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IPE DATA BASE STRUCTURE AND INSIGHTS*

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ABSTRACT

A data base (the "IPE Insights Data Base"), has been developed that stores data obtained from the Individual Plant Examinations (IPEs) which licensees of nuclear power plants are conducting in response to the Nuclear Regulatory Commission's (NRC) Generic Letter GL88-20. The data base, which is a collection of linked dBase files, stores information about individual plant designs, core damage frequency, and containment performance in a uniform, structured way. This data base can be queried and used as a computational tool to derive insights regarding the plants for which data is stored. This paper sets out the objectives of the IPE Insights Data Base, describes its structure and contents, illustrates sample queries, and discusses possible future uses.

INTRODUCTION

A data base, called the IPE Insights Data Base, has been developed that stores data obtained from the Individual Plant Examinations (IPEs) that licensees of nuclear power plants are conducting in response to the Nuclear Regulatory Commission's (NRC) Generic Letter GL88-20. In this paper, the IPE Insights Data Base will be referred to as the "data base." The data base is a collection of linked dBase files, storing information about plant designs, core damage frequency (CDF), and containment performance in a uniform, structured way. The data base was designed to accommodate information in accord with expectations based on the requirements of GL88-20, NUREG-1335, and some early IPE submittals. In the most general terms, the key results called for in NUREG-1335 are the plant-specific dependence table, the dominant accident sequences, and release category information. However, licensees have been given substantial freedom in the presentation of this information, and the level of detail designed into the data base corresponds to the level of detail expected in individual IPE submittals.

Information is extracted from the submittals and entered into the data base in such a way that queries regarding individual plants or classes of plants can be answered using the data base. The kind of query supported by the data base is discussed below.

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OBJECTIVE

The data base is designed to answer general questions such as: What features does each submittal take credit for? How does this factor into the core damage frequency (CDF) and/or containment performance of the plant? If two plants in basically the same class have markedly different CDF and/or containment performance, what is responsible for this? If a class of plants seems to share a particular contributor to risk, what design features are responsible for this?

If a particular difference between two plants is driven by one of them having more redundancy in safety systems, or more success paths for core cooling, this connection should manifest itself in the database. If one plant is an outlier by virtue of lacking a design feature common to other plants, or by virtue of an adverse functional system interaction, this should likewise show up. Not all such significant factors lend themselves to this treatment; details of intra-system topology are beyond the scope, as are plant-specific failure probabilities for all components. However, functional dependencies, success paths, redundancy, diversity, and so on can be addressed. Accordingly, the goal of the present development is to record the presence or absence of hardware in each design, characterize its functional dependencies, and relate these features to the CDF and containment performance.

STRUCTURE OF THE DATA BASE

In order to implement the present design within dBase IV, a number of different data base files have been constructed, each storing a different type of information. There are two sections of the IPE data base, corresponding to the Level 1 analysis in the IPE submittals and the Level 2 analysis. The Level 1 information is further subdivided into BWR and PWR dBase files.

The backbone of the IPE Insights Data Base is a basic list of BWR and PWR systems, in terms of which: (1) the design of any BWR or PWR can be described with reasonable fidelity, (2) plant-specific dominant accident sequences can be described accurately, and (3) the success paths assumed in the IPE (its mission success criteria) can be described.

The relationships between major elements of the IPE Insights Data Base is shown in Figure 1. Several of these elements contain field names corresponding to elements of the basic system list (i.e., system names: A,B,C...etc). This is the essential linkage that relates functional dependencies to accident sequences as well as success strategies. This is why the system list was referred to above as the "backbone" of the data base.

