THE UNITED STATES ADVANCED LIGHT WATER REACTOR (USALWR) DEVELOPMENT PROGRAM

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ABSTRACT

For the United States Nuclear Power industry to remain viable, it must be prepared to meet the expected need for a new generation capacity in the late 90s with an improved reactor system. The best hope of meeting this requirement is with revolutionary changes to current LWR systems through simplification and re-evaluation of safety and operational design margins. In addition, the grid characteristics and the difficulty in raising capital for large projects indicate the smaller light water reactors (600 MWe) may play an important role in the next generation. A cooperative and coordinated program between EPRI, U.S. DOE, the major architect engineers, nuclear steam supply vendors, and the NRC in the U.S. has been undertaken with four major goals in mind.

INTRODUCTION

The United States has embarked upon an aggressive light water reactor development program. A key feature of this program is that it unifies EPRI, utilities, NSSS vendors, architect engineers, Nuclear Regulatory Commission, and Department of Energy into a single comprehensive program to develop the next generation light water reactors for utilization by the U.S. utilities.

The program has four major parts:

1. Determine the set of stable regulatory requirements which must be met by the USALWR designs.
2. Generate utility- and NRC-approved plant Requirements Document for the USALWR power plants.
3. Develop the detailed engineering design and obtain NRC licensing certification for the USALWR.
4. Develop designs for a small simplified (600 MWe) PWR and BWR option for the USALWR program.

The overall program is governed through a joint Memorandum of Understanding between the U.S. DOE and EPRI[1] and is coordinated through a joint management committee of the two organizations. The first two tenets of this program, determination of a set of stable regulatory requirements and the generation of a utility- and NRC-approved Requirements Document, for the USALWR, have been underway at EPRI for several years and remain the primary responsibility of that organization.

The third goal of the program, the development of USALWR detailed engineering designs for NRC licensing certification is being undertaken by the U.S. Department of Energy. This design certification effort will use the utility Requirements Document generated within the EPRI program in formulating the design basis, and building on it, the final design certification will be obtained for one PWR and one BWR USALWR design.

The final effort of the program, the development of designs for small, simplified (600 MWe) Advanced PWR and BWR plants is a joint effort between EPRI and DOE. EPRI has the responsibility for the development of the overall plant designs while DOE has the responsibility for some of the system design and the related hardware development necessary to bring the overall designs to fruition. The relationship between these programs is summarized in Table 1.

REGULATORY REQUIREMENTS

United States nuclear power plants have been faced with an ever-increasing number of regulatory requirements which potentially affect the design of any new future light water reactor. The number of new requirements has increased dramatically since the Three Mile Island accident. As a first step in establishing design requirements for the USALWR, it was necessary to work with the Nuclear Regulatory Commission to determine the stable set of safety and licensing requirements which would have to be met by a new design. In addition, EPRI felt it desirable to involve the Nuclear Regulatory Commission in the design at the earliest possible stage to gain the benefit of their experience as well as to insure that any potential regulatory issues were identified very early on in the design process.

Table 1

USALWR PROGRAM

1. Determine the set of regulatory Requirements for the USALWR (EPRI).
2. Generate a set of utility-approved NRC-certified plant Requirements Documents for the USALWR (EPRI).
3. Develop detailed designs and final licensing certification of the USALWR (DOE).
4. Develop designs of a small (600 MWe) advanced PWR and BWR options for the USALWR Program (EPRI-design, DOE-design and hardware development).

At the beginning of the program in 1982, some 549 outstanding safety and licensing issues were identified by the staffs of EPRI and NRC. Since that time, the staffs of both organizations have worked to eliminate nonapplicable issues and to resolve or close issues down to the base number of 62 which will be treated in the advanced light water reactor Requirements Document. During that period, the total number of issues considered had risen to some 727. This is shown in Figure 1.

