PRISM* DESIGN CONCEPT ENHANCES WASTE MANAGEMENT

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ABSTRACT

PRISM, a modular advanced liquid metal reactor (ALMR), has been designed conceptually by GE under the U.S. Department of Energy sponsorship. The concept design and analyses have been primarily focused on passive safety and improved construction and operating costs. Significantly, the unique design of multiple modules and features of PRISM enhance waste management over conventional reactor systems. This paper provides an overview of PRISM and of these enhancements. Inherent to the ALMR's, the sodium coolant precludes crud buildup on reactor surfaces and in components and waste for disposal. Preliminary evaluations indicate this fundamental feature results in factors of 2-4 less waste volume and 2-3 orders of magnitude less curies per megawatt-electric for ultimate disposal. For example, the trap designed for sodium cleanup is expected to be exchanged only once every thirty years. Also, inherent to ALMR's, burning waste actinides and selected fission products to preclude their accumulation and burial is very attractive. The hard neutron spectrum of the ALMR burns the actinides efficiently and is not poisoned by the actinides and fission products. The modular design of PRISM components (and the fuel cycle equipment) permit replacement without expensive and potentially hazardous volume reduction. For example, the functional components of the reference electromagnetic pump and IHX can be removed intact for waste disposal. Although development of the reference metal fuel is not completed, it is estimated that (low-level) waste from recycle of the fuel will result in significantly less volume than would be generated by aqueous recycle of oxide fuel.

*Power Reactor Inherently Safe Module

INTRODUCTION

The advanced liquid metal reactor (ALMR) is unique among the major power reactor concepts being developed throughout the world in that it can be made to breed substantially more fissile material than it consumes. The utilization of this capability in modern ALMR's will be essential in the next century as the inevitable growth in nuclear power generation using thermal reactors consumes first the currently abundant fissile uranium supply and eventually the recoverable plutonium inventory. This capability alone justifies continued timely development of the ALMR's, but as current studies show, there are important additional benefits that can be obtained from the ALMR, namely: (1) enhanced performance through use of passive, inherent safety features and elimination of more complex, engineered safety systems; (2) improved standardization and licensability as a result of Nuclear Regulatory Commission (NRC) certification of the design based on an affordable full-scale prototypic test; (3) improved economics and reduced cost and schedule risk resulting from both the more reliable licensing process and from design approaches that emphasize modular factory fabrication with minimum field labor, and (4) enhanced nuclear waste management via recycle capability which eliminates the long life high level actinides and can be further utilized to improve LWR waste management.

In 1981 GE initiated, under its own sponsorship, a program aimed at an innovative ALMR conceptual design. Work on the design concept has proceeded for more than four years under U.S. Department of Energy (DOE) programs and has resulted in the PRISM (Power Reactor Inherently Safe Module) concept. Substantial progress has been made by the PRISM team, headed by GE, which now includes Babcock and Wilcox, Bechtel, Borg Warner, Burns and Roe, Foster Wheeler, Stearns Roger Division of United Engineers and Constructors, and Westinghouse. Significant development support has been provided to this effort by Argonne National Laboratory, Energy Technology Engineering Center, Oak Ridge National Laboratory, and Westinghouse Hanford Corporation. Additionally, arrangements are underway to employ Japanese and European support in the planned R&D and test phases of this program.

This paper provides a brief description of the PRISM plant design, safety assessment, cost estimate, and in particular focuses attention on the ALMR waste management enhancement features.

PRINCIPAL DESIGN FEATURES

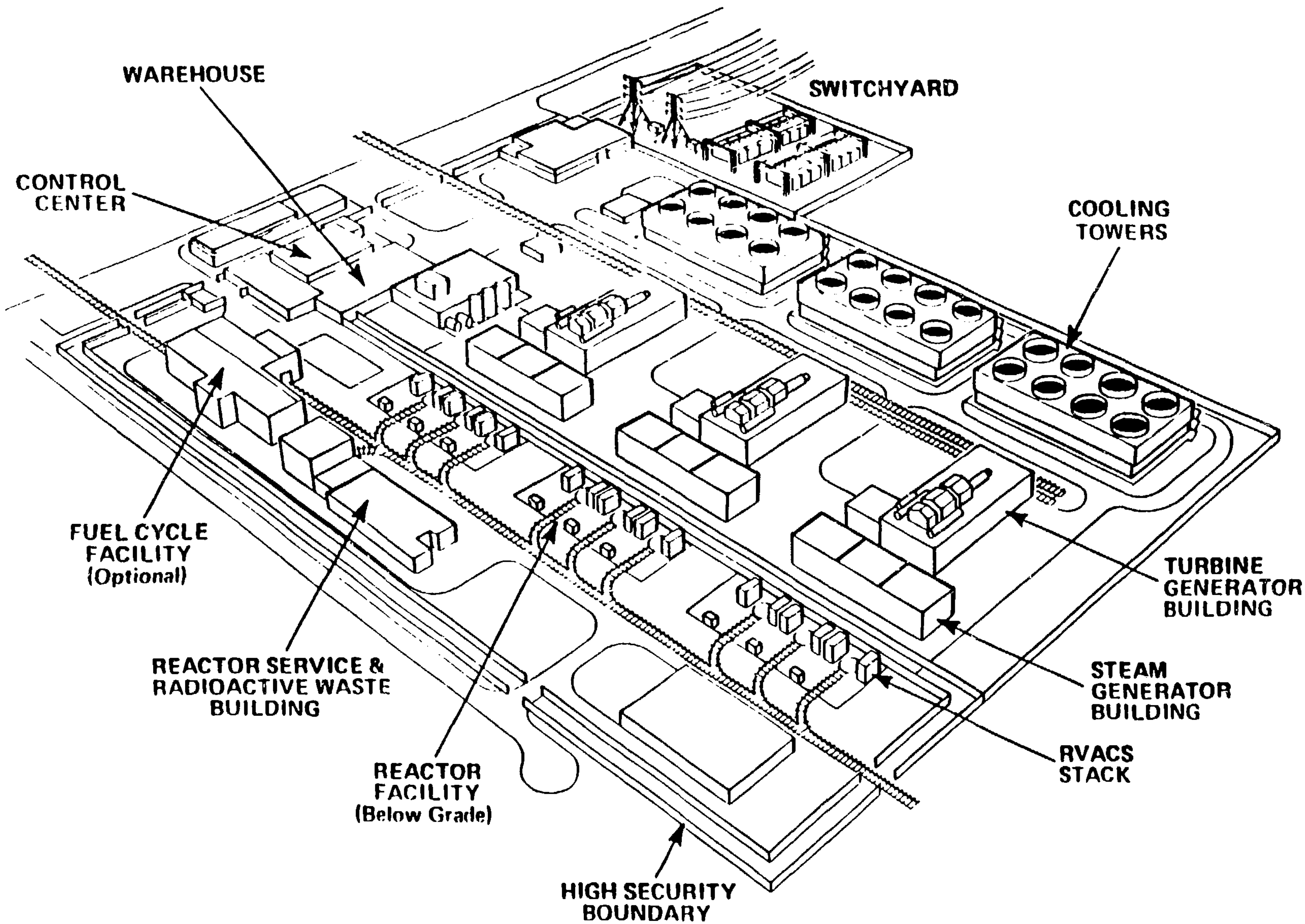
The PRISM design emphasizes a low pressure pool type LMR system enhanced by passive and inherent safety features, modular construction with maximum factory fabrication, seismic isolation and multiple loop operation capabilities. A PRISM power plant includes a number of standardized reactor modules, fabricated in a factory and shipped by whatever combination of barge, rail, and road transport that is most economic for a particular site. Except for the module and its structure, refueling facility and the reactor auxiliary systems, which are safety grade, the balance of the plant is expected to be certified as non-nuclear safety grade construction.

