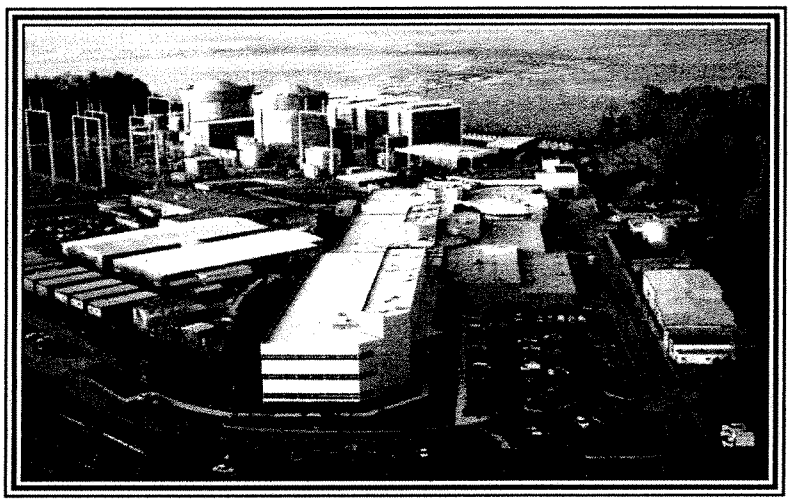

VOLUME I

Joint DOE-EPRI Strategic Research and Development Plan to Optimize U.S. Nuclear Power Plants

March 20, 1998

The U.S. Department of Energy and the Electric Power Research Institute are pleased to publish this Joint DOE-EPRI Strategic Research and Development Plan to Optimize U.S. Nuclear Power Plants. This Plan is intended for use by the research and development (R&D) community, and by the many interested energy experts, policy makers, and others who recognize the important role of nuclear power in our energy supply mix, and the role of R&D in enhancing technology.

Through R&D, we improve the safety, reliability, and environmental compatibility of energy systems. Through R&D we also find better ways to reduce the costs of energy generation, transmission, and use, without compromising the public's expectations for the improving quality of the nation's energy supply. Leadership in energy technology R&D is essential to our strategic national security and economic interests, our balance of trade, and our capacity to expand domestic jobs in high technology fields.

Nuclear energy is no exception when weighing the value of R&D. Improved technology is essential to increasing the operating life of current plants through license renewal, to further reducing the costs of nuclear energy, and to assuring U.S. leadership in nuclear technology worldwide. The President's Committee of Advisors on Science and Technology (PCAST), in a recent report by its Panel on Federal Energy R&D, recommended that the Department establish a new nuclear energy R&D agenda that includes both basic research supporting long-term nuclear energy options, and technology development associated with currently operating nuclear power plants.

Today, nuclear energy is an important part of our nation's electricity supply. Since it does not produce air pollutants or greenhouse gases, it could play an important role in addressing the environmental challenges of the future, along with increased energy efficiency, advanced fossil fuel, hydroelectric power and renewable energy options.

There are clearly barriers to significant expansion of nuclear power in the United States over the next decade. The DOE is supporting a broad portfolio of energy R&D to assure that Americans, in the future, have affordable clean energy options available consistent with our economic, environmental and security goals. As part of that portfolio, the agency's Fiscal Year 1999 budget proposes a new nuclear R&D program consistent with the PCAST recommendations. For its part, EPRI has a responsibility to deliver the best energy technology possible to its utility members. Collaboration between the public and private sectors is important in all areas of energy R&D, particularly in an era of constrained resources.

The marketplace, together with environmental and security considerations, will ultimately set the level of nuclear energy's contribution to long-term energy supply. This joint strategic plan will be a cornerstone for our mutual efforts to execute the best possible nuclear energy R&D programs for this nation's future.