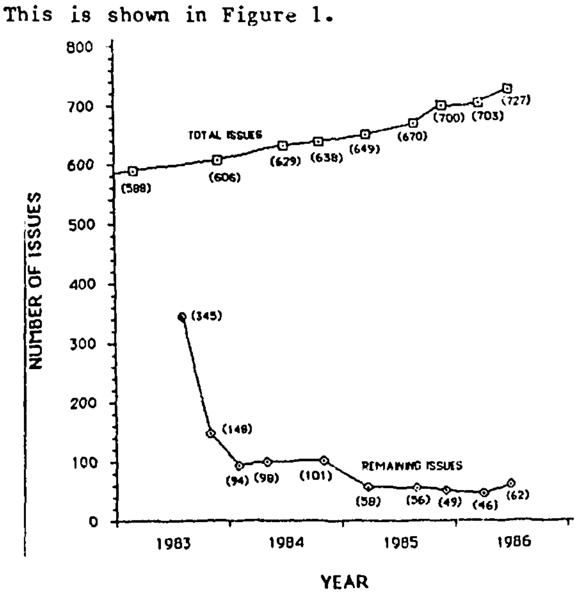

Figure 1. Progress on Remaining Issues.

Some of the most significant of the remaining 62 issues being addressed in the EPRI Program are:

- Hydrogen control measures and effect of hydrogen burn on equipment.
- Safety implications of control systems.
- Nuclear power plant design for the reduction of vulnerability to sabotage.
- Station blackout.
- Shutdown decay heat removal requirements.

Because safety issues are of primary concern to the USALWR Program, it was determined that a set of screening criteria should be applied to newly identified issues, starting July 1, 1986. Subsequently only those issues that represent potential safety issues, as evidenced by passing the screening criteria, will be considered for application to the Requirements Document. The screening criteria will be used to establish issue applicability.[2]

Any new issue which passes initial screening criteria will be judged to have the potential for affecting the USALWR design or construction requirements. Accordingly, to stabilize the USALWR requirements as much as possible, only those new issues which are directed toward correcting a major safety problem, so as to maintain an acceptable level of safety, will be considered applicable to and implemented in the USALWR Requirements Document.

To determine if an issue has major safety significance and is applicable to the USALWR Requirements Document, it will be evaluated using the criteria noted below. EPRI will provide assistance in support of the evaluation.

If one or more of the following criteria apply to the issue, it will be considered to apply to the USALWR and a specific set of plant requirements will be added to the Requirements Document to address the issue.

1. Would the core melt frequency goal established in USALWR Requirements Document be exceeded as a result of this issue?
2. Would the offsite accident radiological consequences dose requirements established in the Requirements Document be exceeded as a result of this issue?
3. Would the Commission's safety goals be exceeded as a result of this issue?

The EPRI program is proposing changes to NRC requirements. These changes have the effect of optimizing the safety effect of the requirements while improving overall plant economics. One example of such optimization is the consideration of leak-before-break principles in the design of piping and support systems. A more flexible piping system with higher reliability results while massive pipe supports and restraint structures are minimized.

USALWR REQUIREMENTS DOCUMENT

The purpose of the USALWR Requirements Document is to apply utility experience with nuclear generating plants to development of the design specifications for the next generation of plants. U.S. utilities require a plant which:

- Has a very low probability of core damage accidents and an extremely low probability of public risk in the event of a severe accident.
- Is significantly simpler to design, construct, operate and maintain.
- Is based on proven technology and has a robust design with improved design margins in important areas.
- Is a standard design assured of ready licensability and short predictable construction schedules.
- Is designed with great emphasis on human factors considerations.
- Is consistent with experience to the extent that a prototype demonstration plant is not required.

To that end, EPRI is developing a set of detailed plant requirements for the USALWR. These requirements are being subjected to widely based utility and industry review to assure that they reflect the needs of the utilities and are consistent with the latest technology available in the industry. This Requirements Document will be reviewed and approved by the Nuclear Regulatory Commission. The NRC has agreed to issue a Safety Evaluation Report for the Requirements Document. As their contribution to the program, the Nuclear Regulatory Commission is performing this review function at no cost to the program and thus are providing total support for their own personnel involved in this effort.

The Requirements Document consists of thirteen (13) chapters. All four U.S. light water reactor vendors, major AE firms and U.S. nuclear utilities are working with the EPRI staff to develop the Requirements Document. A complete list of participants is given in Table 2. A list of Chapter titles is given in Table 3. Chapter 1, Overall Requirements and Chapter 2, Power Generation, have been submitted to NRC. The schedule for submittal of all chapters of the Requirements Document is given in Table 4.

