ESTABLISHING REQUIREMENTS FOR THE NEXT GENERATION OF PRESSURIZED WATER REACTORS - REDUCING THE UNCERTAINTY

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ABSTRACT

The Electric Power Research Institute is managing a major effort to establish requirements for the next generation of U.S. light water reactors. This effort is the vital first step in preserving the viability of the nuclear option to contribute to meeting U.S. national electric power capacity needs in the next century.

Combustion Engineering, Inc. and Duke Power Company formed a team to participate in the EPRI program which is guided by a Utility Steering committee consisting of experienced utility technical executives.

A major thrust of the program is to reduce the uncertainties which would be faced by the utility executives in choosing the nuclear option. The uncertainties to be reduced include those related to safety, economic, operational, and regulatory aspects of advanced light water reactors. This paper overviews the Requirements Document program as it relates to the U.S. Advanced Light Water Reactor (ALWR) effort in reducing these uncertainties and reports the status of efforts to establish requirements for the next generation of pressurized water reactors. It concentrates on progress made in reducing the uncertainties which would deter selection of the nuclear option for contributing to U.S. national electric power capacity needs in the next century and updates previous reports in the same area.

BACKGROUND

United States light water reactor technology has been successful in providing a vital contribution to U.S. national electric power capacity needs. It has also been the basis of much of the light water reactor programs of Europe and Asia. This technology has achieved a record of safety which is truly impressive relative to other energy alternatives. Over the past decade, however, the commitment to new nuclear generating capacity in the United States has paused due to electric power demand leveling, increasing realized costs and a perception of the need for reduced uncertainties.

Nevertheless, mounting environmental concerns with non-nuclear generating capacity, combined with uncertainties associated with the work energy market, motivated a need to renew the nuclear option. The Electric Power Research Institute responded to this need by promoting the U.S. national advanced light water reactor effort which draws on the resources of utilities, governmental agencies, equipment manufacturers and architect engineer-constructor firms.

ALWR EFFORT

The Electric Power Research Institute is providing leadership, management, and sponsorship of three main elements of the ALWR effort. These are regulatory stabilization, the utility requirements document,[1] and the development of small (600 MWe or less) reactors in the U.S. context.[2] This paper focuses on the second element but, of necessity, only mentions the regulatory stabilization effort. Electric Power Research Institute has stimulated the formation of Utility Steering Committee (USC) made up of senior utility executives to guide both the management and technical output of the program. In addition, EPRI is sponsoring contractor teams which have utility experience, architect-engineer-constructor expertise, and nuclear steam supply system (NSSS) design and manufacturing capabilities. EPRI, directly and

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1. K.E. STAHLKOPF, D. M. NOBLE, and J. J. TAYLOR, "Next Generation Light Water Reactor" American Power Conference, April 15, ALWR Program, Electric Power Research Institute

2. J. DOUGLAS, "Toward Simplicity in Nuclear Plant Design" EPRI Journal 11-5, (4-13), 1986

through the USC is promoting the cooperation and support of the U.S. Department of Energy and the U.S. Regulatory Commission.

Each type of organization involved in the Advanced Light Water Reactor effort has its own unique mission and concerns. Each type of organization is vital to the overall effort and contributes its unique capabilities. Leadership exercised by individuals from each type of organization has been vital to the progress made so far and the contributed technical expertise has been crucial to the quality of the output.

Electric Utility companies are participating in the advanced light water reactor effort in two principal ways. They are providing senior experience executives for the USC. They are also participating in contractor teams.

The USC meets regularly with EPRI program management and the contractor teams to review the progress and direction of the requirements document from a programmatic and from a technical point of view. It also acts as the official interface with the U.S. Regulatory Commission (NRC). The USC actually submits completed Requirements Document chapters to the NRC for review and meets with the NRC to facilitate the review process. The NRC review process for the ALWR Requirements Document has been developed and published.[3]

The utility role on contractor teams is to provide unique utility perspective and review. The utilities are most intimately familiar with operational and maintenance issues which have emerged from LWR's in operation and under construction. In the case of Duke Power Company the utility acts also as the architect-engineer-constructor member of the contractor team. Duke Power Company also has the unique utility experience of having designed a balance-of-plant to interface with the Combustion Engineering System 80™ nuclear steam supply system which is the reference for the Advanced Combustion Engineering Pressurized Water Reactor (ACE PWR).