Overall Plant

The target commercial PRISM plant (Figure 1) utilizes nine reactor modules arranged in three identical 465 MWe power blocks for an overall plant net electrical rating of 1395 MWe. Each power block has three standardized reactor modules, each with its own steam generator, that jointly supply saturated steam at 6.6 MPa (955 psi) to a single turbine generator. Since each power block operates independently, smaller plant sizes of 465 MWe and 930 MWe can be provided by using one or two of the standard power blocks, thus providing size flexibility to the Utilities in meeting their load demand growth.

All nuclear safety-related systems and buildings are enclosed within a double-fenced and barricaded high security area. The control center, intermediate heat transport system, steam generator system, and related structures, which are all designated non-nuclear safety-related, are physically separated from the nuclear portion of the plant, and will be designed and built to high standards of industrial quality.

PRISM 1395 MWe POWER PLANT



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A collocated fuel recycle facility is being considered for the target commercial plant. Current studies indicate potential cost advantages for on-site recycle of the metal fuel and recycle system being developed by the Argonne National Laboratory (ANL), and such on-site recycle could reduce safety and security concerns associated with off-site shipments. The PRISM plant design is adaptable to either on-site or off-site recycle and both options are being maintained.

The reactor module, the intermediate heat transport system, and most of the steam generator system are below grade (Figure 2). Benefits that result from this include reduced capital cost and improved standardization by use of seismic isolation of the nuclear island, radioactivity containment, sodium fire mitigation, and protection from external threats such as sabotage and missiles.