Table 2

PARTICIPANTS IN THE USALWR REQUIREMENTS DOCUMENT

- Overall Responsibility - EPRI
- NSSS Vendors
  - Babcock & Wilcox
  - Combustion Engineering
  - General Electric
  - Westinghouse Electric
- Architect-Engineering firms
  - Bechtel Corp.
  - Sargent & Lundy
  - Stone & Webster
  - United Engineers and Constructors
- Utilities
  - Duke Power Co.
  - Commonwealth Edison Co.
  - Yankee Atomic Co.
- Consultants to EPRI
  - MPR Associates, Inc.
  - S. Levy, Inc.

Table 3

USALWR PROGRAM REQUIREMENTS DOCUMENT CHAPTERS

1. Overall Requirements
2. Power Generation
3. Primary Coolant System and Nonsafety Auxiliary Systems
4. Reactor Systems
5. Safety Systems
6. Arrangements
7. Fueling and Refueling
8. Plant Cooling Water Systems
9. Site Support Systems
10. Plant Instrumentation and Control
11. Electric Power Systems
12. Radioactive Waste Processing Systems
13. Turbine Generator Systems

Table 4

SUBMITTAL SCHEDULE OF USALWR REQUIREMENTS DOCUMENT TO NRC

Topic	Submittal Schedule
Chapter 1	
Overall Requirements	6/86
Chapter 2	
Power Generation	9/86
Chapters 3, 4, & 5	
Reactor & Safety Systems	6/87
Chapter 6	
Plant Arrangement	12/87
Chapters 7, 8, 9, 11, & 12	
Auxiliary Systems	3/88
Chapter 10	
I&C	3/88

ESTABLISHING SIMPLICITY OF DESIGN

To assess the practicality of obtaining significant improvements using this approach, preliminary studies have been made. These evaluations have been based on an examination of current design as well as utility input as to the desired characteristics for an optimized light water reactor. In the area of simplification, a number of areas have been targeted, including:

- Reduce the number of pump valves and standardize designs.
- Reduce pipe whip restraints.
- Reduce feedwater heating stages and arrange heaters in condenser neck; eliminate individual heater bypass and low pressure heater drain pump; apply variable speed drives for large pumps.
- Delete containment spray additive system.
- Designate the chemical and volume control system to be nonsafety grade.
- Design to reduce and/or automate required tests and inspections.
- Provide for ease of removal of all components except reactor vessel.
- Reduce boric acid concentration, eliminate heat tracing.

It is interesting to look at the impact of reducing the number of valves. A typical 1,000 MWe nuclear power plant has 30,000 to 40,000 valves while a fossil plant of similar rating has only about 4,000 valves. Each valve is often a system unto itself. It can require motor or air operator and associated piping and cabling, position indicators, torque switches, remote switches, readouts, etc. EPRI and other industry studies have shown valve maintenance as a substantial and increasing burden to the plant operator. Elimination of a single large motorized valve can save tens of thousands of dollars in capital costs as savings from the elimination of maintenance inspection and testing requirements. The complexity of piping and valving has increased through a succession of changes to original designs. The ALWR Program requires a systematic effort to reduce the complexity and enhance safety and economics.

Considerable experience exists that a systematic valve reduction program can be remarkably effective even in the mature fluid systems of current plants. For example, a review of CANDU fluid systems as a part of the 600 MWe plant design effort in the scale-up of the CANDU reactor from 200 to 600 MWe resulted in using 284 valves in the primary heat transport auxiliary systems for the 600 MWe plant while 676 valves were used for the same function in the 200 MWe design.[3]

A recent redesign of an auxiliary cooling water system succeeded in eliminating one-third of the valves and three-fourths of the control valves. There was a net reduction by a factor of five of the number of control components whose failure would effect reliability.[4] An even greater improvement may be achievable in new plants where an integrated approach can be used.