Ernest Moniz
Under Secretary of Energy

Kurt Yeager
President and CEO, EPRI

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EXECUTIVE SUMMARY

Nuclear Energy in the United States

Modern, U.S.-designed nuclear energy plants are the only proven energy sources in use today that are capable of producing large amounts of reliable baseload capacity without contributing to air pollution or greenhouse gas emissions. Over the last twenty-five years, nuclear energy has prevented the cumulative emission of more than two billion metric tons of carbon, 80 million tons of sulfur dioxide, and 35 million tons of nitrogen oxides that otherwise would have been released into the atmosphere by fossil fueled plants if nuclear energy were not available. As much as 90% of the carbon dioxide avoided by U.S. utilities during this period is attributable to nuclear energy. Nuclear energy's avoidance of greenhouse gas emissions and other pollutants, therefore, is necessary to help the United States meet its international commitments to address concerns for global warming.

Nuclear energy also is a highly reliable source of baseload electricity. Nuclear power plants in the United States have shown they can continue delivering electricity to customers during extreme weather conditions and natural disasters that have disabled other electricity sources. More important, commercial nuclear power plants in the United States have an excellent record of protecting public health and safety and the environment.

Because of its record of reliability, public and environmental safety, and large generating capability, nuclear energy is becoming an increasingly attractive energy source for many other countries as well. More than 230 commercial light water reactors are operating throughout the world, and most of these trace their technical origins to U.S. designs. The international trend toward expanding the use of nuclear energy can be expected to continue as natural resource conservation, environmental protection, and global sustainable development grow in importance in the decades ahead.

The United States currently operates 105 large, commercial nuclear power plants that provide more than one fifth of the Nation's electricity. Many states depend on nuclear energy for a substantial portion of their electricity. Of all U.S. electricity generating technologies, only coal is more widely used than nuclear energy. The nuclear energy industry generates more than $70 billion in annual revenues, and employs approximately 400,000 people in nuclear-related jobs and trades.

As the United States deregulates its electricity business sector, nuclear power plant owners are going through a transformation in the way they manage their operating and maintenance (O&M) costs. Experience to date shows that, for most of today's operating nuclear plants, total production costs are competitive with other power generation options. There remains a question of how utilities can recover initial capital investments in nuclear power plants made prior to deregulation while operating in a competitive environment (the stranded cost issue). Congress and the states must determine how to resolve this problem. Plant license renewal (increasing the operating lifetimes of current nuclear power plants by 20 years) is seen by industry as an attractive, potentially viable solution if a workable implementation process can be established.

License Renewal of Current Plants

Nuclear power plants in the United States were initially licensed to operate for forty years although, with proper maintenance, their major components can operate safely and reliably in excess of sixty years. U.S. regulations are already in place that recognize nuclear power plant operating licenses can be extended safely to sixty years. Experience has shown that most components that age over a plant's lifetime can be repaired or replaced economically; many already have been.

