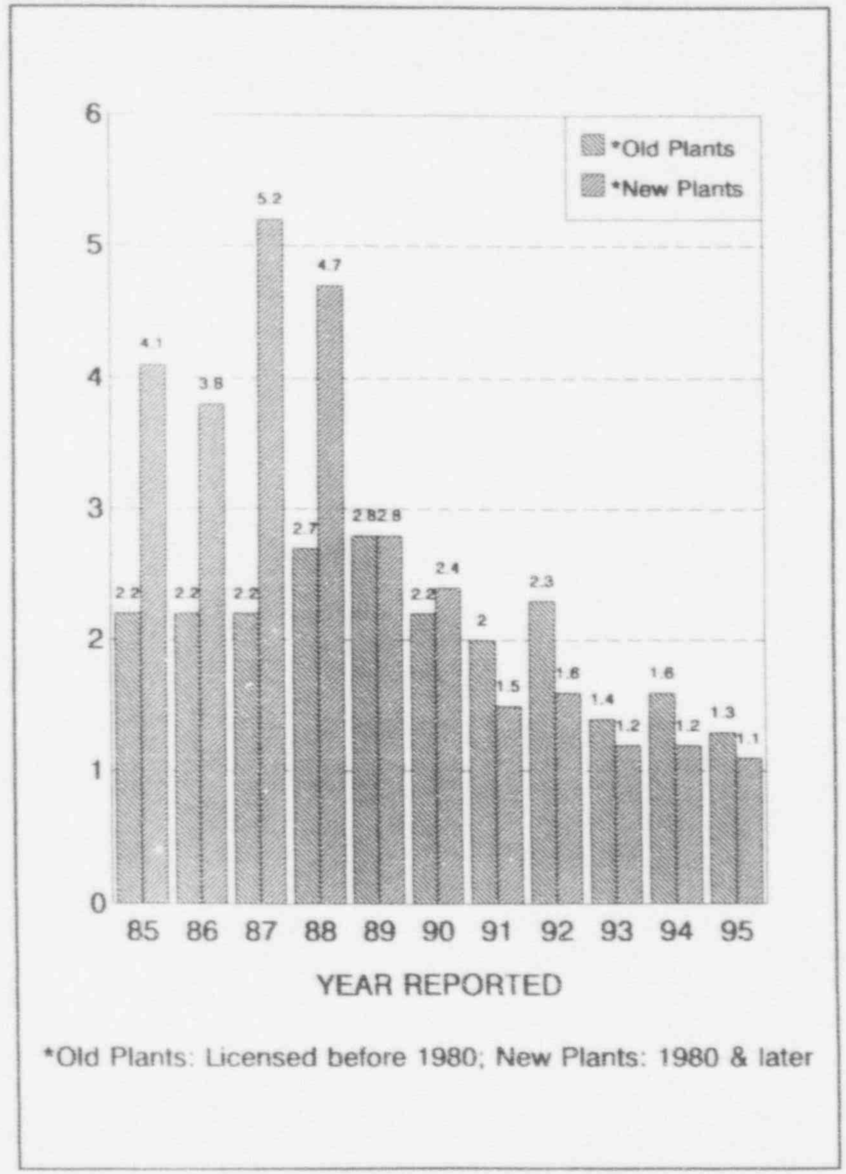