Another means of eliminating valves is through the elimination of unneeded systems. For example, consider the containment spray additive system. Based on our current understanding of fission product behavior, particularly that of iodine, it is felt that the containment spray additive system is not needed. The elimination of spray additives from the containment spray system also avoids current restrictions on using aluminum in containment which could be beneficial in certain applications such as removable insulation.

REQUIRING ADDITIONAL MARGIN

There is a need to increase design margins to establish confidence in the operability and availability characteristics of the next generation light water reactor. Areas where design margins are being increased include:

- Reduction in core power density.
- Design so that safety valves don't lift for common transients.
- Increase margins against fuel damage for small break loss of coolant events.

- Specification of larger primary water inventories.

- Place an upper limit place of reactor coolant hot leg temperature.

- Select vessel steel and fabrication techniques to provide much greater resistance to radiation effects.

Substantial improvements over current designs are available through this approach without departing from proven technology. The examples which have been given point to additional areas which may be studied. Other areas are being identified. Based on the work to date, it is clear that this approach is fruitful and worth pursuing, particularly on an integrated plant-wise basis.

Specific design goals have been established in Chapter One of the ALWR Requirements Document. These criteria have been reviewed by a panel made up of U.S. nuclear steam supply vendors and architect engineers and approved by the USALWR Steering Committee, representing U.S. Nuclear utilities. The specific design goals are summarized in Table 5.

The plant cost goals shown are currently being reevaluated. It may be necessary to set even more aggressive cost criteria to allow the USALWR to compete effectively.

At this point, Chapter 1 (Overall Requirements) and Chapter 2 (Power Generation Systems) have been completed, reviewed by the Utility Steering Committee and are under review by the NRC. Work on the next three chapters (Reactor, Reactor Coolant System and Reactor Safety Systems) are well advanced. They are scheduled for submittal to the NRC in mid-summer. Work has been initiated on Chapter 6 (Plant Arrangement) and Chapter 10 (Instrumentation and Control).

DEVELOPMENT OF DETAILED ENGINEERING DESIGNS AND LICENSING CERTIFICATION

In February of 1986, the Department of Energy selected Combustion Engineering and General Electric to develop detailed designs of advanced light water reactor designs based on the USALWR Requirements Document. It is planned that these designs will receive Preliminary Design Authorization (PDA) and Final Design Authorization (FDA) and will ultimately be granted Design Certification under the procedures being developed by the U.S. Nuclear Regulatory Commission. With design certification, the designs, once approved, become standard certified designs and issues which were brought up during the Design Certification hearings with NRC and resolved cannot be litigated by any outside parties during licensing proceedings for any specific plant site. The design itself will be immune from backfit requirements for a period of ten years, unless a major new issue affecting public health and safety is found.

Table 5

USALWR DESIGN GOALS

Design Goal	Numerical Values
Plant Protection and Safety	
o Core Damage Frequency	$<1\times10^{-5}$ events/yr
o Public Safety - Severe Accident & Health Effects	<25 rem at 1/2 Mile for events freq of $<10^{-6}$/yr
Plant Cost	
o Life Cycle Cost	<6.5 ¢/kWh[a]
o Capital Cost	<4.5 ¢/kWh[a]
o Fuel Cycle Cost	<1.2 ¢/kWh[a]
o Operation and Maintenance Cost	<0.8 ¢/kWh[a]
Plant Performance	
o Availability	>87%
- Planned outage time	<30 days/yr (average)
- Refueling interval	24-month capability
- Unplanned automatic scrams	< 1/yr
o Plant Life	60 years
o Radioactive Waste Shipped	2500 ft^3/yr/unit
o Construction Schedule	48 months[b]
o Plant Personnel Exposure	< 100 man-rem/yr
Regulatory Stabilization	
o Resolution of Current Issues	No major open issues
o Resolution of Future Issues	

[a]Based on dollars levelized for 30 years of commerical operation beginning in 1999, de-escalated to correspond with a 1985 commercial operation date.

[b]First structural concrete to fuel load.

