CONF-9210258--2

PNL-SA-21430

PNL-SA--21430

DE93 004339

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October 1992

Presented at the
Third Working Group Meeting on
NPP Aging and Life Extension
October 12-16, 1992
Moscow, Russia

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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ABSTRACT

Pacific Northwest Laboratory[a] has investigated the capability of current recordkeeping technology to support aging management. This paper discusses technical issues associated with potential enhancements of nuclear plant records systems--from the perspective of the lessons learned about equipment aging degradation mechanisms and associated surveillance and monitoring techniques during the U. S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program. The paper considers both the specific types of technical data needed to ensure continued safe operation and the use of new technology to upgrade record systems.

Specific topics discussed include:

- equipment reliability data needed to support the assessment of the impact of aging on the continued operation of the plant
- operational history data to support the assessment of residual life of mechanical and structural components and piping
- tools for the analysis and trending of equipment reliability data and operational history data
- design and implementation of plant record systems that will provide a comprehensive and usable engineering design basis for the plant
- proposed improvements in the data input process for the plant records system
- computerization of plant records systems, including conversion of existing records into machine-readable forms.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830. Work was conducted under NRC FIN B2865.

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INTRODUCTION

Approximately 60 U. S. nuclear plants will reach the end of their current Operating Licenses between 1995 and 2015. Environmental and nuclear regulations, environmental activism, and the threat of litigation are some of the factors that have made the construction of new electrical generating facilities, both nuclear and fossil, economically risky and expensive. On the other hand, continuing to operate nuclear plants after their construction costs have been fully amortized carries a potential economic benefit of $800 million to $1 billion per plant.

This paper reports on work done for the U. S. Nuclear Regulatory Commission (NRC) as part of its Nuclear Plant Aging Research (NPAR) Program. This work is one task in a research program managed by the Electrical & Mechanical Branch of the NRC Office of Nuclear Regulatory Research (NRC/RES). The NPAR Program focuses on mechanical and electrical systems and components; a complementary program, managed by the Materials Engineering Branch of NRC/RES, is looking at metallurgical issues related to the aging of large pressure vessels and piping. To date, NPAR Program research has generated more than 130 NUREG/CR and National Laboratory reports, as well as a number of journal articles and meeting papers. Similar efforts, evaluating aging mechanisms and/or the requirements for license renewal, are being conducted or supported by a wide variety of organizations, including the Nuclear Management Resources Council (NUMARC), the Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE), the Board of Nuclear Codes and Standards, the International Atomic Energy Agency, and industry and regulatory organizations in a number of foreign countries.

The objective of this work has been to ascertain if existing nuclear plant records systems are adequate to support the management of aging and to recommend enhancements, if necessary. Topics considered were:

- the status of current nuclear plant records systems
- the results of NPAR Program research
- implications of the above for the management of aging
- specific recordkeeping requirements in the context of aging management and the License Renewal Rule
- consideration of the technology available to meet recordkeeping needs for the support of aging management.

There are a number of reasons for a nuclear utility to maintain a comprehensive records system; these include NRC regulations, other regulatory requirements, and adherence to engineering and business good practices. U. S. nuclear utilities currently maintain extensive records systems, partly in response to 10 CFR 50.71 and to the Quality Assurance requirements of Regulatory Guides 1.28 and 1.33, ANSI/ASME NQA-1, ANSI/ASME NQA-2, ANSI/ASME N45.2.9, ANSI/ANS 3.2, and the 10 CFR Part 50, Appendix B, and partly as an implementation of good business practices, as with the records the same utilities maintain to support their fossil plants.

WHAT IS THE PROBLEM?

Metals fatigue; small flaws already present when the metal component was fabricated grow as it is subjected to temperature and pressure transients and to mechanical forces. If not replaced or repaired, or if it doesn't fail due to some other mechanism, the component will eventually fail due to the growth of this flaw. Examples abound: de Haviland Comets and Lockheed Electras fell out of the sky because of fatigue failures of high-strength aluminum alloys; more recently, an Aloha Airlines Boeing 737 lost a large piece of its skin and airframe while in flight. The Silver Bridge dropped into the Ohio River because of the fatigue failure of a single pin connecting two of the chain links in one of its cables.