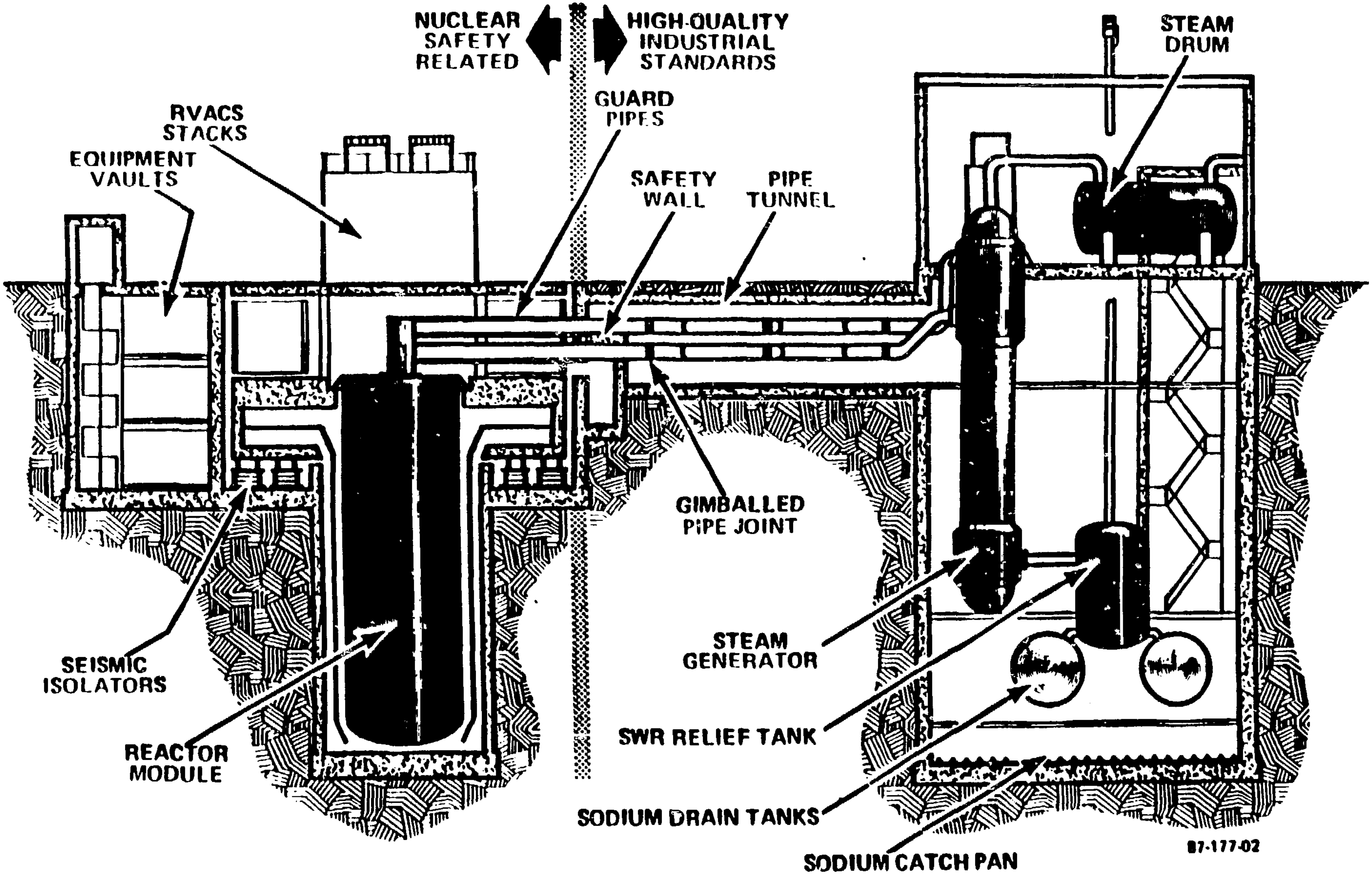
Plant Control

Control of the plant for startup, load following, shutdown, and response to emergency situations is accomplished by a highly automated plant control system (PCS). The reactor protection system (RPS) is entirely separate and independent from the PCS; it functions solely to continuously monitor reactor flow, core inlet and outlet temperatures, flux, and sodium level and if the specified trip limits on these parameters are exceeded, to scram the reactor. There is a separate RPS for each reactor which is located in hardened and seismically isolated equipment vaults at the reactor. The RPS is safety-grade and its operation cannot be interfered with by either the PCS (non-safety grade) or the operators, however, the operator can scram the reactor and can remain fully aware of reactor status via appropriate monitoring capability.

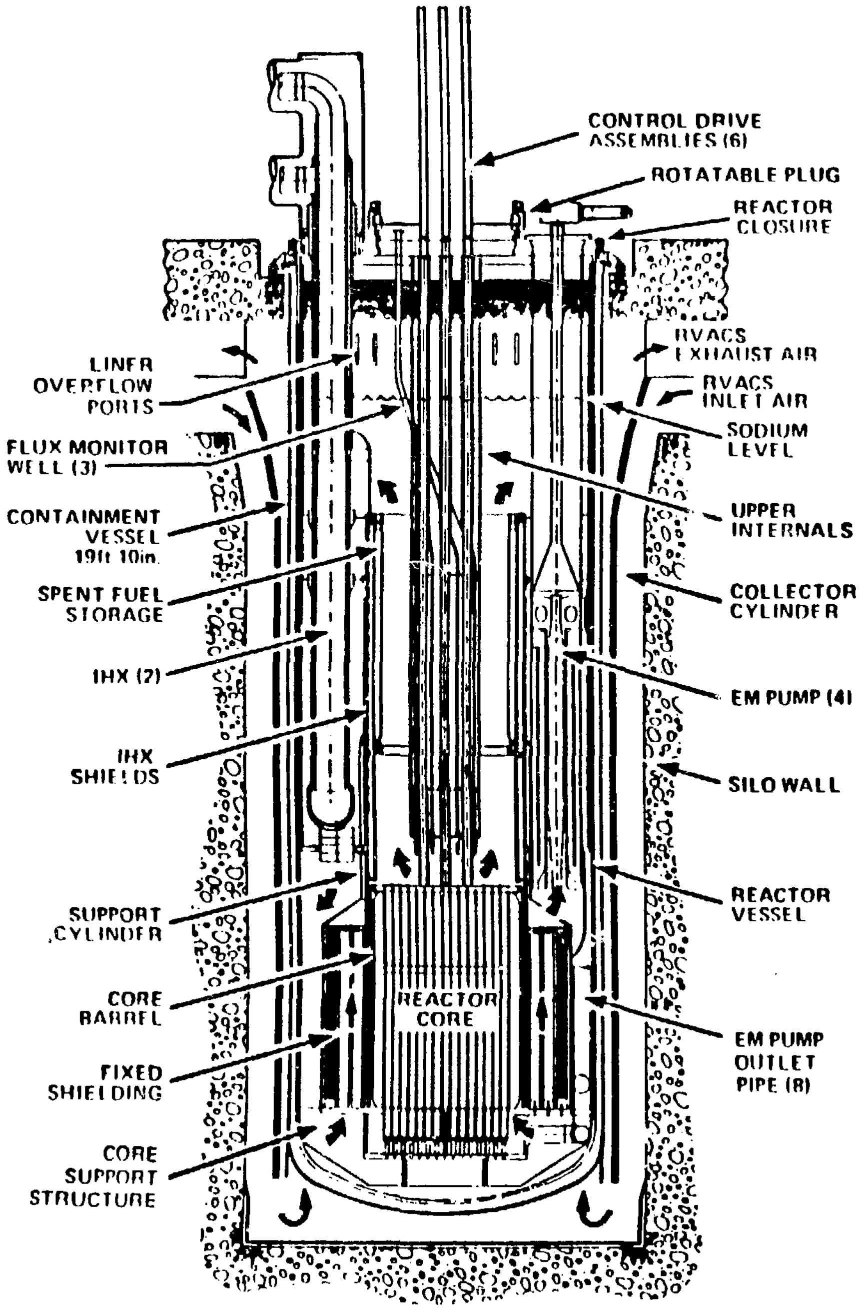
Reactor

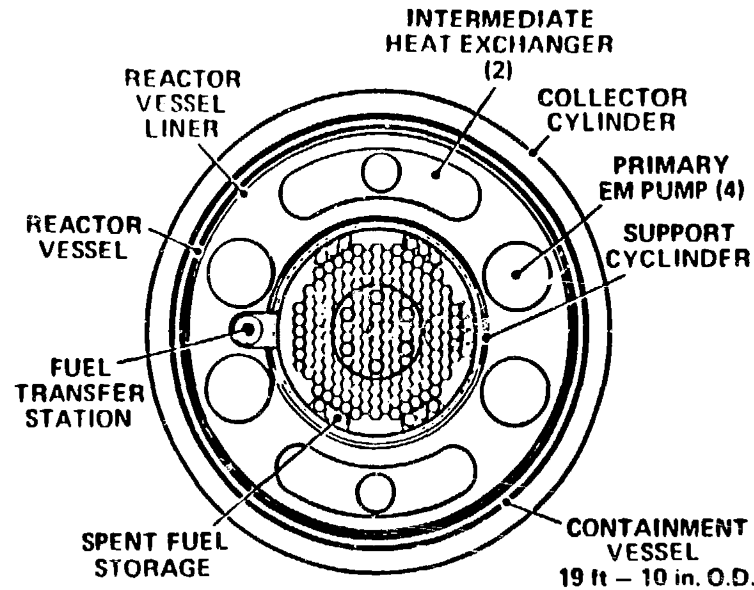
The reactor module (Figure 3) is about six meters in diameter (19 ft 10 in.) and about 18 meters high (60 feet). The vessels, head closure, and permanent internal structures are fabricated in a factory and shipped as an assembled unit to the site. The shipping weight is about 726 tonnes (800 tons). Removable internal equipment is shipped separately and installed through the top head.