EPRI, DOE, and General Electric; and EPRI, DOE, and Combustion Engineering have entered into separate three-party agreements to insure that the specific intent of the USALWR Requirements Document is met in the submittals to NRC by the nuclear supply vendors for design certification. Under these agreements the Chapters of the USALWR Requirements Document will be submitted to NRC on the schedule shown in Table 4. Three months after the dates shown in Table 4 the nuclear steam supply vendors will submit to EPRI design certification information covering the same technical areas as the USALWR Requirements Document Chapter submittal.

ADVANCED SMALL SIMPLIFIED PLANT DEVELOPMENT PROGRAM

EPRI has a program to develop the designs for small (600 MWe) USALWR options. In the first phase of the program, three contractor teams developed preliminary conceptual designs. These teams include Westinghouse/Burns & Roe, GE/Bechtel/MIT, and Babcock & Wilcox/United Engineers & Constructors. The first phase ended in mid 1986. Based on the results of a review of preliminary conceptual designs, two design teams, Westinghouse/Burns & Roe and GE/Bechtel/MIT, were chosen for the further development of complete plant conceptual designs. The Department of Energy is supporting EPRI's plant design development effort by a parallel program of system design and hardware development to support major features coming out of the EPRI design effort.

One of the keys to the success of this program will be the ability to capitalize on unique aspects of the lower plant rating. One such aspect is the potential for use of passive safety features. Passive system designs can improve the level of safety while at the same time greatly simplifying the designs and reducing cost. When gravity and thermal density differences are used as motive power for fluid systems, a drastic reduction in active components and supporting systems such as electric power and control is achievable. This simplification in turn can result in significantly decreased cost, not only capital cost of the equipment that is no longer needed, but also engineering and construction costs since the plant will be simpler and easier to build. It is believed that pursuing this strategy will also allow the plant construction schedule to be significantly shortened, further reducing costs by limiting the financing cost component.

There are, however, natural limits to the ability to employ passive system concepts. Gravitational and thermal driving heads are much less concentrated than the power from active devices such as pumps. Thus, the price for employing passive system concepts is usually to increase physical dimensions. Fluid volumes must be higher in elevation, heat transfer surfaces larger, etc. Work to date indicates that a plant rating of 600 MWe is already challenging in this respect, and many of the passive system concepts may not be able to be extended to higher power ratings.

This smaller, simplified USALWR will meet the top level requirements contained in the Requirements Document. Detailed requirements appropriate to the simplified designs and passive safety features will be included in appropriate chapters of the Requirements Document.

Both the Westinghouse/Burns & Roe and the GE/Bechtel/MIT design concepts make fullest use of passive system design.

The GE/Bechtel/MIT design employs an elevated pressure suppression pool that is central to its passive safety system design. For decay heat removal in cases where steaming to the condenser is not available, an isolation condenser is provided. Unlike early BWR designs, the isolation condenser is housed in and cooled by the pressure suppression pool. A steam injector in the feedwater system allows for passive high pressure makeup to the reactor system without use of electric power. For a larger leak or rupture in the reactor coolant system, the reactor is depressurized by valves that blow down to the suppression pool, and the core is covered and kept cool by gravity drain from the suppression pool. A water wall with enough water to last for at least three days is provided to transfer heat from the suppression pool to atmosphere without need to vent the containment. Taken together, these features allow the plant emergency AC power system and its diesel generators to be nonsafety grade, and result in significant simplification of the overall plant. These features are shown in Figure 2.

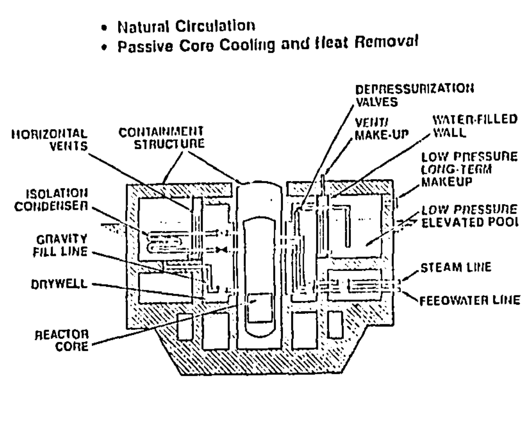

Figure 2. 600 MWe BWR Concept.