The contractor teams, each of which has utility expertise, architect engineer-constructor expertise, and NSSS design and engineering expertise are now providing two types of participation in the requirements document effort. The first type of participation is as lead technical contractor having the responsibility for the technical adequacy of the overall approach to assigned areas. The second role of the contractor teams is to be a technical resource to conduct technical investigations assigned by EPRI to resolve questions generated by ALWR requirements document team meetings, utility steering committee meetings, or by industry review.

UNCERTAINTIES

From the viewpoint of a utility considering future electric capacity the uncertainty associated with the nuclear option detracts from its viability. The ALWR program must succeed in addressing the uncertainties before utility executives can view investment in new nuclear capacity as prudent business decisions. Although the uncertainties are inter-related and can be categorized in a multitude of meaningful ways, the following categorization seems appropriate. The areas of uncertainty are safety, economic, operational, and regulation.

Safety uncertainties are related to the reduced public risk levels which will be acceptable in the future and the desire for increased levels of investment protection.

The economic uncertainties have to do with cost associated with construction and operation. They involve the length of time needed to construct (thus monetary carrying charges), the cost associated with redesign and backfit during construction caused by regulatory uncertainty and by mid-stream design improvements. The economic uncertainty is also impacted by constructibility considerations.

The operational uncertainties are mainly associated with being able to assure high availability, the likelihood of institutional shutdowns, and vulnerability to backfits during commercial operation.

The regulatory uncertainties involve the resolution of generic safety issues, compliance with severe accident policy, obtaining NRC concurrence with requirements before detailed design, regulatory verification that the design meets the requirements, and obtaining a high degree of design and regulatory completion before construction. These areas of regulatory uncertainty are themselves inter-related and inter-relate to economic, operational and safety uncertainties.

In order to attack these uncertainties the Requirements Document effort has focused on proven technology, simplification, increased constructibility, and up-front design for higher availability through increased reliability and maintainability. Targets for reduced risk and increased protection of the public have been explicitly included.

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3. D. H. MORAN, "Advanced Light Water Reactor Program, Program Management and Staff Review methodology", NUREG-1197, U.S. Nuclear Regulatory Commission, December 1986.