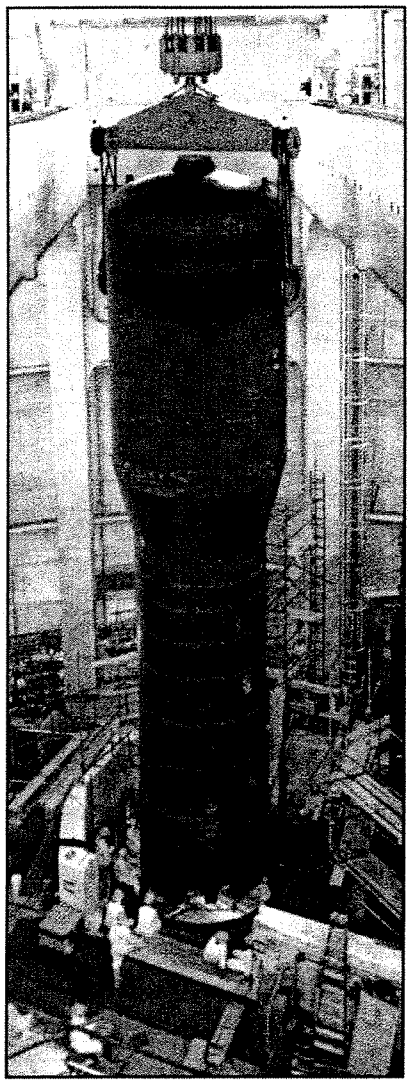

Figure ES-1. Steam Generator Replacement

License renewal of currently operating plants would require modifications to current programs for managing aging effects to satisfy U.S. Nuclear Regulatory Commission (NRC) requirements to ensure continued safety and optimize performance. When satisfied that the plants met the appropriate standards, the NRC would renew the license of these plants for an additional 20 years. License renewal would help resolve the stranded cost issue because increasing the operating lives of these plants would provide a longer amortization period. This would allow utilities more time to recover their initial capital investment costs. License renewal also would reduce the annual operating costs of these plants by lengthening the time available to accumulate decommissioning funds. Research and development leading to new technologies for improving plant performance and advancing risk-informed regulation are expected to produce further opportunities to improve the economic competitiveness of these plants.

From a societal point of view, there is another, very strong economic incentive for license renewal. Without it, projected growth in U.S. electricity demand will require replacement of roughly 100,000 megawatts electric (MWe) of baseload nuclear generating capacity in the next 35 years. The costs of prematurely replacing this generating capacity would be very large compared to the relatively modest costs of continuous plant life cycle maintenance and the cost of upgrades to obtain NRC license renewal. There also is a major environmental incentive to increasing the currently licensed lifetimes of combustion-free nuclear power plants. If they are shut down, the most likely sources of equivalent replacement power in this timeframe are greenhouse gas-emitting fossil plants. In the longer term, nuclear energy will be needed, along with energy efficiency and renewables, in order to produce sufficient amounts of economically competitive power, as older fossil plants are retired. For these reasons, maintaining the operation of existing nuclear power plants through license renewal is essential to meeting near-term greenhouse gas emission reduction goals.

For these economic and environmental benefits to be realized, a large percentage of today's plants must successfully achieve license renewal. Currently, the total time required to prepare a license renewal application, respond to NRC requests for additional information, and prepare for and respond to issues that may arise in a public hearing is estimated to be ten years. Under current NRC regulations, a licensee cannot submit an application for license renewal until after a plant has been licensed for twenty years. It is recommended that utilities file license renewal applications as much as 15 to 20 years before license expiration to allow time for NRC review of the application and the pursuit of supply alternatives, if necessary. Between now and the year 2015, the licenses of 46 plants will expire. As utilities need to submit their renewal applications 15 to 20 years prior to license expiration, a large percentage of plant owners should be actively involved today.

For most of the older plants, preparations for license renewal have not yet begun because of uncertainties associated with the technical requirements of NRC regulations and the future O&M costs associated with additional regulatory requirements that could be imposed as a condition of the renewed license. This uncertainty stems from lack of a defined and demonstrated process for developing an application that will be acceptable to the NRC and for working through the application to obtain the renewed license.

Additional R&D is needed to ensure that nuclear plant license renewal is a viable, attractive option for the following reasons:

1. Industry and the NRC agree there are no "show-stoppers" associated with a 20-year license renewal. A number of age-related material degradation phenomena that could negatively affect the economics of license renewal, however, remain to be better understood. These mechanisms must be better defined to establish high confidence they can be managed cost-effectively over the full license renewal term.

2. Additional nuclear R&D will likely produce new technologies that will optimize plant operation and O&M processes during the renewed license term, making the plants much more economical. Examples of such cost enhancements include more cost-effective, advanced technology replacements for obsolescent equipment (e.g., advanced digital technologies for older analog instrumentation and controls); refined safety and plant performance analysis tools that enable power upgrades; optimized fuel cycles that allow higher fuel burnup and less frequent refueling outages; and advanced inspection and repair technologies that reduce the time, cost, and radiation exposure associated with these tasks. All of these enhancements have indirect benefits in improved plant safety, although the primary focus of this R&D is on performance and economics, not safety research.

3. Further development and near-term (within the next five years) demonstration of the complex, yet untested, regulatory process for license renewal is essential to establish investor confidence that the federal government has a reasonable, predictable, stable, and affordable process in place. DOE has an important role in supporting adequate demonstration of this capability.

Public-Private Partnerships in Nuclear Energy R&D

In this era of reduced resources and growing demand for new and competitive technologies, the United States must continue its modest investment in nuclear energy supply R&D. This investment obviously must be balanced with government investments in other energy supply options and must recognize that both industry and the federal government must get more "bang for their buck" from their R&D investments.