Other portions of the plant have also been significantly simplified. The reactor coolant system will employ natural circulation, rather than recirculation pumps, for normal full power operation. The feedwater, condensate, and main steam systems have also been significantly simplified. The designers have set a goal of 36 months for construction, which is believed to be achievable due to the significant simplifications in plant design.

The Westinghouse/Burns & Roe project is developing two plant configurations in parallel. Concept A is an evolutionary improvement of the standard two-loop design. Concept B, which will receive the primary emphasis in the ongoing work, is a more progressive advanced design with features developed for use in the 10MWe reactor design developed for Defense Department use. Both concepts feature improved arrangement and modular constructibility including compatibility with the Westinghouse barge mounted concept. Major features of the Westinghouse/Burns & Roe proposal include a lower power density core with reduction of approximately 30% kW/ft from current offerings, a larger core and vessel to provide increased primary water inventory, and a stainless steel and water reflector to improve neutron economy and protect the reactor vessel from excessive neutron fluence. A reduction in soluble boron systems utilization is anticipated through the utilization of gray rods for load follow. The reactor coolant system Concept B includes a low resistance loop which eliminates the traditional Westinghouse crossover leg, allowing use of canned-motor reactor coolant pumps.

Passive design concepts are being investigated to perform each of the necessary safety functions. A natural circulation heat exchanger in a tank inside containment is used to remove decay heat at full system pressure in the event that the normal feedwater and startup feedwater pumps are not available. If a rupture in the reactor coolant system were to occur, gravity flow from the core makeup tanks would keep the core covered with water while the system pressure is being reduced. A depressurization path from the pressurizer into the Reactor Water Storage Tank (RWST) would then be used to complete depressurization of the reactor coolant system. Gravity flow from the RWST would then fill the reactor coolant system and the lower part of the containment with water for long term cooling. Heat would be removed from the containment by conduction through the free-standing steel containment vessel, and natural convection air flow on the outside. These features are illustrated in Figure 3.

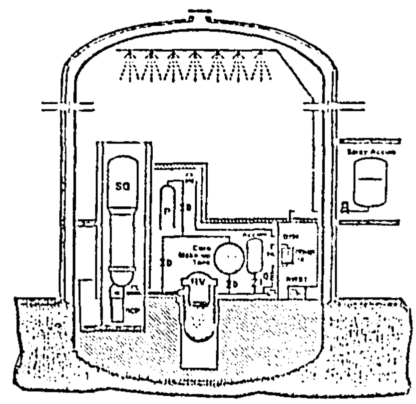

Figure 3. Westinghouse Small ALWR Passive Safegards LOCA (Initiation).

Table 6 presents a comparison of Concepts A and B. Future efforts for development will focus on Concept B since it offers more opportunity for extensive simplification and the application of passive features.

Table 6

SMALL PLANT CONCEPTUAL DESIGN PROGRAM
W/B&R PROJECT

Simplifications Compared to Standard 2-Loop

Plant Feature	Concept A	Concept B
Reactor Vessel	Larger	Larger
Pressurizer	20% larger	20% larger
RCPs	Same	4 canned
HHSI Pumps	25% less flow	Eliminated
ECCS Recirc. Mode	Eliminated	Eliminated
ECCS Test Realignment	Eliminated	Eliminated
RHR Pumps	Same	Eliminated
EFWS Pumps	40% less flow	Eliminated
Spray Pumps	Eliminated	Eliminated
RHR HX	20% less area	15% less area
Load Follow	Gray rods	Gray rods
BTRs	Eliminated	Eliminated
CVCS Safety class	NNS	NNS
CVCS Tech specs	None	None
Safety Grade Diesels	Lower rating	Eliminated

CONCLUSION

The United States is currently embarking upon an aggressive campaign to develop the next generation light water reactor for application in the 1990s. This campaign is characterized by close cooperation between EPRI, DOE, the NRC, U.S. utilities, U.S. reactor vendors and architect engineers. The USALWR Requirements Document being developed by EPRI will serve as the design basis for new LWR designs. Designs developed to the EPRI Requirements will obtain the Design Certification through the Nuclear Regulatory Commission. In addition, USALWR design options are being developed for small simplified (600 MWe) reactor concepts.

REFERENCES

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