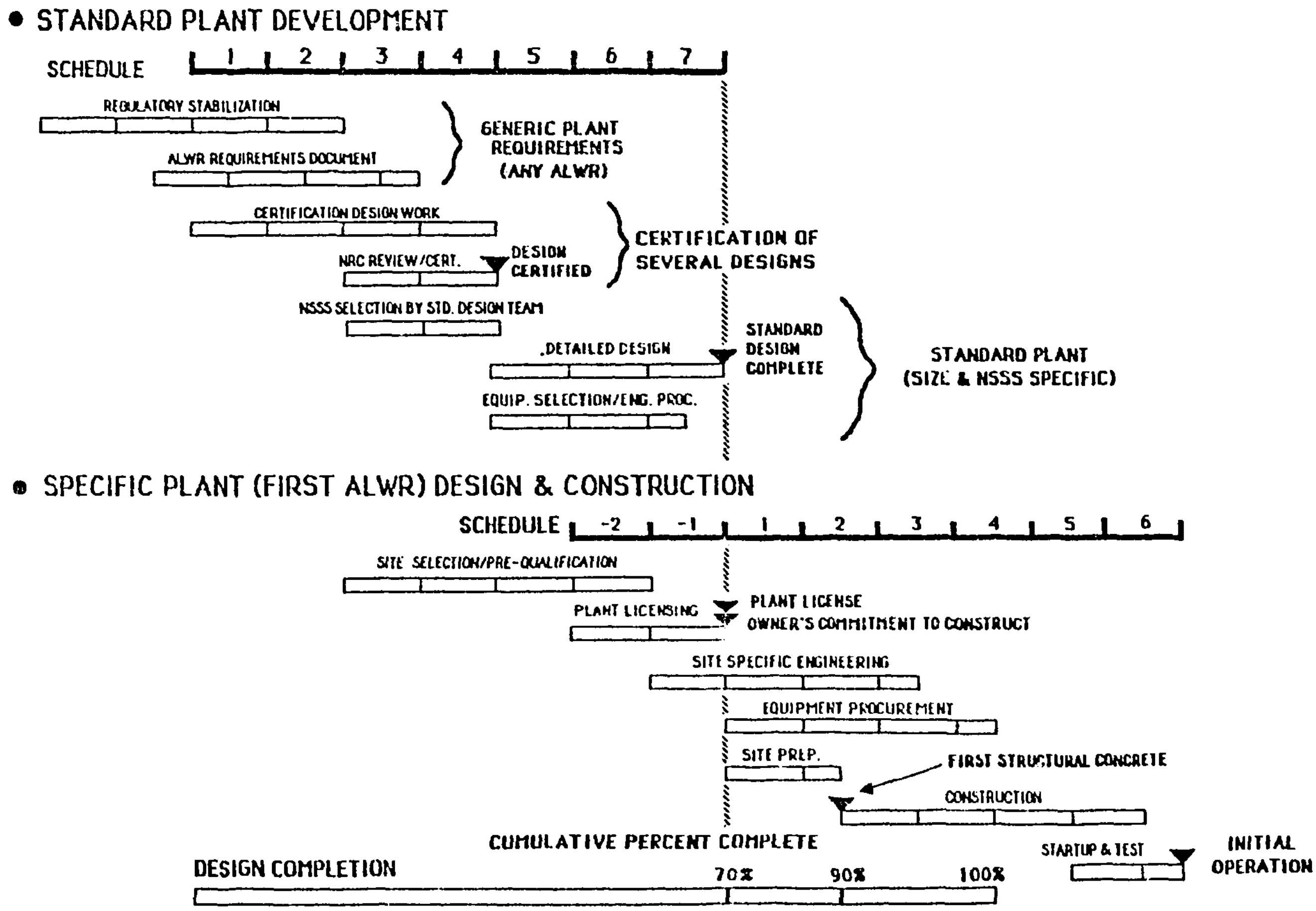

Fig. 1 ALWR Implementation Logic

PROGRAM SEQUENCING

The overall goal for the U.S. national ALWR effort is to have designs available with sufficient scope and depth of regulatory approval to provide for accelerated licensing and construction following utility commitment. Figure 1 is an EPRI representation of the time sequence of activities encompassed in the overall effort.[4] The approach taken is to have a utility requirements document, which specifies the features of an advanced LWR, feeding into a design certification effort, which provides for more in-depth regulatory consideration.

The requirements document, being a product of intense utility interaction with supplier and architect-engineer-constructor groups is expected, when combined with a requirements level review by the U.S. NRC, to greatly assist design certification in producing designs which will readily meet utility requirements, NRC requirements, and general industry objectives. The products of the design certification effort are intended to be such that utilities could confidently commit to a nuclear station project with a high degree of certainty that the project could move forward without delay due to regulatory, design, procurement, or construction issues. Equally important is that such new plants be fully expected to experience successful operation and reliability to promote the confidence of the industry and the public.

While the EPRI Requirements Document will spell out the design criteria for the new generation of LWRs, the new designs, themselves, will still not be available until vendors have actually implemented the EPRI requirements. Therefore, the Department of Energy (DOE) has established a Design Verification program to assist reactor (PWR) design and a Boiling Water Reactor (BWR) design. The DOE program will demonstrate how the EPRI requirements can be met and will show the impact on plant cost, construction, and

4. Electric Power Research Institute Advanced Light Water Reactors Program, "The Advanced Light Water Reactor Utility Requirements Document, Part I: Executive Summary" Palo Alto, CA, June 1986.

licensability. In the end, reactor vendors will be able to have their advanced designs certified by the Nuclear Regulatory Commission (NRC) for use in future U.S. nuclear plants.[5] Of course, much more work will be required to implement the EPRI Requirements on balance-of-plant designs before all programs goals can be realized.