The imperative for collaboration between DOE and industry is especially acute for nuclear energy R&D. Resources are limited, R&D needs for current plants are urgent, and closer scrutiny is being applied to the funding of all energy R&D by both industry and government. This environment demands a thorough planning process that articulates the rationale and value of the planned R&D, shows no overlap or gaps between industry and government R&D, and prioritizes the work.

Both industry and government should continue to participate in public-private partnerships, with international participation, to fund and manage nuclear energy R&D. With decreasing resources and increasing demand that R&D investments achieve market relevance, these partnerships are essential to achieve efficient, highly leveraged, market-driven results. They also can help accelerate the R&D process, better ensure customer needs are met, and help transition government-sponsored R&D effectively to the private sector and into the global marketplace.

Goals and Objectives of this Joint Nuclear Energy R&D Strategic Plan

The purpose of this Strategic Plan is to help the federal government and private sector jointly develop and prioritize the essential R&D needs of commercial nuclear energy for the next five to ten years, based on strategic national goals that both industry and government endorse. These goals are directly related to preserving and promoting economic strength, energy security, environmental quality, and science and technology leadership. This effort requires articulating a joint vision for nuclear energy, developing R&D objectives that support that vision and these national goals, and ensuring that the proposed R&D objectives and tasks have the support of the marketplace that will ultimately apply the technology developed, i.e., that the utility industry sees high value in the proposed R&D and anticipates applying the results to its plants. Even though this plan currently focuses on R&D needs for the next five to ten years, future revisions are intended to expand this goal-based approach into longer term R&D. It is quite possible for a goal-based, market-driven R&D planning process to guide long-term R&D. The ultimate implementor of that R&D, the utility industry, is capable and willing to support DOE's long-term planning process. This effort is essential if DOE is to achieve its dual goals of focusing on longer-range, higher risk R&D, while simultaneously gaining reasonable confidence that the R&D results will justify government's investment by eventually demonstrating their value as a result of being applied to strengthen and serve the U.S. economy. The following Strategic Goals were developed to guide the further development of this Plan.

Goal 1: Ensure current nuclear plants can continue to deliver adequate and affordable energy supplies beyond their initial 40-year license period by providing a strong technical basis for long-term operation via stable and efficient license renewal programs, by resolving open issues related to aging mechanisms, and by applying new technologies to improve the cost-effectiveness and predictability of the life-cycle management process.

Goal 2: Ensure current nuclear plants can continue to deliver adequate and affordable energy supplies by continuing to develop and apply the best technology to enhance nuclear generation capability, efficiency, and productivity.

For the next five to ten years, this goal-based approach will focus on the safe, cost-effective license renewal of currently operating nuclear plants. Related R&D to further improve the reliability and performance of these plants will contribute to these goals. Specific emphasis will be placed on demonstrating a predictable, affordable process for license renewal by the NRC.

While the current focus is on the next five to ten years, this Plan will be maintained as a living document to serve as the primary strategic planning document for industry and government collaboration on nuclear energy R&D needs. The Department and the Electric Power Research Institute (EPRI) plan to update this document annually.

Scope of this Joint Nuclear Energy R&D Strategic Plan

This Strategic Plan is focused on R&D of common interest to both industry and government as it relates to improving nuclear fission technology for the generation of electricity from currently operating plants. The Plan includes short-term nuclear R&D that industry should be doing on its own, and short term and medium term R&D for which industry seeks support from DOE based on partnership, cooperative funding, etc. For the R&D of common interest to government and industry, this Plan includes all R&D requirements, without regard to where the funding will come from or who will conduct the work. This approach provides a stable, clear assessment of strategic R&D needs that is independent of fluctuations in industry and/or federal funding decisions.

The scope and organization of this Plan are needs-driven, but the Plan recognizes the need for fiscal restraint. For this reason, the Plan targets the DOE funding levels recommended by the President's Committee of Advisors on Science and Technology (PCAST) in their November 1997 report to the President on federal energy R&D needs. These levels are modest by comparison to the other energy supply R&D budgets proposed by DOE and recommended by PCAST. This needs-driven approach focuses heavily on short and medium-term R&D in the first year of this Joint DOE-EPRI R&D Plan. Longer-term R&D needs will be expanded in future years.