Metals and other materials are subject to chemical attack, gradually losing the properties that led to their selection by the designer of the component or system. Sometimes a subtle interplay of corrosion, temperature, water chemistry, and flow conditions will lead to accelerated corrosion and early failure of pipes or fittings, as with the failure of a pipe elbow at the Surry plant, which introduced the nuclear industry to "single phase erosion/corrosion," leading eventually to an understanding of the phenomenon.

Organic materials, such as elastomeric seals and electrical cable insulation, are subject to attack and degradation by high temperatures, steam and high humidity, radiation, oxygen, and other oxidizing materials. Electrical connectors are subject to corrosion at their interfaces, increasing both electrical resistance and the heat generated thereby. Corrosion of heat transfer surfaces can degrade both the heat transfer properties and the flow resistance of the surface. All of these phenomena can reasonably be considered to be aging degradation mechanisms. The challenge to the designer of components and systems is to choose materials and designs so that the component fulfills its mission throughout its design lifetime, even though it is subject to these degradation mechanisms.

Sometimes designers are spectacularly successful in meeting this challenge. Approximately 1500 of the 20,000 or so Douglas DC-3s built 45 to 55 years ago are still airworthy and still flying. Concrete buildings and piers built two thousand years ago by the Romans survive to this day. Archaeologists depend on artifacts which through design or good fortune have survived the hundreds or thousands of years elapsed since their creation. Organic materials survive thousands of years only under special circumstances. Egyptian mummies are still intact because of the combination of funerary preparations and a dry environment. Bog burials in northern Europe are preserved by the combination of an acidic and anaerobic aqueous environment. Clothing and other organic materials have been preserved in two thousand year old Scythian burials in the Pamir mountains by cold, stagnant air in the rubble covering the tombs.

WHAT DO RECORDS SYSTEMS HAVE TO DO WITH ALL THIS?

From the standpoint of aging management, there are two major justifications for recordkeeping requirements: 1) maintenance and reliability records can be used to monitor the condition of equipment, to predict failures, and to design appropriately conservative predictive and preventive maintenance programs and 2) design, maintenance, operational history, and reliability records provide the basis for comparing the actual operating environment and operational stressors to the design assumptions. This comparison provides the basis for continuing to operate systems or components out to or beyond their original design lifetime.

Virtually all parties considering nuclear plant life extension--industry and regulators, both in the U. S. and abroad--have recognized the likelihood that nuclear plant records systems would need to be upgraded. These upgrades are needed to support both the plant owners, in the planning and implementation of life extension refurbishment activities, and the regulators, in certifying the adequacy of the planned refurbishment.

Existing records systems have exhibited a number of deficiencies, including the fact that they are primarily based on hard copy records (on paper or on microform), with the attendant slow retrieval and difficulty in processing or manipulating the records in any way. In an emergency, "timely" retrieval of information about the engineering design basis of the plant will mean retrieval in minutes, rather than hours or days. Computerization of nuclear plant records systems is extensive (although not consistently so throughout the industry), but has concentrated on computerized indexing of the hard copy records, rather than computerized delivery of the information.

Extensive records of maintenance, equipment reliability, and plant operating status are maintained, but they have not always been adequate to support the desired analyses of past performance and predictions of future performance. In addition, at a number of nuclear plants, the records constituting the engineering design basis of the plant were originally incomplete or have not been kept current with the state of the plant. In particular, the quality of trending and root-cause analysis at nuclear plants is frequently considered to be inadequate. On the positive side, a number of utilities have implemented computer-assisted drafting (CAD) systems for the storage and maintenance of plant drawing records, with the associated benefits in retrievability, legibility, and ease of modification and use. Also, a number of utilities have put procedures and similar controlled distribution documents online, resulting in improved accessibility and reduced cost for controlling the distribution and managing the configuration of those documents.

