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DRIVING FORCES SHAPING ADVANCED REACTOR DESIGNS: NEAR - TERM AND LONG - TERM PROSPECTS

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ABSTRACT

This paper explores the forces which have driven and which in the opinion of the author should be driving advanced reactor development programs. Four general driving forces are identified: cost, safety, environmental concerns, and non-proliferation concerns. It is suggested that the primary driving forces should be cost and safety concerns.

It is suggested that advanced reactors need to demonstrate the following characteristics:

(a) A design which explicitly accounts for severe accidents, including severe external events (not necessarily limited to contemporary design basis events) and which results in a frequency of severe core damage substantially lower than in current plants. The goal for the frequency of severe core damage should reflect a reasonable assurance that a severe core damage accident will not occur during the operating lifetime of a "fleet" of such plants.

(b) A design which explicitly accounts for severe accidents in terms of accident mitigation, resulting in a very low conditional likelihood of a substantial fission product release given a severe accident.

(c) A design which utilizes near-passive and passive concepts (whose safety and reliability are demonstrable by experiment and/or full-scale test) for both accident prevention and accident mitigation to the maximum extent feasible.

(d) A design which allows for a suitably long time between refueling outages, with a balance struck between refueling outage duration and refueling outage frequency so as to maximize availability and capacity factor.

(e) A design which emphasizes modular construction and exceptional quality control.

(f) A design which deemphasizes the importance of maintenance and human reliability more generally to assure that safety functions are performed with acceptable reliability, and to assure that passive safety characteristics are not compromised by design, manufacturing, or installation defects.

It is further suggested that key factors in gaining public acceptance are the early public availability of design information on advanced reactors and, once there has been time for an initial review of this information, the occurrence of a period of dialogue between the designers and parties concerned with safety issues. This will promote the early identification and resolution of potential safety issues – most importantly, occurring at a time when tradeoffs in design and accommodative design changes are more easily and less expensively accommodated – and the sharpening of the residuum of safety issues for resolution in design certification rulemaking (to the extent that significant issues remain). Late disclosure of significant design details or outright secrecy, on the other hand, could breed distrust and unnecessarily and profitlessly (for all parties) extend litigation on the advanced reactor designs.

PREMISE

The purpose of this paper is to explore what is and what should be the forces driving the development of advanced reactor designs for both the near-term and the long-term. These driving forces are further examined to identify the underlying factors which make these driving forces important. The approach taken is to first identify the factors which shaped the current reactor programs, and then to merge this information with an identification of factors which will be important in the near-term and long-term but which perhaps have not played a major role in the current reactor programs.

Driving Factors for Current Reactor Programs

There are four principal areas of concern for reactor programs which have been important throughout the history of the nuclear industry. Two of these – safety and cost – are obvious, and have perhaps had more to do with the current state of the industry than the remaining two – environmental and non-proliferation concerns. Consequently, it seems evident that safety and cost considerations will dominate the discussions about advanced reactor designs, although a caution should be raised in that it will be necessary to demonstrate that environmental and non-proliferation issues are not made worse by advanced reactor designs.

A number of underlying factors were and are important in making these four factors the driving forces for current reactor programs. Safety and cost are closely related. The drive for cost competitiveness led to large reactors for which when safety problems are discovered there is a large premium to be paid for fixing the problem.[1] As a result, reactor sizes rapidly grew and there are only a handful of reactors which are smaller than 600MWe in the U.S. (15 out of 115). (This is the approximate size of the largest advanced reactor which has been proposed to date, not including the large evolutionary PWRs and BWRs.) One result of the drive to large reactors was the early abandonment of "inherent" or "passive" safety in performing many safety functions. Instead, active systems are required to perform nearly all safety functions in existing reactors.[2]

The cost of existing large reactors in the U.S. has been driven by both high fixed costs and long construction cycles, as well as relatively significant operations and maintenance (O&M)

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[1] For instance, when a large plant must be taken off line to implement a backfit or perform some type of special surveillance, this takes 1100-1250MWe off the grid at once. Accordingly, a considerable amount of replacement power must be provided by the utility. If, on the other hand, one had a pair of 500-600MWe plants, in the absence of a critical emergency, a reasonable argument might be made to take one unit off line at a time. This has a less significant impact on the grid. In addition, as a matter of design, it is very difficult to design more or less passive systems for the large units due to the absolute amount of decay heat present. This makes it more imperative for such units to be taken off line in the event that some safety discrepancy is identified. In contrast, smaller units can be designed with more or less passive systems which are less significantly affected by safety discrepancies in the rest of the plant. This makes a mandatory shutdown potentially less likely.