For purposes of illustration, consider the particular PWR system corresponding to the emergency feedwater system (the safety-grade system supplying makeup to the secondary side). For each PWR plant, the dependence table data base file shows what other systems support this system (SS1, SS2, etc. in Figure 1); the mission success data base file shows what role this system plays in each of the success paths; the dominant accident sequence data base file shows whether a failure of this system is essential in any given dominant accident sequence. The data base file containing information on the dependence of BWR systems is analogous to the PWR file. Finally, a Frontline Systems data base file shows how many trains of this system each plant has and what this system is called at any given plant. The intent is to store similar information about every important BWR and PWR system.

The relationship between accident sequences and release categories is established through the Plant Damage State field, which is common to the accident sequence data base file and the containment matrix (C-matrix) data base file. No scheme for plant damage state definitions was prescribed in NUREG-1335, nor has one been presupposed here. If a submittal defines plant damage states, its scheme is used. The presumption is that the IPE submittal will contain a partitioning of the frequency of each accident sequence over a set of release categories. If this is true, then the present scheme can accommodate the variety expected in the submittals. An assumption which is made here is that the submittal's definitions of release categories can be put into reasonable correspondence with the release categories used in the data base. This scheme allows linkage of (for example) the frequency of "Early Failure" (one of the data base parameters related to release categories) to particular combinations of system failures, dependencies, mission success criteria, etc. It should be noted here that later experience with IPE submittals has shown that a significant fraction of them do not report the plant damage state to which each dominant accident sequence is assigned. In these cases the link between the Level 2 information and the Level 1 data is lost.

MAJOR ELEMENTS OF THE LEVEL 1 IPE INSIGHTS DATA BASE

The Level 1 dBase files are General Plant Information, Front-Line Systems, Support Systems, Dependency Table, Core Damage Prevention Strategies, Mission Success Paths, and the Accident Sequence Table. A brief description of each file follows.

General Plant Information

The General Plant Information data base file contains the following information: plant name, plant type, NSSS vendor, number of loops (PWRs only), plant output, containment type, number of units, total core damage frequency, and, if a multi-unit site, are support systems shared, does crosstie capability exist, and is there a common control room. This information enables the user to sort or query across a subset of the entire data base, i.e., by plant type, by containment type, by NSSS vendor.

Front-Line and Support Systems

Development of a key systems list for both BWRs and PWRs was a crucial first step in the construction of the data base files. The files relate the generic key systems list (Frontline and Support) to plant specific nomenclature and information on the number of trains and any credit taken for cross-tie from another unit. The files, therefore, contain the following fields: plant name, key systems list, plant-specific nomenclature, number of trains and notes. These aspects of the files are described in the following paragraphs.

The first field is the name of the plant. The second field contains the key systems list. In the previous section, the key systems list was described as the backbone of the IPE Insights Data Base, because defining this list goes a long way towards defining the structure of the entire data base. Dependencies, mission success criteria, and accident sequence descriptions are all keyed to this list. However, its formulation is not unique. As experience was gained, it was necessary to modify the definition of this list in order to improve the usefulness of the data base. Accordingly, compromises had to be made, as summarized below.

Consider the simple problem of comparing two BWR (or two PWR) designs at the system level. The approach taken in the data base is to develop the system list in such a way that a very simplified design comparison between two plants could be formulated as a statement of (a) which systems on this list are present in both designs, (b) which systems are present in one design and not the other, and (c) which systems are present in neither. Unfortunately, even this simple task is not straightforward when all methods of injecting water into the reactor coolant system (RCS) are considered. The capabilities of individual BWR and PWR systems in the U.S. vary somewhat, even for systems which have the same name and perform similar functions. Proceeding formally, one could have assumed that every BWR and PWR system is completely unique. This would have led to a very long list of systems which could not be used to compare plants in any meaningful way, since no two plant designs would appear to have anything at all in common. Approaching from the opposite extreme, one could have combined all systems which perform a low pressure injection function (for example) into a single entity. This would also thwart the objective of plant design comparison, because on this basis, plants would differ only in the number of trains of this entity, and aggregating several frontline systems into one masks any differences in their support requirements.