PRISM NUCLEAR STEAM SUPPLY SYSTEM



PRISM REACTOR MODULE





DESIGN DATA

THERMAL POWER	471 MWt
PRIMARY SODIUM TEMPERATURE	625°F INLET 905°F OUTLET
PRIMARY SODIUM FLOW RATE	42,840 GPM

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The relatively tall, slender reactor geometry enhances uniformity and stability of internal flow distribution and natural circulation for shutdown heat removal. The relatively small reactor diameter results in a structure that is stiff in the vertical direction and thereby permits use of simple horizontal seismic isolation and eliminates any need for vertical isolation. Refueling operations are conducted one module at a time with the reactor shut down and the primary sodium cooled to 204°C (400°F). The other two modules of the power block will continue to operate, thus enhancing availability.

Fuel

Uranium-plutonium-zirconium metal fuel of the type under development by ANL in its IFR program has been selected as the reference for PRISM. This selection was based on the excellent negative reactivity feedback it provides for loss of cooling and transient overpower events, the competitive fuel costs expected to be achieved with it, and the excellent inherent safety performance demonstrated with metal fuel in the Experimental Breeder Reactor-II. Mixed oxide (UO_2/PuO_2) fuel is being retained as an alternative particularly for potential international application. The mixed oxide core will fit in the same space as the metal core with no change of internal structures required, and the two cores are interchangeable.

PUBLIC SAFETY AND INVESTMENT PROTECTION

Temperature and Pressure

The PRISM core outlet temperature is moderate, 485°C (905°F) at full power. This selection enables the use of conventional, well characterized, fully qualified materials for the reactor structures (stainless steel 316 and 304 for the reactor vessel and internals, 2-1/4 Cr-1Mo for the containment vessel), is expected to enhance fuel life, and provides additional temperature margin during accidental transients. PRISM operates at low pressure--the reactor cover gas pressure is approximately atmospheric at normal full power conditions; thus, there is minimum pressure loading on the reactor primary vessel and very little stored pressure energy available to be released if a breach of the vessel should occur. PRISM maintains substantial temperature margin to boiling, over 400°C (720°F), at full power operating conditions. Even under reactor vessel breach conditions, the close coupled containment vessel will maintain excellent natural circulation for decay heat removal.

Shutdown Heat Removal

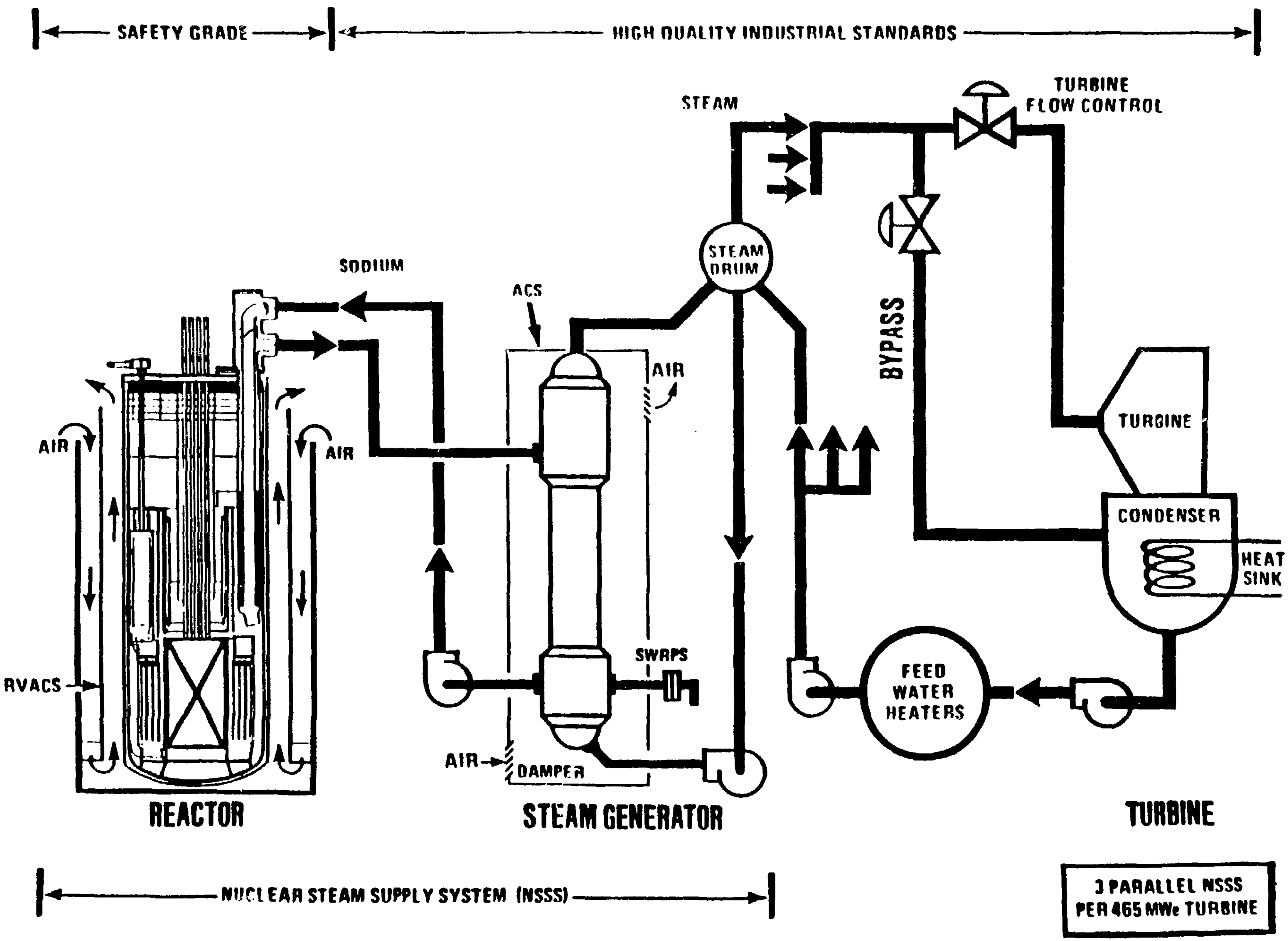
Normal heat removal (see Figure 4) is via the bypass condenser or an auxiliary air cooling system around the steam generator. In the rare event that the intermediate heat transport system (IHTS) becomes unusable during power operation, for example because of a main sodium pipe break or a sodium dump, the reactor will scram and the reactor vessel auxiliary cooling system (RVACS), which is always operating, will automatically and totally passively take over full decay heat removal. (Reference 3). Temperatures will rise and heat transfer to the atmospheric air circulating upward around the containment vessel will increase until equilibrium between reactor heat generation and RVACS cooling is established. Figure 5 shows calculated core outlet sodium temperatures for RVACS cooling alone after loss of all cooling by the IHTS at full power, with reactor scram. The temperature peaks after about 30 hours at a nominal value of less than 590°C (1094°F) with a 2σ margin below the American Society of Mechanical Engineers (ASME) service level C limit of 636°C (1176°F).