Safety System Functional Inspections (SSFIs) and Safety System Outage Modification Inspections (SSOMIs), I & E Notice 85-66, and Systemic Assessment of Licensee Performance (SALP) have all highlighted the safety impact of failure to adequately document a plant's engineering design basis and to provide adequate configuration control and timely retrievability of the information in the plant's records system (Brackney et al. 1987). Tennessee Valley Authority (TVA) engineering personnel have been candid in describing the problems resulting from poor recordkeeping. As the root cause of these problems, they identify fundamental management deficiencies, and stress the importance of the regulatory push in persuading utility management to solve the problems (Cox and Filiak 1987). TVA and about three dozen other U.S. utilities have been upgrading their Configuration Management and Design Basis Documentation programs in response to these problems. The recent Nuclear Information and Records Management Association Configuration Management Guidelines also respond to this situation.

RESULTS OF NPAR PROGRAM RESEARCH

The Phase I Tasks of the NPAR Program Plan have typically either characterized a particular aging degradation mechanism or have characterized all of the mechanisms affecting a particular nuclear plant system or type of component. These reports list or, less frequently, evaluate the in-service inspection (ISI) and on-line monitoring techniques that have the potential for tracking the degree of component or system degradation due to the mechanisms considered. These reports frequently call for increased monitoring and surveillance to mitigate the impact of the degradation mechanisms; this represents a tacit recommendation for increased recordkeeping, since presumably the data resulting from the increased monitoring and surveillance will not simply be discarded.

Only in a few cases are there explicit recommendations regarding the data that should be collected, on what schedules, and to what purpose. An example that stands out is the report by Hoopingarner and Zaloudek (1989) on emergency diesel generator (EDG) aging. They propose periodic EDG tests consisting of a slower start-and-load sequence (e.g., 30 second start and two-minute load sequence) followed by fairly extensive monitoring and logging of EDG operational parameters. In Appendix A of Hoopingarner and Zaloudek, they propose logging of about 25 parameters. These parameters are chosen to provide confirmation of the operability and stability of the EDG and its subsystems. Interestingly, these recommendations arise from evidence that the current regime of monthly (or more frequent) fast start-and-load testing of nuclear plant EDG sets is the major contributor to the rapid aging of those machines (that is, rapid aging by comparison with similar diesels on locomotives, ships, and in other electrical utility applications).

A major NPAR Program effort is the work by Sandia National Laboratory, the National Institute of Standards and Technology (formerly the National Bureau of Standards), and the Franklin Institute on aging mechanisms of electrical cable and on monitoring and testing techniques for detecting and trending those aging mechanisms. The major aging mechanisms are the synergetic effects of temperature, radiation, humidity, and oxygen on insulation and cable sheathing. Although there are several techniques for in situ testing of electrical cable, they are still developmental and tend to be sensitive to noise and to give results that cannot be reproduced under slightly different conditions. More to the point, the regulatory requirement for electrical cable is that it be able to function during and after a design basis loss of coolant accident (LOCA) occurring at the end of its design lifetime. The best that current in situ testing techniques can offer is some assurance that the cable can fulfill its function now, in the current (non-LOCA) environment.

There is a general sense throughout many of the NPAR Program documents (and in the documents of other organizations investigating aging management) that to demonstrate that piping and large pressure vessels can continue to operate out to 60 years within their design fatigue life will require significant improvement in the characterization and records of operating pressure and temperature transients. The original design and fabrication of these components, following provisions of the ASME Section III Code, provided "allowable" numbers (based on an assumed lifetime of forty years) of operating transients, such as temperature increases and decreases and pressure transients. At many plants, the operating transients have simply been counted, rather than characterized in detail as to rate of heat up, total temperature increase, etc. To establish that particular pressure vessels will be able to operate safely out to sixty years, a utility may need to characterize more precisely each transient and calculate its actual impact on the total fatigue life of the vessel.

IMPLICATIONS OF NPAR RESULTS FOR UTILITY RECORDKEEPING

Components having an expected lifetime on the order of the original design lifetime of the plant are those of most relevance and interest from an aging management standpoint. They are reliable and long-lived enough that the operating history and failure records can not be expected to provide statistically strong guidance to assess their residual life and expected performance during the license extension time period. Accordingly, data from ISI and NDE may be relied upon to assess the condition of the component and estimate its residual life. Similarly, there may be components for which a careful assessment of the operating history and environment, particularly with respect to thermal and pressure transients, may be critical to an assessment of the remaining fatigue life of the component.