After some experimentation, the following basic set of BWR functions has been used to organize the frontline systems list: Reactivity Control, Pressure Boundary Integrity, High Pressure Injection, Low Pressure Injection, and Containment Systems. Under each function a group of plant systems are considered, each of which could carry out the function.

In a similar manner, a basic set of PWR functions were defined and used to organize the frontline systems list: Reactivity Control, Primary Integrity, Primary Inventory-injection, Primary Inventory-recirculation, Secondary Integrity, Secondary Inventory, Containment. This set has been used in the data base in the formulation of the systems list.

These schemes work for the BWRs and PWRs to which they have been applied. Extra places ("alternate systems") on the list have been defined under some functions, in the expectation that some plants will take credit for systems which cannot be placed in reasonable correspondence with a shorter list.

It has been necessary to develop conventions regarding how the correspondence is to be established between this list and any particular BWR or PWR design. For example, if a plant has several auxiliary cooling systems, one could ask how to place these into correspondence with the several auxiliary cooling systems which have been allowed for in the systems list.

No single BWR or PWR may have all of the systems which appear on the respective BWR or PWR lists, but essentially any system playing a significant role should correspond to some entry, even if it is necessary to resort to one of the "alternate" system designations. (If a violation of this is encountered, the list is modified.) Thus, the list itself is a vehicle for comparing design features of two plants.

The third field stores the nomenclature used in the submittal corresponding to the equivalent system in the key systems list.

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In order to make meaningful comparsions of systems between plants, more detail is needed on such questions as redundancy of systems. Accordingly, the number of trains of each system at each plant is stored in a separate field. This permits comparison of what different plants require in order to deal with a given initiator, what alternative means can be brought into play if the first success path fails, and so on.

The data base stores how many trains each system has, whether the pumps are identified with more than one system, and whether a given system can be supplemented by cross-tying to another unit. For example, for low pressure injection and suppression pool cooling in a BWR, the same pumps may be involved in both functions, but the flowpaths are different, and the consequences of failing the two functions are different. The data base approach is to reflect the number of pumps under both low pressure injection and suppression pool cooling. In order to indicate that the pumps in the low pressure injection field are also part of a different system, two fields adjacent are provided: one to signal that this hardware is multi-purpose, and another to give the name of the system's other identity.

Dependence Table

This file shows the direct functional dependences of each frontline and support system; that is, what other systems any given system depends on. There are separate files for BWRs and PWRs. The dependence table can be drawn as a matrix: headings across the top are systems from the key systems list; the labels going down (labelling records in this data base file) are support systems. If a system performs a frontline function and also supports another frontline system, it shows up on the left-hand side of the matrix as if it were a support as well as in the systems list across the top. Each element of this matrix then tells about the direct functional dependence of the column system on the row system. A blank entry means that there is no direct dependence.

Core Damage Prevention Strategies

For each challenge i.e. initiator category (i.e. transients as well as LOCAs) for which success criteria are provided in the IPE submittal, this data base file provides a list of strategies to prevent core damage. Each strategy is described in terms of a combination of safety functions which have to succeed in order to prevent core damage, given the initiator in question. A special set of safety functions has been defined for this purpose.

Mission Success Paths

The mission success data base file tells what success paths the IPE assumed in its reported results. Each record in this data base file relates a specific complement of equipment to a particular type of initiator and a particular type of safety function. If a safety analysis takes credit for more than one way to remove heat, its results cannot be understood without an unambiguous statement of exactly how decay heat can be removed.

Each distinct way of performing a given function receives its own record. For example, following a transient with failure of high pressure systems, depressurization and low pressure injection are called for. There may be several low pressure systems which are capable of injecting enough water to cool the core. This situation is represented by several records.

IPEs of plants whose core damage frequency from transients is especially low should be expected to explain this result in terms of credit for numerous and diverse ways of cooling the core. By showing all success paths explicitly, the data base shows why the frequency is low. If the low frequency cannot be understood on this basis, then perhaps the failure expression has been quantified with low frequencies, and this may warrant scrutiny.