The redundant air flow passages combined with substantial margins in the design make RVACS extremely tolerant of accidental flow blockages, as well as surface fouling. Even with 90 percent air blockage, the temperature remains well below the ASME service level D.

Reactivity Shutdown

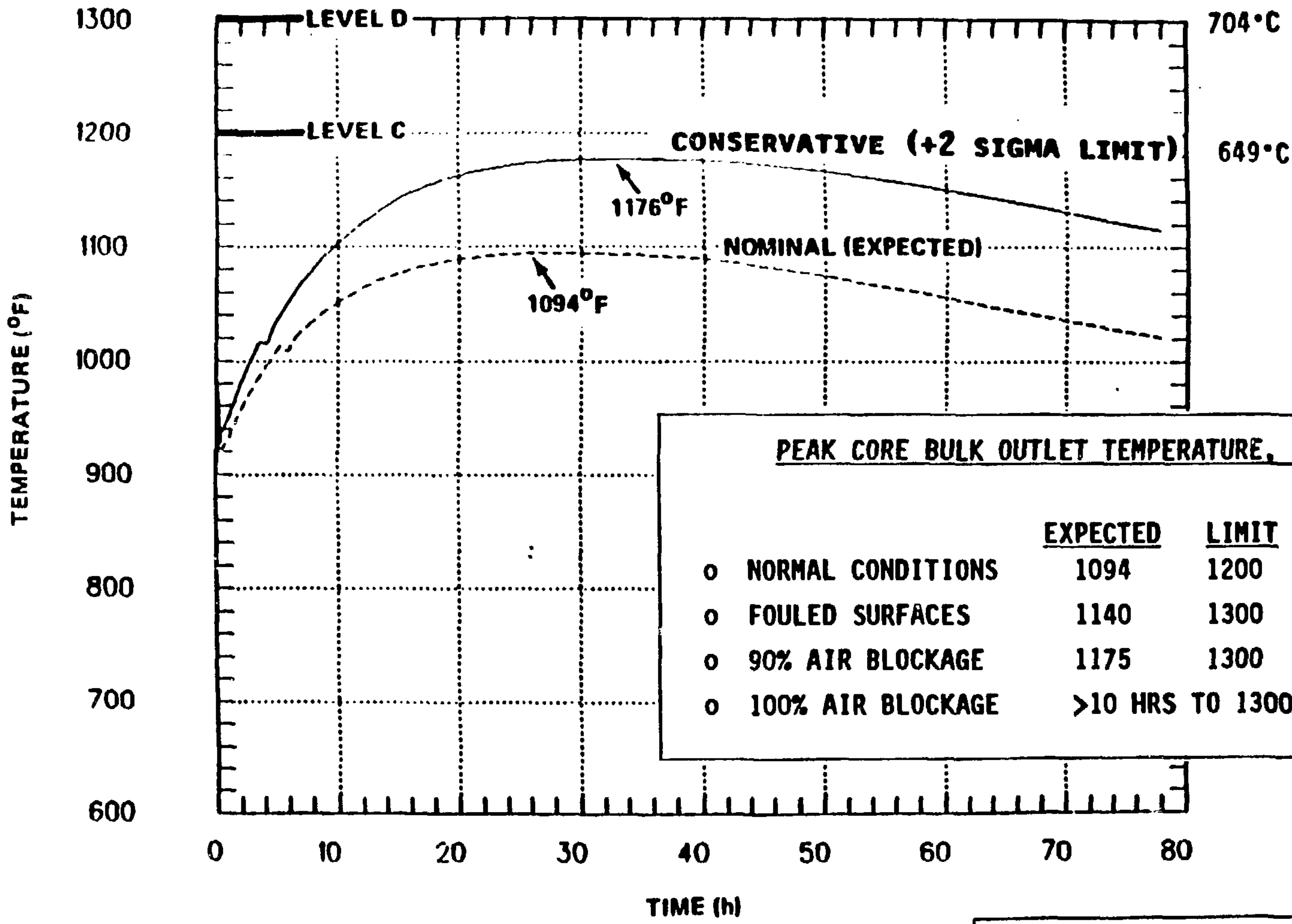
The plant control system (PCS) causes the six control drives to insert control elements to adjust power to respond to load requirements and to maintain core outlet sodium temperature within specified limits. If an emergency event develops too rapidly for the PCS to control it, then the safety-grade reactor protection system (RPS) will independently sense this and will respond by "scramming" the reactor.