For components with an expected lifetime significantly less than forty years, the plant maintenance program will have already an established track record on the use of in-service inspection and monitoring to track aging degradation so that the component can be replaced or refurbished in a timely fashion. The function of the records system in this context is to support the evaluation of aging degradation and determination of timely replacement or repair.

The method used to prioritize, or screen, components and systems to determine which will require aging management will require the development of information on the risk importance of components, how the failure rate changes as the component ages, the inspection interval for the component, the probability of detecting aging degradation at the time of inspection, and the conditional probability of correcting or mitigating the degradation, given that it has been detected. The risk importance of a component is determined using a plant probabilistic risk assessment, but the plant records system will have to support determination of the other four parameters or of equivalent data.

Finally, there should be consideration of the alternatives to expanded record- keeping, such as conservative preventive maintenance, system or component refurbishment, or the development and implementation of testing and examination techniques capable of establishing the condition of the system or component, as if it were new.

SPECIFIC RECOMMENDATIONS FOR RECORDKEEPING REQUIREMENTS TO HELP MITIGATE PLANT AGING

Some specific recommendations:

1. To the extent possible, data should be entered by maintenance, operations, and engineering personnel directly in a machine-readable form;

2. Databases distributed throughout the nuclear plant should have common organization, format, and central indexing and be stored and archived digitally on stable and usable media;

3. The integrity of data in plant records must be carefully managed, including attention to the possibility of aging degradation of the records themselves; and

4. Consideration should be given to the types of data needed to avoid unpleasant "surprises".

AGING DEGRADATION OF RECORDS

One of the major data integrity issues with potential impact on license renewal is the adequacy of weld radiograph storage. Even under ideal storage conditions, the proven archival lifetime of photographic media is on the order of the original forty year license period. Other types of records may also be subject to age-induced deterioration. Utility records from the design and construction period may be copies of originals produced by vendors, architect-engineer, or constructor. These copies may be subject to considerable fading and legibility problems after a few years of storage. Data stored on magnetic tape requires careful control of environmental conditions, periodic rewinding, and periodic recopying to maintain data integrity. Ten years of experience with optical information storage media, along with the results of accelerated testing, suggests that the design life of these media will be at least fifteen years.

In addition to these problems of physical deterioration, design and construction records, particularly, may suffer from loss of the original context of supporting assumptions in which they were generated. At the time of their generation, that context was provided by the memory of the individuals involved. Many years later, with those individuals unavailable (or their memory faded), it may be extremely difficult to reconstruct all of the information in the original record in its original context.

BENEFITS OF DIGITAL STORAGE

The most important benefit of digital storage of information is that it can be designed to degrade gracefully rather than catastrophically. As noted in the previous paragraph, information storage media age and degrade, just like all other materials. To say that digital storage degrades gracefully, we mean that error-correcting encoding of the data can be used to assure that gradual deterioration of the storage media, which leads to "small" errors, can be spotted and the original information can be completely restored and transferred to fresh storage media.

A second important benefit of digital storage is that it can easily made machine-readable, enabling the use of a wide variety of data manipulation, storage, analysis, and transmission tools.

Finally, digital storage allows significant data compression, in two senses: 1) modern technology has significantly reduced the physical size of the media or material needed to store a given amount of information, and 2) digital storage allows the use of mathematical techniques for removing redundant information using data-compression algorithms. The CD-ROM described later in this paper is an example of the first point; 150,000 typewritten pages of information are stored on a small plastic disk. It should be noted that data- compression algorithms remove redundancy and error-correcting codes add redundancy, so the two techniques work at cross-purposes. It turns out to be possible to design data compression algorithms that incorporate specified levels of error-correcting capability, thus achieving both benefits.

AVOIDING SURPRISES

Consideration was given to the types of records required to identify "surprising" physical and operational phenomena with the intent of enabling early identification of phenomena such as intergranular stress-corrosion cracking, steam generator tube thinning and denting, and pipe wall thinning due to erosion/corrosion. By definition, a "surprising" physical or chemical phenomenon is unexpected. As such, it is difficult to predict what information should be collected and evaluated to permit early identification and characterization of the unexpected phenomenon. Experience suggests, however, that broad collection of data on (1) plant water chemistry; (2) plant temperatures, pressures, and flows; and (3) noise data (neutron, pressure, temperature, and audio noise), even if no immediate need for the data is seen, will provide opportunities to predict some "surprises".