Accident Sequences

The accident sequences file stores dominant accident sequences from each submittal. Every dominant accident sequence appears as a record in this file. The goal is to record which systems failed in the sequence, what sort of phenomenology goes along with these failures, and the frequency of the sequence.

Licensees have considerable freedom in how they report this information. The data base structure is a compromise between simplicity and searchability. The fields in this data base file are as follows: plant name, the submittal's name for the sequence, plant damage state, core damage frequency, the initiator, lost supports, failed functions, causes, a field called "attributes," the key systems list, and a comment field. In the following paragraphs some of these field are elaborated on in the context of this data base file.

The Plant Damage State field stores the submittal's plant damage state designator. The purpose of this field is to link accident sequences with phenomenology, as represented in the containment performance data base file.

The Initiator field stores the accident sequence initiator. This information may be implicit in the submittal's sequence designator, but this is not standard across plants since submittals do not be use a universal scheme for designating initiators or sequences. In this field, the initiators are designated within a universal scheme. Support system initiators receive special designation.

If the accident sequence involved total loss of one or more support systems, such as emergency ac, service water, and so on, then the field name(s) of the lost support function(s) are given in the Lost Supports field.

Every accident sequence involves failure of at least one safety function. In the Failed Functions field, the name(s) of the lost function(s) are indicated.

The purpose of the Causes field is to record whether a particular physical cause enters into the particular accident sequence. The causes allowed as entries are fire, internal flood, or common cause failure.

For a number of ad hoc characteristics of sequences, such as station blackout or ATWS, the catchall field "Attributes" has been defined. This field contains a list of key attributes separated by commas, based on a dictionary of allowed entries.

The Key Systems List fields store which systems fail in each sequence. As discussed above in previous sections, the same systems list is used to discuss dependencies, mission success criteria, and sequences. The convention is to show which frontline systems failed in order to bring about core damage and only those systems. If the sequence involved a human failure, this is also recorded. By definition, every sequence must fail all success paths in some functional area discussed above under Mission Success.

The Notes field is used to record any additional information not captured in the previous fields, which is considered important for understanding the sequence.

MAJOR ELEMENTS OF THE LEVEL 2 IPE DATA BASE

As noted previously, the Level 1 portion of the data base is connected to the Level 2 portion through the Plant Damage States (PDS). In the Level 2 analysis, the plant damage states are divided into several possible fission product release paths and/or containment failure modes via the C-matrix. Each failure mode is associated with a quantity of fission products released to the environment (Source Terms or Release Classes). The Data Base is structured to capture the various elements of the Level 2 portion of an IPE. Each element of the Level 2 IPE is allocated a separate dBase file as follows: Plant Damage State Definitions, C-matrix (containment performance), Source Terms, and Level 2 Analysis Parameters (source term characteristics).

Plant Damage State Definitions

The Plant Damage States file is structured to capture information which the IPE analyst used to define the various plant damage states. The assumption is that the IPE submittal specific PDSs can be characterized in terms of the following parameters allowed in the data base file: level of RCS pressure (high, medium or low); containment integrity (intact, pre-existing leak, or bypassed); RWST/CST inventory (injected or not); availability of containment sprays and heat removal; and, for PWRs, whether the steam generators are available for cooling.

Containment Performance

Information on containment performance is captured in a file in the form of a matrix, which relates the plant damage states to various failure modes. The PDS designation scheme is flexible but some structure had to be imposed on the various failure modes to be included in the containment matrix. Currently, six failure modes are included.

Each record in this file contains a plant name, a plant damage state designator, frequency, and split fractions which allocate the indicated plant damage state over the following possibilities: bypass, early failure, late failure, basemat melt-through, vessel breach without containment failure, and no vessel breach. Because the entries are split fractions, they should sum to unity within a given plant damage state. In addition, each split fraction is allocated to one or more release category designators. These designators connect the containment performance file to the source term file.