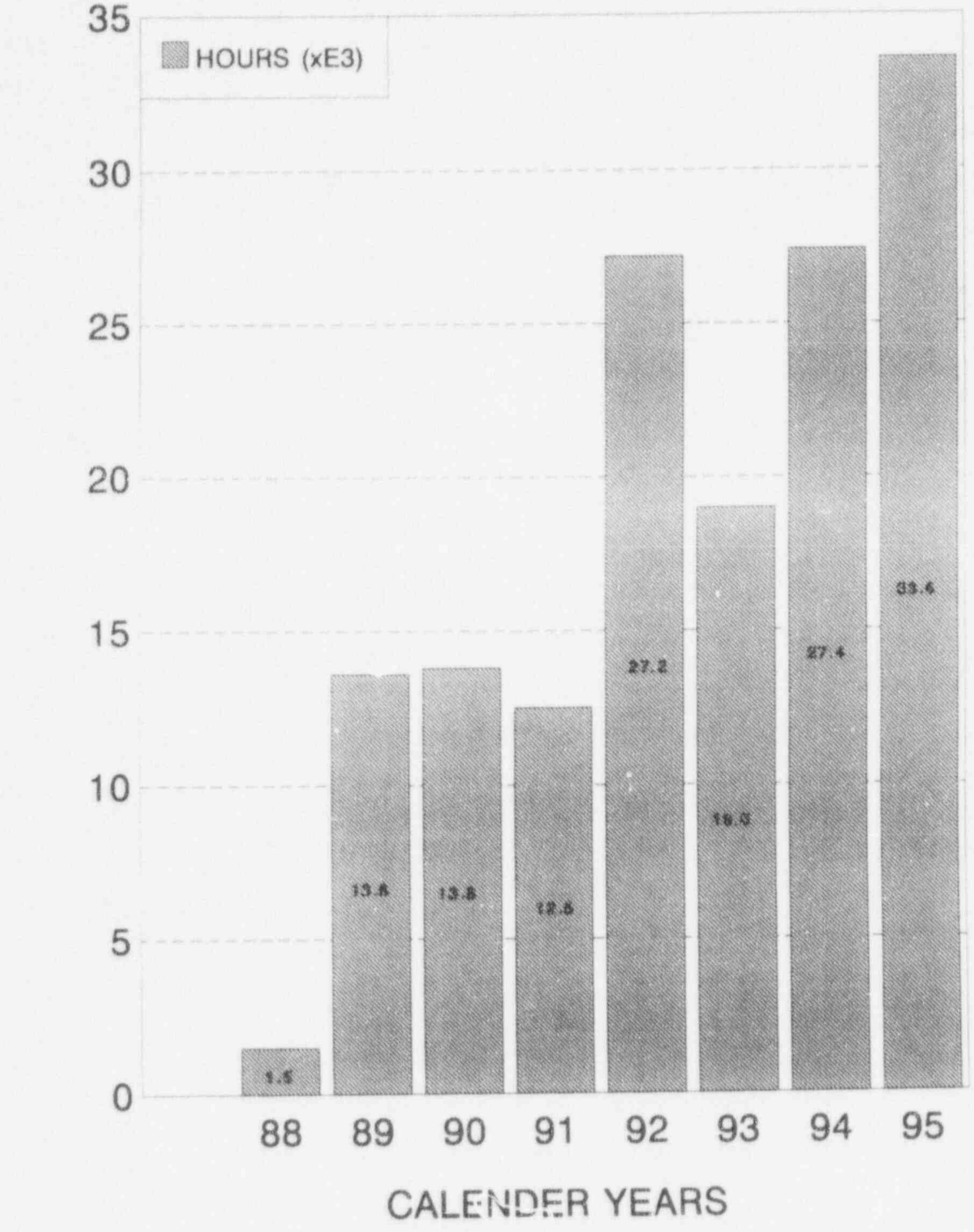