Since such surprises are frequently preceded by apparently unrelated anomalous behavior of the system, this data should be reviewed regularly by experienced engineers using software tools facilitating graphical representation of the data; this provides effective data compression (one picture is worth a thousand words -- and perhaps a million bits of data) but also enables the reviewers to use uniquely human capabilities of visual pattern recognition to pick anomalies out of the data. For some kinds of data, transformation of the data into an audio signal may provide similar benefits. A former colleague of one of the authors discovered a rather gruesome bug in the Lotus 1-2-3 (TM) spreadsheet's implementation of the exponential function when he saw a completely unexpected spike in a graph produced using the spreadsheet (Flower 1989).

For a somewhat speculative, state-of-the-art, technology, the San Diego, CA firm, HNC, Inc., is marketing a hardware/software product they call the Database Mining Workstation. This workstation, based on a neural network architecture, is intended to explore relations among the variables stored in a database and form predictive hypotheses about those relations. It does this while operating in the background, in the time left over from normal queries to the database, by utilizing the ability of the neural network architecture to construct a self-organizing pattern recognition algorithm.

FEASIBILITY OF RECORDKEEPING IMPROVEMENTS

If the needs of aging management leads to the collection and analysis of additional records, the good news is that this happens at a time when rapid change in the computer industry is providing powerful and inexpensive (by historical standards) tools to implement those changes.

DIRECT DIGITAL INPUT

Direct input to the records system of data in a machine-readable form is enabled by bar code readers, passive and active transponders, FM modems, FM transmission of data over normal plant AC power lines, write-once laser cards, and portable computers. Maintenance and operations personnel can use laptop or hand-held computers or terminals to log operating data or complete maintenance reports directly in a machine-readable form. Additional benefits include the possibility of online, context-sensitive "help files" and immediate error checking of some of the input data. Southern California Edison has joined with Radix of Salt Lake City in a pilot study of the use of hand-held computers to automate the data logging required by the San Onofre plant's Control Room Surveillance procedure (Electric Light and Power 1988). Portable computers that accept hand-written input have recently become widely available. In addition to the methods described above, control panels and plant systems can be designed or modified to enable direct interrogation of the equipment by the operator's portable computer.

OPTICAL DISKS

Optical disks offer many significant advantages for nuclear records applications, including low cost per bit stored; a stable archival media; access to massive amounts of data, even on desktop machines; and, in the case of CD-ROM and write-once read-many (WORM) systems, a secure audit trail and the assurance that configuration managed data have not been subject to unauthorized changes.

Depending on the application, the day is fast approaching, or already here, when digital scanners and optical character recognition software can be used to reliably convert existing hard copy records into machine-readable form. The records management decision will be based on a balance between the cost of hardware, software, labor, and QA/QC needed for the conversion against the benefits to safety and productivity from having the information available in machine-readable form.

Publication on CD-ROM is very attractive for controlled document publication and distribution. When the Final Safety Analysis Report (or Technical Specifications or Operating Procedures) needs to be revised, the changes can be made to the machine-readable original of the document, the whole document re-mastered, and the requisite number of disks produced and distributed to document holders. There is no need to deal with large amounts of paper and no need to bully the recipient into distributing the update pages appropriately throughout the document.

Organizations planning to publish only a few CD-ROMs can provide their data on tape or disk to one of the many CD-ROM publishers (who tend to be the same companies that produce audio compact disks) for pre-mastering, mastering, and production of the disks. Software and/or hardware is available (from $200 to $4000) for in-house pre-mastering (and external mastering and production) of CD-ROMs. Organizations planning to publish many CD-ROMs or having data security concerns can purchase CD-ROM manufacturing workstations for a few tens of thousands of $US or can use writable CD-ROM drives (around $12000) for in-house mastering (and outside production) or for in-house small production runs of a CD-ROM.