As the PWR participant in this DOE program, Combustion Engineering will begin the effort with the System 80™ Standardized Design[6] and will modify it, as appropriate, to conform with the EPRI and NRC requirements for future plants. System 80™ has already received a Final Design Approval (FDA) from the NRC, for use in existing nuclear plants, and it is currently operating at the Palo Verde Nuclear Generating Station.[7] NRC certification of the improved design should be completed by 1990.

The NRC issued its Severe Accident Policy (SAP) in 1985, which defines the NRC's requirements for future plants in the U.S. These are:

- compliance with current NRC regulations, including the Construction Permit (CP) rule
- resolution of the NRC's unresolved safety issues
- completion of a probabilistic risk assessment and evaluation of the design against it
- consideration of degraded core issues

If the Severe Accident Policy is carried out, submittal of a standard design for NRC review against the SAP requirements should close out virtually every known technical safety concern. The NRC is currently developing guidance for implementing the SAP requirements on future plant designs. In addition to the NRC efforts, the EPRI Design requirements (which will undergo NRC review) will include criteria that address the unresolved safety issues. The DOE Design Verification program includes a probabilistic risk assessment and evaluation. Further, the DOE is establishing a new program, entitled the Advanced Reactor Severe Accident Program (ARSAP). It will address the degraded core issues for future plants, as well as certain other aspects of the Severe Accident Policy.[8]

REQUIREMENTS DOCUMENT PROCESS

The method being used to generate the requirements document has been refined over the course of the effort. The intent has not changed from that of having the utilities be in charge of the requirements but utilizing the unique resources of other participants as well as the utilities. The current process has each chapter and selected groups of Chapters move through an orderly process whereby key issues are explicitly resolved to the satisfaction of the Utility Steering Committee.

Each new chapter is described initially by a baseline document which sets forth the scope of the chapter, defines the key technical issues to be addressed and provides a preliminary listing of the studies needed to assist in resolution of those issues. The baseline documents are fleshed-out in an iterative process involving intensive writing and decision ("Boiler Room") sessions of experienced, knowledgeable, and authoritative representatives of the various classes of participants. The Utility Steering Committee becomes involved at each stage so as to provide perceptive guidance as to what the utility community desires. At an advanced stage of completion each chapter is subjected to an industry review and comments generated are resolved to the satisfaction of the Utility Steering Committee.

The chapters having Utility Steering Committee approval are forwarded by the Utility Steering Committee to the U.S. Nuclear Regulatory Commission for review. A Safety Evaluation Report will be issued for each of the chapters and for the requirements document as a whole. Interim NRC staff comments and concerns flow back to the process via letters[9] and via quarterly meetings of the USC with the NRC.

At an advanced stage of the NRC review there will be a "reintegration" effort to assure that modifications made to one chapter as a result of the review process do not make the chapter inconsistent with other chapters.

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5. G. A. DAVIS, "A Standard Design for the Nineties", 1986 Annual Meeting of the American Nuclear Society, Reno, Nevada, June 15-19, 1986.

6. Combustion Engineering Standard Safety Analysis Report (CESSAR) Combustion Engineering, Inc., USNRC Docket Number STN 57-470

7. "C-E's Standard APWR Design for 1990's" S. T. Brewer, Nuclear Europe, April 1, 1986

8. H. A. Mitchell, "Lessons Learned from IDCOR Analysis of Severe Accidents" DOE/ID 10149, International Technology Corporation, October, 1986.