Figure 11 Other Design Errors per Plant for Old and New Plants



Eng.Inspections: Insp. Procedures: 37001, 37550, 375[illegible], 37700, 37701, 37702, 37703, and 37828.

Figure 12 Direct Inspection Effort for NRC Engineering Inspections

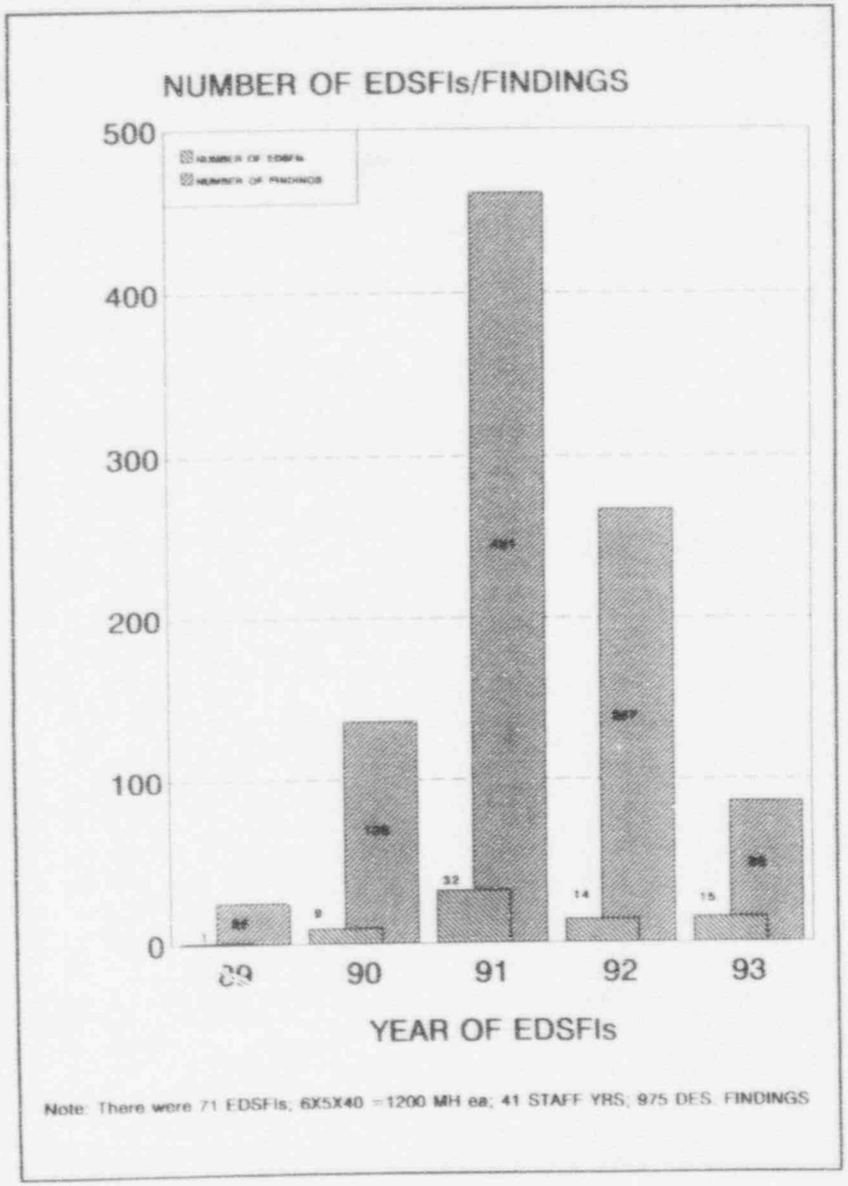


Figure 13 EDSFI Findings on System Design

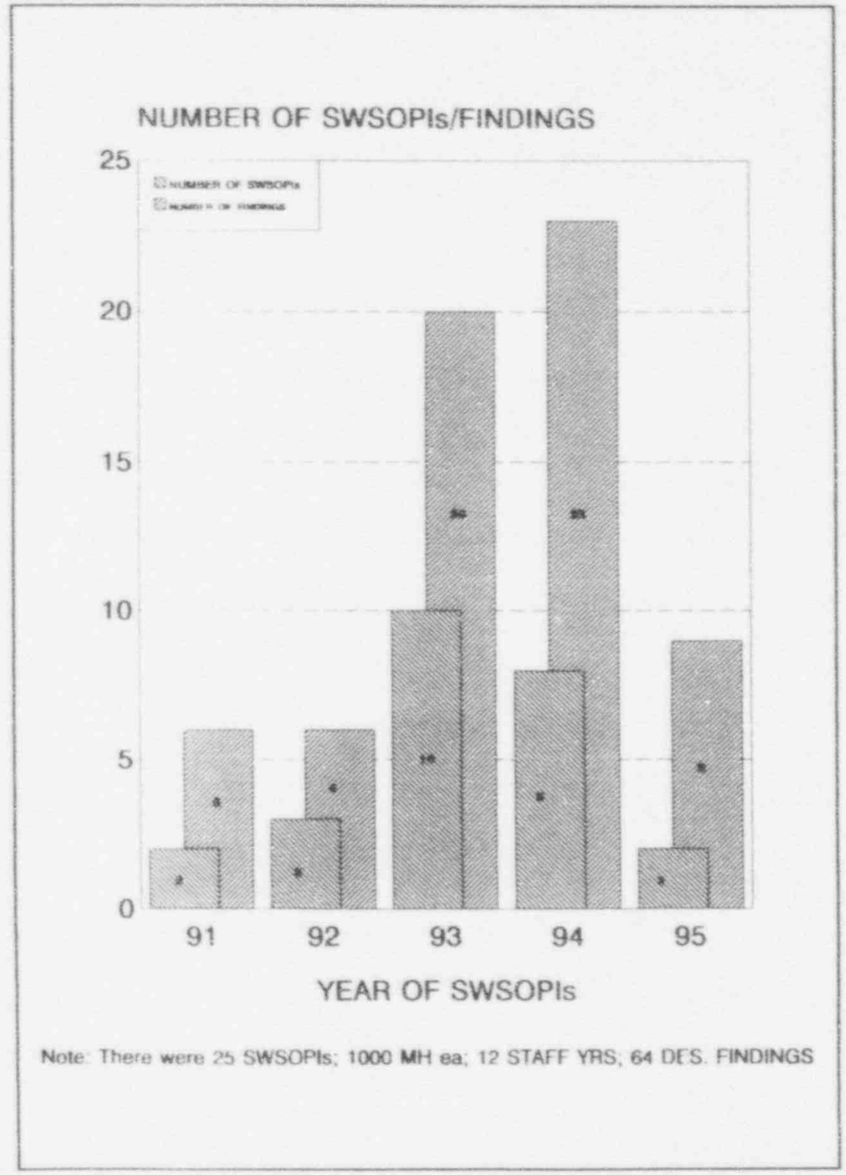
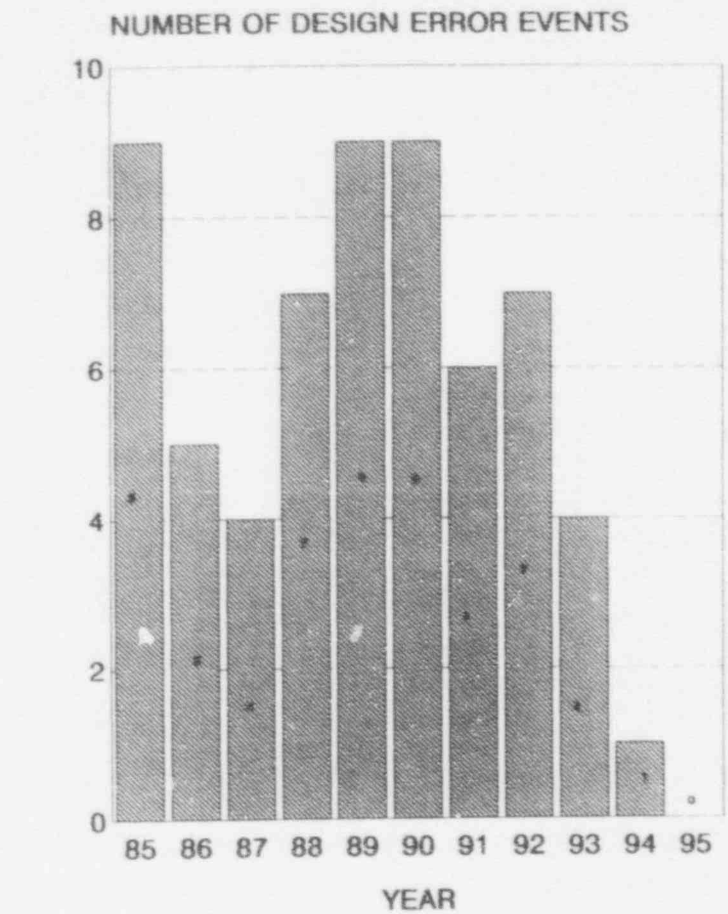