For an example of the current CD-ROM cost structure: an entrepreneur has published a CD-ROM disk containing approximately 600 Mbytes of text files and computer program source code and executable; he was able to do this in six weeks (evening and weekends) at a cost of $4000 for mastering and the first 500 disks. Additional disks can be manufactured later at a cost of $1.75 each. The price of the disk drive for reading CD-ROMs is now in the $200-$600 range or around $1000 for a "juke-box" providing access to six disks at once. It should be noted that the $4000 cost cited above does not include any cost for collecting the 600 Mbytes of information or verifying its accuracy. It is precisely these costs that make a utility's decision whether to convert old, hard copy records to machine-readable form so daunting.

For records systems, archival storage is available using large WORM disks or digital optical tape; digital magnetic tape (in the helical-scan 8mm, VCR, or DAT formats) is a cost-effective alternative. For rapid retrieval of large amounts of data, servers controlling up to 64 CD-ROM drives can access up to 48 Gigabytes raw data capacity on-line (two to four times as much if data compression encoding is used) or "juke boxes" accessing up to 100 large WORM disks can provide approximately 1000 Gigabytes of on-line storage (with access to any of that information within a few seconds) (Imaging Magazine 1992a).

CONVERSION OF EXISTING HARD COPY RECORDS TO DIGITAL FORM

There are two major strategies used for converting existing records to digital, machine-readable form. First, the existing hard copy records can be optically scanned and stored as an analog (or "bit-mapped") image of the record. This strategy essentially uses the scanner and the computer as a substitute for the microfilm camera and the microfilm storage cabinets. The second strategy does the same as the first with records that are visual images of something (such as drawing and weld x-rays), but converts textual information (e.g., letters, procedures, etc.) to computer text files using a combination of scanning and optical character recognition (OCR).

The advantages of bit-mapped images are the relatively inexpensive and essentially error-free conversion combined with the possibility of using data-compression and error-correction techniques on the stored images. On the disadvantage side, indexes must be built manually, using relatively skilled labor, to attach appropriate key words to each image. Also, any textual information in the bit-mapped image is not directly accessible for manipulation and reuse. A further disadvantage: a page of text will average around 4000 characters, requiring 4000 bytes storage (which data compression may reduce by a factor of two to four); when stored as a bit-mapped image, 500 Kbytes to 1 Mbyte of raw data storage is needed (image compression may reduce that by a factor of 15 to 20).

Using the second strategy, with textual information stored as text files, the user has access to a much wider variety of tools for searching, retrieving, manipulating, analyzing, transmitting, and storing the information than with bit-mapped images. The major disadvantage is that OCR is not perfect and the text files resulting from OCR conversion must be carefully proof-read to assure accuracy. As an extension of the second strategy, bit-mapped images of plant drawings (requiring several Mbytes of storage each) can be converted to vector-format CAD system files, requiring a few thousand bytes of storage each, thereby being available for manipulation and modification by the CAD system.

The choice of image compression encoding require trade-offs involving the resolution in the original document, the desired resolution in the retrieved document, and whether the document is in color, black and white, or in multiple gray scale. The CCITT Group 3 algorithm is a one dimensional encoding used to compress fax images, scan line by scan line, for transmission over telephone lines. CCITT Group 4 is a two-dimensional algorithm, which can achieve greater compression, but is more susceptible to noisy transmission channels. The Joint Photographic Experts Group (JPEG) has created several compression algorithms that can be used to compress color or gray-scale image with tradeoffs between loss of resolution (including lossless) and the compression factors achieved (Imaging Magazine 1992b). New, promising, but not-standardized, compression algorithms include the fractal transforms offered by Iterated Systems, Inc. of Norcross, GA, and the two dimensional wavelet transforms developed by Ingrid Daubechies and other mathematicians.

One of the authors has seen an interesting hybrid system, which uses the bit-mapped image as the QA record, but uses OCR conversion of the images to construct text files, which are then used to build the index into the collection of bit-mapped images.

INTEGRATED PLANT DATABASES

Already available are integrated plant databases, providing a single, coherent, database that can be used to support plant construction, produce drawings, manage maintenance, prepare licensing submittal, and support plant operation. Examples of such databases are the EPRI-supported Plant Information Model and the Plant Configuration Model (TM) of Construction Systems Associates (Smith 1989).