[2] Of course this is not uniformly true. Indeed, the genesis of the term "inherently safe" appears to have arisen in connection with the ability of conventional light water reactors to avoid positive reactivity coefficients for coolant voids (compared with liquid metal reactors of the time) -- that is, runaway power excursions are inherently avoided in conventional LWRs. Conventional LWRs do have some inherent or passive safety attributes, including favorable reactivity coefficients (in most cases) and the presence of substantial heat sinks in the containment. The difference in advanced reactors is both a matter of scope and degree -- inherently and/or passively safe processes are being designed to wholly perform multiple safety functions (such as emergency coolant injection, containment heat removal, and reactor coolant system residual heat removal).

costs. The long construction cycles for conventional plants resulted from a synergism of a number of factors, including changes in demand, a period of high financing costs, increasing regulatory requirements, and external factors (such as the Three Mile Island accident in 1979, the Browns Ferry fire in 1975, and the oil embargoes of the early 1970s). Long construction cycles result in higher financing costs (AFUDC), and a longer period of exposure to increasing regulatory requirements and external factors, which result in still greater fixed costs and an even longer construction period -- in essence, a positive feedback loop.

The safety question which was thought by regulatory agencies to have been answered in the early 1970s has been found to have been answered only partially. One important reason for this lies in the early and continuing focus on artificially constrained design basis accidents (DBAs) and the plant designs and regulatory structure which resulted from this focus.

It seems to be generally recognized that the public is not at significant risk from a design basis accident (since by definition very little bad happens by any realistic analysis of a design basis accident).[3] Risk studies in the 1970s and 1980s have shown that the safety risks of existing reactors are posed largely by severe accidents. Although existing reactors have some margin against a variety of severe accidents (a margin which varies among designs and varies with the particular type of severe accident under consideration), this is a somewhat serendipitous outcome resulting from conservative assessments of certain design basis accidents and the safety factors inherent in contemporary engineering practice.

In a rational world, existing reactors would have been designed against severe accidents (with some mixture of prevention and mitigation) and the regulatory structure would have been focused on severe accidents. This has simply not happened to any significant extent in the United States (indeed, except in certain very narrow circumstances, the licensing process doesn't even address severe accidents). One outcome of this situation is that every time there is an actual severe accident (TMI-2 or Chernobyl) or a significant precursor event (Browns Ferry fire, Davis-Besse loss of feedwater, Vogtle station blackout during shutdown), new safety requirements are issued, the already large fixed costs of existing plants increase, and the regulatory process is changed to pay increased attention to yet another facet of operational safety.

Safety and costs for existing reactors have also been found to be significantly affected by the human factor. Operators and other plant personnel can unfortunately easily interfere with the operation of active safety systems. Thus, a great premium has begun to be paid in the last decade in terms of operations and maintenance costs for improved procedures, more and better training, and larger plant staffs. In addition, management has been recognized as being significantly more important to both safety and costs than was initially thought to be the case. Several multi-year shutdowns of some plants, and implementation of expensive "performance improvement programs" at many other plants have resulted from regulatory concerns about the adequacy of plant management at utilities in the U.S. Management concerns have not been limited to plant operations, however, but have extended to design and construction, as well as other aspects of the fuel cycle.

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[3] In a realistic analysis of a design basis accident (such as a large break LOCA) in a conventional LWR, for example, the emergency core cooling, residual heat removal, and containment isolation systems would successfully operate in the presence of single active failures, and no core damage would result. This can be contrasted with regulatory safety analysis assumptions (10 CFR Part 100 and TID-14844) in which some core damage occurs and a fission product release to the containment takes place which crudely approximates significant core damage. Analyzed realistically (with best estimate codes and calculations), no such damage or release would take place.

Environmental concerns as a driving factor for current reactor programs dates to the late 1960s. Early concerns about thermal pollution appear to have largely been resolved, and replaced with concerns about the impacts of severe accidents, such as the Chernobyl accident. The possible use of nuclear power as an answer to some environmental problems, rather than as a cause of environmental problems, is a relatively new development and is more properly discussed as a driving factor for advanced reactor programs.

Proliferation concerns over existing reactors also seem largely to have been answered, with the exception of breeder reactors and reactors fueled with natural uranium. With the abandonment of reprocessing and plutonium recycle in the United States, proliferation concerns have generally not been a major driving force in affecting U.S. reactor design in the recent decade (nor were they major driving forces prior to 1980).

What Level of Safety has been Achieved in Existing U.S. Reactors?

How safe are existing reactors? This question is not easily answered. The simple answer is that every existing commercial nuclear power plant has the potential for a very severe accident which could result in significant impacts on public health and safety and on society more generally (through resource deprivation, such as abandonment of severely contaminated areas, and through secondary effects such as implementation of new safety requirements in the remaining plants).

The difficult answer involves determining an accurate estimate of the likelihood of such an accident and evaluating in more qualitative terms the adequacy of the management of operational safety (the risk impact of which is difficult to quantify within the current state of the art). This may in some measure be accomplished for all U.S. plants by the Individual Plant Examination (IPE) program which is required by NRC Generic Letter 88-20 to be accomplished within the next 2-4 years. In the meantime, plant-specific probabilistic risk analyses (PRAs) of varying scopes and vintages have been completed on a large number of plants in the U.S. A survey of these studies indicates that the likelihood of severe core damage per reactor-year for U.S. light water reactors may lie in the range of one in 122,000 to one in 700 per reactor-year, with an average value in the range of one in 3,400 per reactor-year.[4]