Source Terms

Information on Source Terms is entered into a file which relates the release category designators identified in the containment performance file (C-matrix) to the quantity of fission products released to the environment.

Each record in the file contains the release class designator and the fractional release (to the environment) of up to nine different fission product groups.

Level 2 Analysis Parameters

Information on containment failure modes and other analysis parameters related to the source term characteristics is contained in a file which is connected to the rest of the data base through the release category designators. This file, therefore, provides information on how the source terms were calculated for each release category.

Each record in the file contains a Release Class, Containment Failure Mode, Containment Failure Cause, Failure Location (BWRs only), Containment Failure Size, Zr Oxidation (in-vessel), Amount of Core in Core/Concrete Interactions (CCI), CCI Disposition, Vessel Failure Mode, Suppression Pool Bypass (BWRs only), Sprays Available, Credit Taken for Decontamination in Reactor Building (BWRs) or Auxiliary Building (PWRs), and notes. The various fields are described in terms of a dictionary of allowable entries categorizing each field. For instance Containment Failure Cause records the cause of containment failure (steam and gas pressurization, H_2 combustion, DCH, or Basement melt-through). Loss of containment isolation or bypass events can also be entered into the field.

EXAMPLES OF QUERIES

Dbase 4 allows the user to find particular fields or entire records satisfying certain conditions as well as to perform calculations such as summing or counting. The following examples illustrate the types of questions that can be asked of the data base and the types of results that can be extracted.

One may want to know how "important" is RCP seal LOCA to total core damage frequency. This could be asked for a particular plant or across all PWR plants, or for a subset of PWR plants, i.e., Combustion Engineering (CE) PWRs. First, consider the case of a particular plant. Using the data base, the sequences involving RCP seal failure, as indicated in the sequence equipment failure list, would be sorted out and their CDF would be summed. The result would be divided by the total CDF of all sequences for the particular plant. The resulting fraction would give an indication of the "importance" of seal failure to CDF in the plant in question. This same fraction could be obtained for any number of plants in the data base with a particular characteristic, for instance CE PWRs, and averaged over the group to obtain the "importance" of RCP seal LOCA for the group.

One could carry the above exercise one step further by asking for a list of plants for which RCP seal sequences constitute more than 10% of the core damage frequency contained in the described sequences. A series of commands can be applied to the data base whereby iteratively for each plant the accident sequences are searched, summed and divided by total CDF as above and then the plant is listed if the result is greater than 0.1.

Another question of interest for an analyst trying to gain insights might be: For core damage sequences, how often does loss of offsite power (LOSP) result in station blackout? To obtain the answer one could search the accident sequence part of the data base for sequences where the initiator was designated with "LOSP" and add up the CDF of these sequences. From this group of sequences, those with "SBO" (station blackout), in the attribute column can be selected and their CDFs summed. Dividing this latter sum by the total CDF for the LOSP sequences will provide a fraction indicating how often LOSP results in SBO.

As a final illustration of a data base query consider the following. One may wish to compute the percentage of CDF due to LOCA for all plants which require human action at switchover to recirculation, and compare this with the percentage of CDF due to LOCA for plants which do not require human action at switchover. This could be accomplished with these steps: The percentage of CDF due to LOCA for each plant could be calculated in a similar manner as percentages were calculated for the previous examples. (LOCA sequences are identified from the initiator or, if it is a transient induced LOCA, from the "TIL" designation in the attributes field of the sequence). One could then determine what class a given plant is in according to whether HPR (high pressure recirculation) or LPR (low pressure recirculation) has an "H" designation in the mission success paths for LOCAs. The H designation means human action is required. The CDF for each group, i.e. with and without H, can than be summed, normalized and compared.