9. T. P. SPEIS, USNRC, letter to E. E. Kintner, Chairman, ALWR Utility Steering Committee, January 5, 1987.

REQUIREMENT DOCUMENT STRUCTURE AND CONTENT

The ALWR Requirements Document consists of several major parts. Part I, the Executive Summary, was approved and issued by the Utility Steering Committee in June, 1986. The Executive Summary is a concise, management level synopsis of the advanced light water reactors requirements program including design objectives and philosophy, overall configuration and features, and the steps necessary to proceed from the conceptual design stage to a completed, functioning power plant.

Part II of the Requirements Document is the set of utility requirements applicable to entire advanced light water reactor plants. It consists of thirteen chapters, beginning with overall plant design requirements (Chapter 1) and proceeding through detailed requirements for each major portion of the plant. Important supporting technical evaluations and other backup material are compiled in Part III of the Requirements Document.

Chapter 1, Overall Requirements, was approved by the Utility Steering Committee and submitted to the NRC in June 1986. The scope of the Overall Requirements includes:

- Program objectives and general design requirements
- Definition of the design process for developing the ALWR design
- Broad requirements covering design basis events, structural design, materials, reliability and availability, constructibility, operability and maintainability, quality assurance and licensing.

The scope of Chapter 1 was directed at broad program objectives and general requirements which affect the entire plant. Table 1 illustrates the principal objectives incorporated into Chapter 1, Table 2 the Program Goals and Table 3 illustrates major resulting requirements of Chapter 1.

Table 1

PRINCIPAL OBJECTIVES

- Increased Public Safety and Protection of Plant Investment
- Enhanced Plant Performance
- Reduced Cost
- Regulatory Stabilization

Table 2

PROGRAM GOALS

- Meet Applicable Requirements for Protection of Public Health and Safety
- Based on Proven Technology
- Eliminate known Problems
- simplify Plant Design
- Reduce Construction Time
- Enhance Plant Operability, Availability and Maintainability
- Reduce Probability and Consequences of Accidents

Table 3

REQUIREMENTS OF CHAPTER 1

- Severe Accident Radiation Dose not greater than 25 rem
- Plant Investment Protection - Core damage Frequency not greater than $1x10^{-5}$/yr
- 24 Month Refueling cycle Capability
- Refueling Time Capability not greater than 17 days
- 60 Year Design Life
- Availability of at least 87%
- 72 Month Schedule
- Plant Personnel Exposure not greater than 100 man-rem/yr
- 6.5 cent/kWh-Life Cycle Cost Target

Chapter 2, Power Generation Systems was approved by the Utility Steering Committee and submitted to the NRC in October 1986. The scope of Chapter 2 includes the requirements for the following systems:

- Main/extraction steam
- Feed/condensate
- Chemical addition
- Condensate makeup purification
- Auxiliary Steam

Table 4 summarizes design selections that were based on economic evaluations.

Table 4

POWER GENERATION SYSTEMS DESIGN REQUIREMENTS

- Leak-Before-Break Eliminate Pipe Whip Restraints
- 50% Load Rejection Without Turbine or Reactor Trip
- 2 Adjustable Speed Motor Driven Feedwater Pumps
- One Constant Speed Motor Driven Spare Feedwater Pump
- Deaerator provided
- Titanium-tubed Condenser for Brackish/Salt Water
- Side Stream Condensate Polishing
- Stainless-Steel-Tubed Feedwater Heaters
- Chemical Monitoring and Addition Systems Required

Chapter 3, Reactor Coolant Systems and Reactor Non-Safety Auxiliary Systems, Chapter 4, Reactor Systems and Chapter 5, Safeguards Systems are being considered as a group by the Utility Steering Committee for submittal to the NRC. The scope of Chapter 3 includes:

- PWR Reactor Coolant System
- PWR Steam Generator System
- BWR Reactor Coolant System
- Chemical and Volume Control System (PWR)
- Process Sampling System
- Boron Recycle System (PWR)

Table 5 summarizes some of the requirements of these systems that have been proposed for incorporation into the Chapter.