PRISM MAIN POWER SYSTEM



DECAY HEAT REMOVAL BY RVACS ONLY - CORE OUTLET TEMPERATURE

- LOSS OF PRIMARY FLOW AND IHTS COOLING <u>WITH</u> SCRAM



PEAK CORE BULK OUTLET TEMPERATURE, °F

	EXPECTED	LIMIT	ASME LEVEL
o NORMAL CONDITIONS	1094	1200	C
o FOULED SURFACES	1140	1300	D
o 90% AIR BLOCKAGE	1175	1300	D
o 100% AIR BLOCKAGE	>10 HRS TO 1300		

RVACS HAS LARGE MARGINS FOR FAILURE ACCOMMODATION

The PRISM core is designed to also provide strong inherent negative reactivity feedback with rising temperature. This design characteristic, combined with the RVACS heat removal capabilities makes PRISM capable of safely withstanding accidental transients without scram while maintaining investment protection, including, for example: (1) Loss of all cooling by the intermediate heat transport system and loss of primary pump power from a full power condition, without scram; and (2) Withdrawal of all control rods at the maximum rate from a full power condition.

ECONOMICS

In addition to providing outstanding safety and performance characteristics, the design approach for the ALMR system (reactor and fuel) enables capital cost reductions through increased factory fabrication, expedited learning curve effects, fewer nuclear safety-related systems, and design standardization with NRC certification to a degree beyond that for plants that have been built or are under construction in the US. The projected capital costs for the Nth-of-a-kind ALMR system over a range of plant sizes compare favorably with those projected for future LWR's and coal plants (Figure 6). Estimated busbar costs for the ALMR system also compare favorably with those projected for both future LWR's and future coal plants (Figure 7). While it is early in the development process, these competitive cost projections have been extensively reviewed and are felt to be achievable.

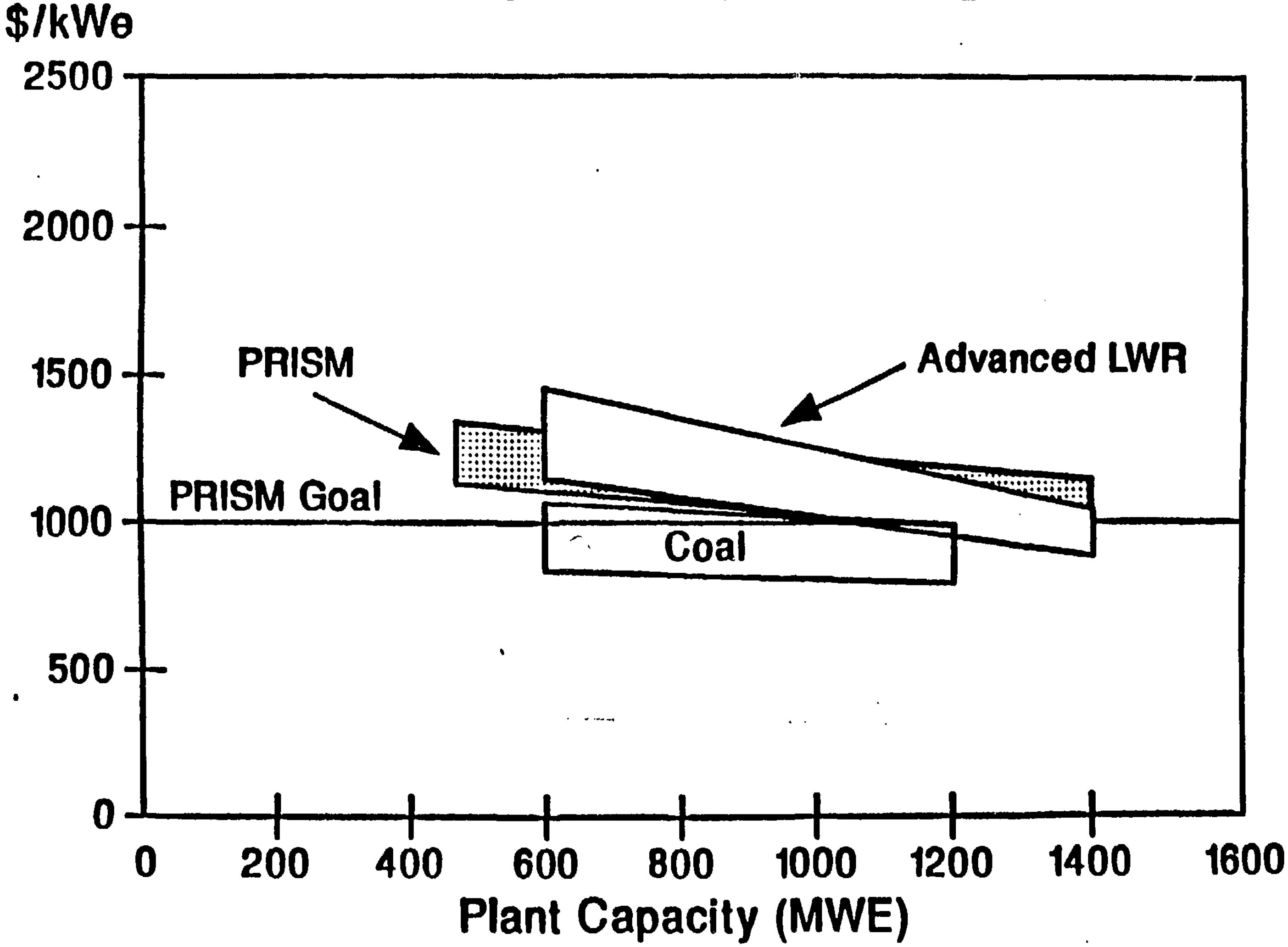
WASTE MANAGEMENT ENHANCEMENT

Significantly, the design features of the ALMR system enhance nuclear waste management over conventional reactor systems. These enhancements (see Figure 8) are discussed below.