In addition, partly because of the internal division of responsibilities for nuclear energy within DOE, nuclear waste R&D (both for spent fuel and low-level waste) is not addressed here, although the option to include this in future revisions to this Strategic Plan is being considered.

On the other hand, no attempt has been made to eliminate R&D requirements from this document based on year-to-year funding projections. Also, no attempt has been made to structure this document to match current or future DOE or EPRI budget line item allocation, which can change from year to year for reasons other than strategic R&D needs. Rather, this needs-driven assessment of required nuclear energy R&D will remain stable during fluctuations in DOE/EPRI funding levels, as well as during changes in line item allocation structures by DOE management, the Office of Management and Budget, and the Congress during the appropriations process.

For Fiscal Year 1999, DOE budget planning follows the PCAST recommendations for two funding line items, one associated with the continued operation of current nuclear power plants and a second called the Nuclear Energy Research Initiative (NERI). The latter will competitively select among proposals by researchers from universities, national laboratories, and industry to address key issues affecting the future of fission energy. This Plan is intended to provide a baseline set of R&D needs for use in both program approaches. It clearly and directly addresses the PCAST recommendation for R&D in support of the continued operation of current plants. Also, even though the scope of the NERI (as defined by PCAST) is broader and longer term, its scope includes and allows for R&D proposals that could benefit current plants.

Plan Organization

Following a needs-based development of the Goals and Objectives for nuclear energy R&D in Chapter 1 of this Plan, Chapter 2 describes the Implementation Plan, and Chapters 3, 4, and 5 present the elements of this R&D plan that support the goals and objectives, organized as follows:

Chapter 3 - R&D for Managing Plant Aging: This chapter covers the R&D required for long-term, cost-effective management of various material degradation phenomena that are important to the economic operation of current plants. Even though none of these environmentally-induced aging phenomena is an immediate obstacle to a plant-specific application for license renewal by the NRC, they can affect the economics of existing plants and result in premature closures. Thus, completing this generic R&D is essential to overall utility industry and investment community confidence in proceeding toward license renewal. Further, the inspection, repair, and performance prediction technologies developed here will have important applications to nuclear plants around the world, as well as other industries, giving the U.S. a strong global leadership position in safe, economical license renewal technology services. This chapter is organized by major component areas: reactor pressure vessels, reactor internals, steam generators, piping systems, cables, structures, and generic R&D.

Chapter 4 - License Renewal: This chapter is concerned with the demonstration of the license renewal process under current NRC rules and procedures. Industry and DOE anticipate that the current regulatory process for license renewal will be a costly, protracted, and uncertain process. No U.S. plant has formally applied for license renewal, although a small number are currently evaluating the option. This is largely because of uncertainty about the process. Uncertainties associated with implementing the regulatory process for license renewal must be removed before utilities can make informed business decisions to file license renewal applications. Ensuring a viable, efficient process for license renewal is, therefore, essential to preserving the investment in

these plants for their full economic operating life and to enabling the United States to meet its goals and commitments to reducing greenhouse gas emissions. This chapter calls for and is organized around four license renewal demonstration plants, one for each nuclear steam supply system (NSSS) design. These will provide the resolution of technical and process issues for application by other plants of that NSSS type.

Chapter 5 - Generation Optimization: This chapter focuses on improving the economic performance of current plants through development of technologies that will improve capacity factors, lower operating costs, ensure long-term economic performance, and increase power output where excessive design or regulatory margins exist in licensed plant power limits. This chapter relates to Chapter 4 in that successful introduction of new technologies that improve plant economics (along with resolution of potential plant aging issues) will contribute to a greater likelihood of license renewal—thus continuing the contribution of nuclear plants to national efforts to reduce greenhouse gas emissions. This chapter is organized by the following technology areas: digital instrument and control systems, advanced sensor technologies, advanced monitoring, diagnostic, and control systems, human factors, advanced safety analyses, and advanced nuclear fuels.