ENHANCED RETRIEVABILITY AND USABILITY OF INFORMATION

A variety of current and developing technologies will offer significantly enhanced information retrieval. These include content-addressable memory, pattern recognition techniques, hypertext software, optical disk "jukeboxes," and database "engines" (computer hardware specialized by architecture for the storage and retrieval of data). The CD-ROM servers and WORM "juke boxes" described above, provide on-line access, within a few seconds to massive amounts of data.

On the human factors side of the data retrieval equation, the Environmental Protection Agency has recently produced a hypertext version of its regulations on leaking underground storage tanks (Foskett 1990). Entitled "Reg-in-a-Box," it has been widely distributed at nominal or no cost in versions compatible with the two commonest types of microcomputers. Hypertext incorporates links between sections of text that reflect the document's logical structure, offer footnotes, give parenthetical information, and trace cross-references through the regulations and the underlying laws. It allows the reader to navigate freely through the document following logical "threads" and backtracking to pick up previous paths. As before, the driving force behind these advances is the enormous increase in the power and cost-effectiveness of microprocessors, enabling development of these compute-intensive technologies.

Usability of the textual information in the database can be enhanced by incorporating into the text file information about the formatting and the logical structure of the document, using "tags" created using the recently standardized (International Standard ISO 8879) Standard Generalized Markup Language (SGML). Documents incorporating SGML tags can be moved freely among ISO 8879 compliant software (e.g., word processors, desktop publishing, databases, etc.) without losing the formatting and logical structure information. Endorsement of ISO 8879 by a number of governmental, industry, and professional organizations (and the requirement that documents submitted to these organizations be SGML-compliant) have led many software vendors to include SGML capability in their software (Reynolds and Derose 1992).

RECONSTRUCTION OF "MISSING DATA"

One of the ways of attacking "missing data" reconstitution problems is to construct simulations that can be used to approximate a solution to the inverse problem (i.e., what would the value of the missing data have to be to produce the observed behavior of the system). One effort to directly solve the inverse problem is an EPRI project investigating the construction of Green's Functions which transform their input values, available reactor coolant system temperatures and pressures, directly into fatigue-usage factors for vessel locations for which the desired local temperature records are not available. Other possible approaches to "missing data" reconstitution include a variety of multi-variate statistical techniques, including correlation analysis, principal component analysis, regression analysis, and cluster analysis (Samanta et al. 1989).

CONCLUSIONS

An effective data collection and recordkeeping system, supportive of aging management activities, should meet the following performance criteria:

- Provide sufficiently comprehensive and accurate information about the plant, including engineering baseline data, historical operational status, and maintenance history.
- Provide for flexible management of that information.
- Provide secure storage of the information.
- Provide for the integrity of the information over the life of the plant.
- Provide timely and accurate retrieval of the information.
- Provide adequate tools for data analysis, graphical display, and production of reports.

Expanded recordkeeping and enhanced databases will be necessary to manage aging in operating nuclear power plants. The records should be, wherever feasible, machine-readable, to facilitate later use of the information in ways not originally contemplated. The information should be integrated throughout the plant, using common formats, and centralized planning and management of the information systems function. The information should be carefully preserved and itself protected against aging. Finally, the plant databases and records system should include more than the "minimum necessary" to operate the plant, providing the engineering staff with the data and tools needed to minimize the impact of unexpected degradation phenomena.

Most observers feel that for a utility to establish the safety of continued operation of a nuclear plant will require supporting records of the plant's operational and maintenance history beyond those currently maintained.

The computer-based technology for meeting this need and implementing these recommendations already exists and the recommendations can be implemented at a reasonable cost. An appropriate computer-based system is likely to yield a substantial savings over the life of the plant, compared to a records system based on management of "hard copy" records.

ACKNOWLEDGEMENTS

The work summarized in this paper was performed for the U. S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research (FIN B2865) under the direction of Jitendra P. Vora (NRC/RES) and PNL Project Managers A. B. Johnson, Jr. and Richard P. Allen. A more detailed description of the results of this research is being published as a NUREG/CR report (Dukelow 1992). 1-2-3 is a trademark of Lotus Development Corporation.

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