Table 5

DESIGN REQUIREMENTS

REACTOR COOLANT SYSTEM AND NON-SAFETY AUXILIARY SYSTEM

- Leak-Before-Break Eliminates Pipe Whip Restraints
- No core Uncover for up to 6" LOCA
- Load Follow on Rods only (No Boron Change)
- 10% Plugging Margin in Steam Generators
- CVCS Not Safety Related
- Capability to de-gas Letdown Flow
- Sampling system Designed for Normal and Post Accident Service
- Larger Pressurizer Volume
- Lower Concentration Boric Acid
- Steam Generator Level Trip Bypass at Low Power

The scope of Chapter 4, Reactor Systems include:

- Reactor Vessel and Internals
- Core and Fuel
- Control Rod Drive System

Table 6 summarizes some of the requirements of the Reactor Systems that have been proposed for incorporation into the Chapter.

Table 6

DESIGN REQUIREMENTS - REACTOR SYSTEMS

- 10% Design Margin in Reactor
- Diverse Means of Shutdown
- Improved Reactor Pressure Vessel Materials
- Active Core Region of Reactor Vessel Free of Welds
- Permanent Refueling Cavity Seal

Chapter 5, Safeguards Systems has been the major activity in the past year. The obvious importance to the viability of a future nuclear industry in the U.S. of the Safeguards Systems has resulted in a longer and more encompassing process to develop requirements. The Safeguards Systems were approached by generating interim documents in specific areas such as decay heat removal and reaching industry and Utility Steering Committee concurrency before proceeding with details of the Chapter. Table 7 summarizes the key proposed features of the Safeguards Systems requirements.

Table 7

SAFEGUARDS SYSTEM REQUIREMENTS

- Refueling Water Tank Inside Containment
- Emergency Feedwater System Upgraded
- Higher Pressure Residual Heat Removal System
- Safety Pressure Residual Heat Removal System
- Safety Grade Feed and Bleed Capability
- One Set of Safety Injection Pumps
- Delete Containment Spray Additives
- No Operator Action for 20 Minutes

The efforts on Chapter 6, Plant Arrangements and Chapter 10, Instrumentation and Controls have been initiated. The importance of these two chapters to meeting the overall goals of th ALWR program has resulted in a close cooperation with the Department of Energy funded programs on constructability and Advanced Instrumentation and Control. The results of related studies will be factored into the requirements for these two chapters. Table 8 indicates some of the proposed Plant Arrangement features that are currently planned to be requirements. Table 9 indicates some of the Instrumentation and Control features under review for Chapter 10.

Table 8

PLANT ARRANGEMENT REQUIREMENTS

- Constructability Major Factor in Plant Arrangements
- Operability and Maintainability Requirements Factored not Plant Arrangements
- Component Replacement
- Decommissioning Requirements Identified
- In-Service Inspection Requirements

Table 9

INSTRUMENTAL AND CONTROLS REQUIREMENTS

- Simplification
- Improved Alarms and Annunciator Systems
- Advanced Data Communications (Multi-Plexing)
- Advanced Sensors Systems
- Improved Control System Performance

The remaining chapters to be addressed in the complete program are listed in Table 10.

Table 10

REMAINING REQUIREMENTS DOCUMENT CHAPTERS

Chapter 7	-	Fueling and Refueling Systems
Chapter 8	-	Cooling Water Systems
Chapter 9	-	Site Support Systems
Chapter 11	-	Electrical Power Systems
Chapter 12	-	Radwaste Processing
Chapter 13	-	Turbine Generator Systems

CONCLUSIONS

By means of the process outlined in th ALWR implementation logic of Figure 1 and as further described above in the Requirements Document process the major uncertainties related to the nuclear option will be identified as they relate to the light water reactor. Technical resolutions will be proposed in all areas amenable to resolution by technical and managerical means. It remains to be seen whether resolution of technical uncertainties only will be sufficient. The institutional uncertainties which are largely outside the scope of current efforts may still interpose themselves to impede the nuclear option in the near-term.