Figure 14 SWSOPI Findings on System Design



Note: 61, out of 3540 design errors reported, were evaluated under ASP.

Figure 15 Design Error Events in ASP Database

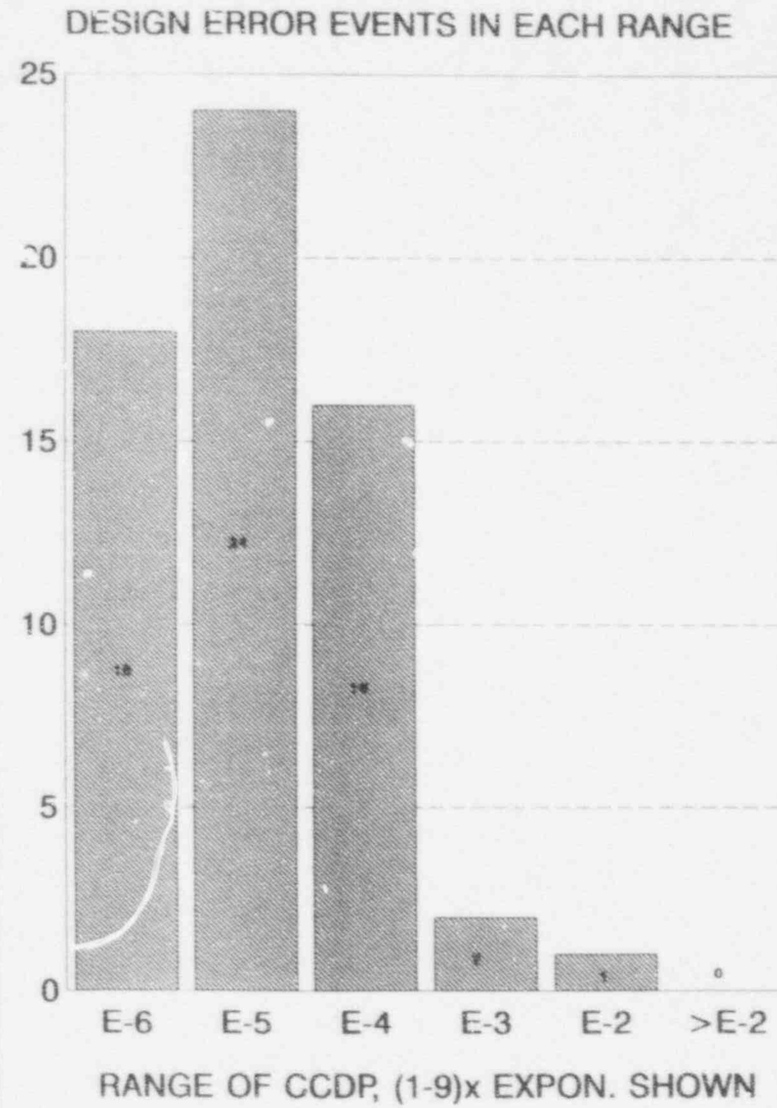


Figure 16 CCDP Distribution of Design Error Events in ASP Database