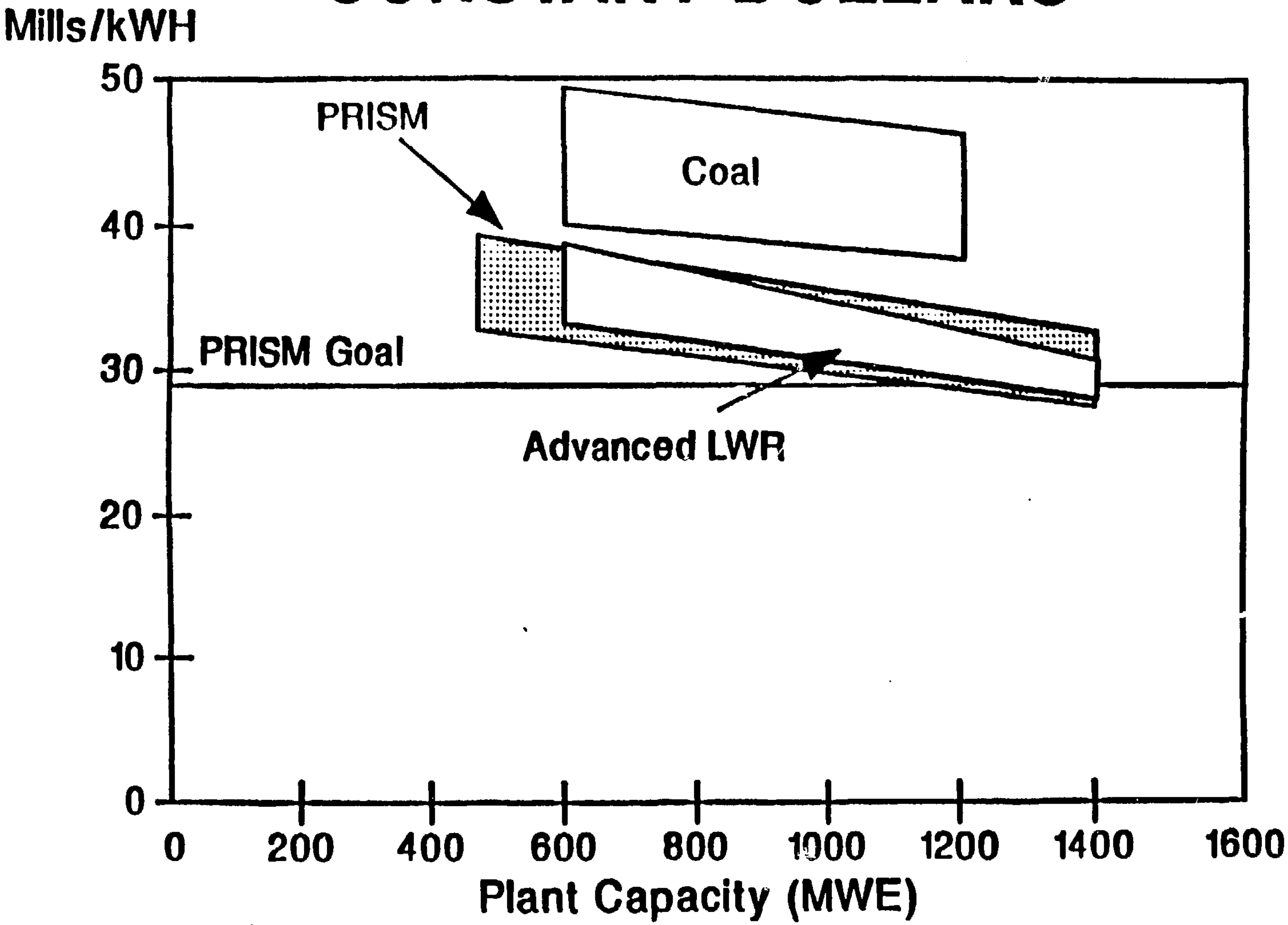
Modularity

The modular design of the ALMR system and its components permits replacement without expensive and potentially hazardous volume reduction (required for larger designs). For example, the functional components of the reference electromagnetic pump and the intermediate heat exchanger

PLANT OVERNIGHT CAPITAL COST IN 1987 DOLLARS



BUSBAR COST IN 1987 CONSTANT DOLLARS



WASTE MANAGEMENT ENHANCEMENT

- MODULARITY
  - ENHANCED COMPONENT CHANGEOUT/WASTE DISPOSAL
- SODIUM COOLANT
  - CLEAN SYSTEM; NO CRUD BUILDUP
- FUEL RECYCLE
  - ACTINIDES PROCESSED WITH THE FUEL IN THE METAL FUEL PYROPROCESS
- ACTINIDE BURNING
  - ALMR BURNS ITS OWN ACTINIDES
  - ALMR CAN BURN LWR ACTINIDES AS STARTUP FUEL

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(IHX) can be removed intact for waste disposal. Essentially all of the ALMR system (reactor and metal fuel system) components will be designed to be modular and are readily replaced as required. The removed components can be decontaminated, if necessary, and disposed of intact in waste packages without excessive volume reduction.

Sodium Coolant

In contrast to water coolant in LWR's, the sodium coolant in ALMR's precludes crud buildup on reactor surfaces, piping and other components and results in very low curie content in the reactor waste for disposal. Preliminary evaluations indicate this very important feature results in factors of 2-4 less waste volume and 2-3 orders of magnitude less curies per unit of power produced for ultimate waste disposal. Due to this feature, the cold trap system designed for sodium cleanup is expected to be exchanged only once every thirty years of operation. Obviously the data for ALMR's are limited because of a limited number of operating LMR's. However, the very favorable experience with the FFTF and EBR-II reactors indicates a very significant benefit in terms of waste volume and curie content. Since the radiation exposure in the ALMR plants is primarily due to the sodium coolant activation, which decays rapidly upon shutdown, personnel exposure is expected to be very minimal with a present goal of 20 man-Rems per year per ALMR plant (1400 MWe).

Fuel Recycle

The reference metal fuel pyroprocess being developed by ANL provides opportunity for reduced quantities of waste. The primary reason for this is the small process stream and fewer process steps to process metal fuel compared to processing oxide fuel. In addition, and very importantly, the higher, longer life actinides are processed with the plutonium and uranium in the metal fuel pyroprocess. Assuming the actinides are transferred quantitatively with the fuel, this could reduce the high level waste (HLW) storage requirement from millions (10^6) to hundreds (10^2) of years. While development of the ALMR metal fuel process is ongoing, it appears to hold great promise for removing long life actinides from the waste stream. Partitioning of actinides in oxide fuel recycle, while also feasible, does not appear to presently offer the same economic potential.