This last example also illustrates a caveat for data base users. Suppose a significant difference were found in the CDF for the two classes of plants. An analyst then would have to ensure that the difference really is due to the presence or absence of human action at switchover and not for other, not immediately apparent, reasons.

POSSIBLE FUTURE USES OF THE IPE INSIGHTS DATA BASE

As the above examples have illustrated, the data base has a number of unique features which make it a useful tool to carry out meaningful comparisons of plant features and gain insights about their strength and weaknesses.

First of all, the data base captures information about all PWRs in a unified structure and information about all BWRs in a unified structure.

Besides capturing the essential characteristics of each of the significant accident sequences, the data base also captures the success strategies that the IPEs take credit for.

Since the information in the IPEs, and therefore in the data base, is essentially at the system and function level, the data base can be used as a tool to determine the importance of plant features at this level. In other words, the data base can indicate how particular design features are related to core damage frequency in positive and negative ways. Certain features may represent vulnerabilities which will show up under the accident sequence part of the data base. Others may show up as assets in the core damage prevention strategies that the data base captures.

Because the data base can work with classes of plants, the potential significance of certain generic issues can be obtained with the data base.

SUMMARY

As described in the previous sections, the IPE data base stores information about plant design and aspects of the plant risk profile in a structured way. This uniform characterization in the data base is made difficult by the inhomogeneity of content among the IPE submittals. The greatest challenge in setting up the database and capturing data from the IPEs is to achieve uniformity while accurately preserving the salient points of the analysis contained in each individual IPE. It is the uniformity of the information which makes the data base amenable to high-level but complex queries dealing with classes of plants.

Currently, no checking of licensee-provided information is performed prior to data entry. The facts provided in the IPE submittals are taken at face value and translated into the data base structure without further review.

The level of detail recorded in the database is at the systems level. Therefore, the database can be used to efficiently gain insights for many safety issues of interest at the systems level or at the function level. More detailed information was not required in the submittals, and has not in general been made available.

As of October 1993, data from approximately half of the expected IPE submittals has been entered in the data base, with all entries expected to be completed by mid-1995. Data entries undergo a comprehensive quality assurance process. In addition a thorough trouble-shooting and shakedown of the data base is also needed; this is expected to start in early 1994.

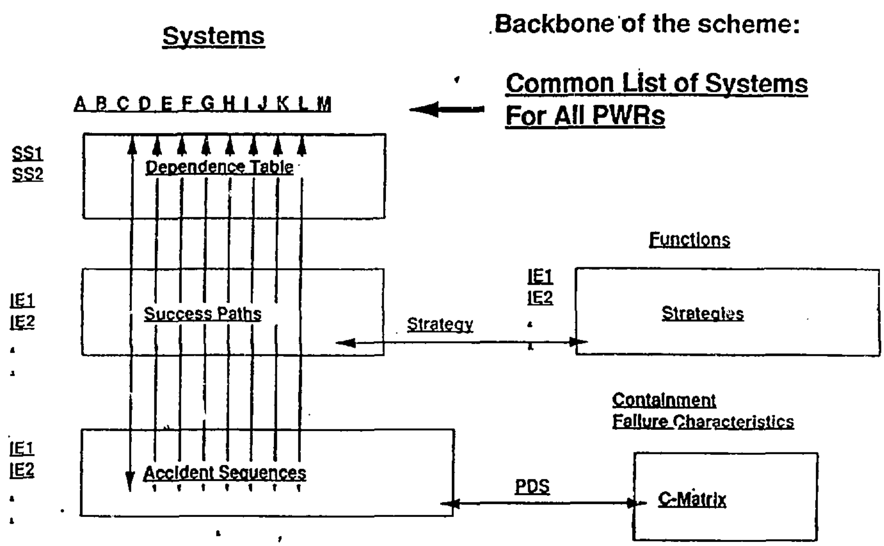

Figure 1. Structure of IPE Data Base