Actinide Burning

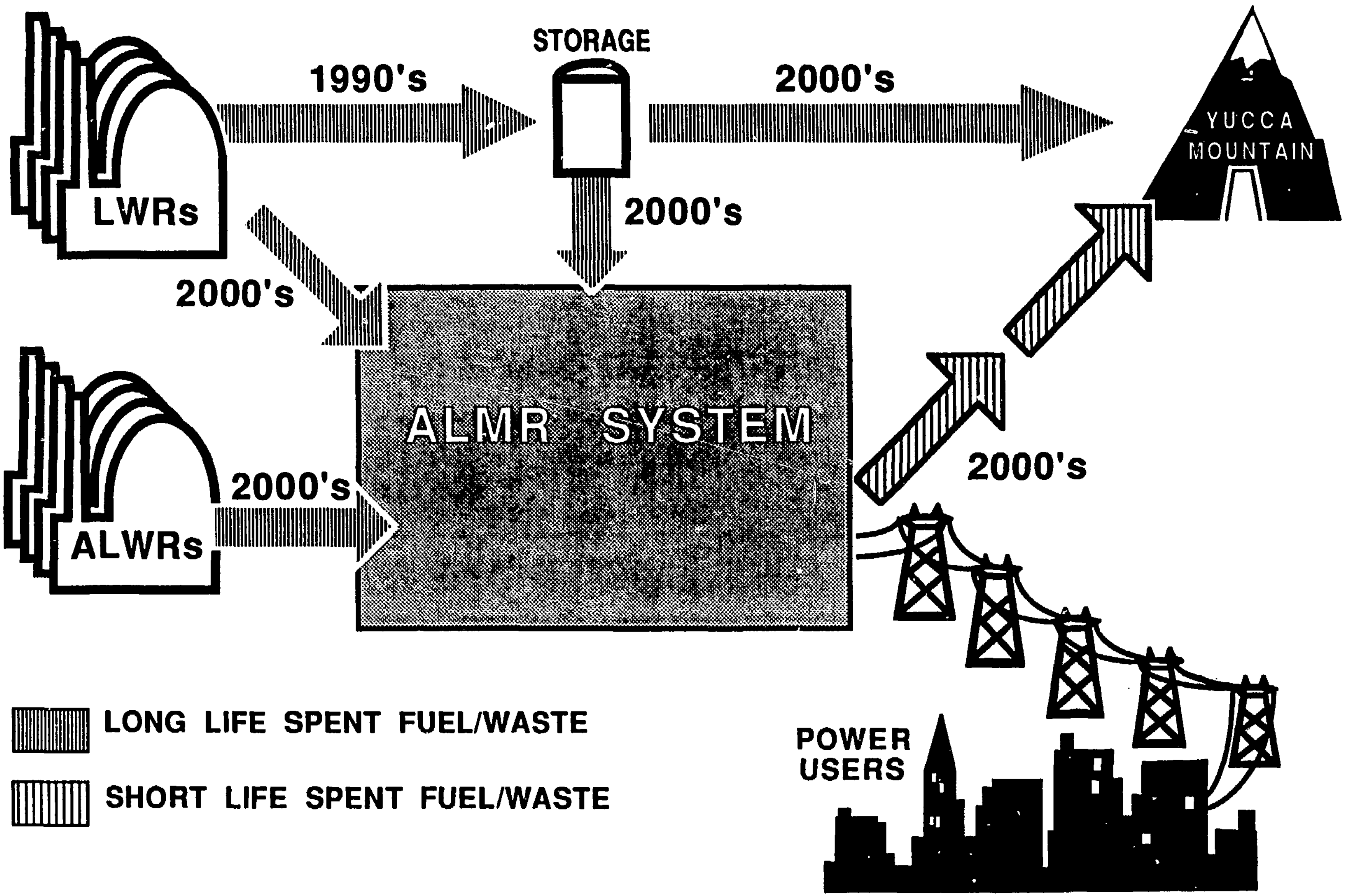
The ALMR system is better suited to burn actinides than other reactor designs due to its harder spectrum. Burning the higher, longer life actinides (and selected fission products) in the ALMR precludes their accumulation and subsequent burial. As indicated above, an attractive feature of the ALMR metal fuel recycle system is that the actinides are recycled with the fuel. This feature, in concert with the ALMR reactor capability to burn the actinides without significant technical (not poisoned by the actinides or fission products) or economic impacts offers an attractive waste management option. This would allow the ALMR to "eat its own actinide waste" and to additionally eat the LWR long life actinide waste as startup fuel for appropriate deployment of the ALMR system (see Figure 9).

CONCLUSIONS

The ALMR's features of fewer and simpler safety systems, seismic isolation, passive decay heat removal, inherent reactivity control, and substantial margins from structural and fuel damage limits during potential accident situations result in significant gains in public safety and protection of the owner's investment. The use of a standardized and certified (by full scale test) modular design with minimum field construction and extensive factory fabrication coupled wtih a breakthrough fuel recycle system results in a plant and fuel system design that is economically competitive against projected coal plants and other nuclear design approaches in the next century.

The design of the ALMR system and its capability to efficiently burn long life actinides due to its harder neutron spectrum, is a major improvement in solving the nuclear waste management challenge. This potential for the ALMR system to not only eliminate long life HLW from its own recycle but also from the LWR spent fuel cycle is a major step towards better public acceptance of the nuclear option. This ALMR nuclear option offers an environmentally attractive long term energy security approach (see Figure 10).

ALMR - Actinide Burning Potential



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ALMR (PRISM AND IFR)

- A REACTOR AND FUEL SYSTEM USING PASSIVE AND INHERENT FEATURES FOR SAFETY AND INVESTMENT PROTECTION
- A CLOSED CYCLE SYSTEM ELIMINATING LONG LIFE HIGH LEVEL WASTE
- A COMPETITIVE REACTOR AND FUEL SYSTEM FOR LONG-TERM ENERGY SECURITY
- A MEANS TO IMPROVE NUCLEAR WASTE MANAGEMENT

ALMR
A SAFE, CLEAN, FLEXIBLE POWER GENERATION SYSTEM FOR THE FUTURE

89-061-05

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