The best current information suggests that given such an accident, the likelihood that the containment will fail early or be bypassed--thus resulting in a potentially large release of radioactivity to the environment--may range from a few percent or less to higher than 50% depending on the containment design and the relative likelihood of various accident sequences. Thus, the potential for a fairly severe accident in the U.S. may lie in the range of one in a few thousand to one in a few hundred thousand per reactor-year (slightly more in perhaps a few cases and slightly less in some others).[5]

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[4] To the extent that recent nuclear plant performance in the U.S. indicates a clear trend toward lower transient initiating event rates and considering that transients tend to dominate risk, PRAs which have been performed using historical data (which show much higher transient rates) may somewhat overestimate risk. On the other hand, in the consequence estimate area, the recent BEIR V report indicates that latent health effects have been underestimated in previous PRAs, perhaps by a factor of 4-8.

[5] For perspective, the following results are reported in the second draft of NUREG-1150, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants* (June 1989); mean large release is taken as the sum of the mean frequency of early containment failure and containment bypass:

Driving Factors for Advanced Reactor Programs

Cost and safety will continue to play a major role in advanced reactor programs, however the means by which cost control and adequate safety are achieved will likely be different than with previous reactor programs, particularly for long-term advanced reactor programs. Near-term "evolutionary" designs will be very likely to be subject to the same driving forces as existing plants, with perhaps some optimizing of safety (within the constraints of a more or less conventional PWR or BWR design). Examples of such designs are the General Electric Advanced BWR (ABWR), the Westinghouse SP/90 advanced PWR, and the Combustion Engineering System 80 Plus reactors.

Environmental concerns may play more of a role with advanced reactor programs than has been the case for existing reactor programs. This is likely to be true on both the "cause" and "answer" sides of the issue as alluded to above. Improved safety characteristics (such as reduced core damage frequency and near-passive to passive decay heat removal characteristics) should enhance the status of nuclear power as being a comparatively clean energy source (by reducing the likelihood of environmental damage resulting from reactor accidents). On the answer side of the environmental equation, nuclear power plants can be seen as partial answers to acid rain and greenhouse problems, although a significant near-term impact should not be expected for a variety of reasons.

On a practical level, only the large (1100-1350MWe), evolutionary plant designs will be available in the very near term (such as the General Electric ABWR and Combustion Engineering System 80 Plus). The usefulness of these plants for many utilities in the U.S. is open to question. Smaller, near-passive LWRs (such as the Westinghouse AP-600, General Electric SBWR, and ABB-Combustion Engineering PIUS-600) and other designs (such as CANDU-3) will be available on a somewhat later schedule, but the first of these units will probably not be design certified, constructed, and placed into operation until the end of the century. Even then, it is not clear whether large numbers of these reactors could be built and placed in operation on less than a 10-15 year schedule beginning at the end of the century. Acid rain and global warming problems could have shorter time frames in which solutions are needed.

PLANT	MEAN CORE DAMAGE	MEAN LARGE RELEASE
Surry PWR *	1.7×10^{-4}	2.2×10^{-5}
Zion PWR	3.4×10^{-4}	6.8×10^{-6}
Sequoyah PWR	5.7×10^{-5}	7.4×10^{-6}
Peach Bottom BWR*	1.0×10^{-4}	5.3×10^{-5}
Grand Gulf BWR	4.0×10^{-6}	9.2×10^{-7}
AVERAGE**	1.3×10^{-4}	1.8×10^{-5}

* Includes external events.

** CAUTION: These averages are not necessarily meaningful in a statistical sense, nor representative of other reactors (these five reactors have been the subject of multiple PRAs, and their safety has been improved as a result of PRA insights; some plants may not experience results as favorable as these, while others will be better). If, notwithstanding these problems, these values are taken as representative for the sake of argument, they indicate roughly a 20% chance of a core damage accident and a 2% chance of a core damage accident with a large release within the next 20 years in the U.S. across the industry (assuming no improvement). Although there are extraordinarily large uncertainties in using these results in this manner, it does provide (in the author's opinion) some perspective on existing plants in the U.S. Some improvement in these results may be expected within 5-10 years due to the NRC IPE program (Generic Letter 88-20).

Near-Term Directions -- The Next Five to Eight Years

For the near term, it seems that large evolutionary reactors and half-size advanced light water reactors will be available for deployment by the mid-1990s. The large evolutionary reactors (ABWR and System 80 Plus) will probably not have a large market in the U.S., but may see some use elsewhere. These reactors--assuming that the designers have paid adequate attention to the lessons of the operating history of existing plants--should achieve moderately better economic performance and should be more optimized in terms of preventing and mitigating severe accidents than their existing counterparts. However, notwithstanding their licensing as advanced reactors (i.e., through design certification), they share more in common with existing plants, and will be subject to many of the same forces which have affected existing plants. The large evolutionary reactors will still probably require a lengthy construction cycle, and as a result may wind up being impacted by unforeseen external events. In addition, ratemaking regulatory agencies may not be entirely receptive to new nuclear plants which share much in common with existing facilities due to their mixed experience over the past decade. Should either or both of these factors come substantially into play, the large evolutionary plants will be overtaken by events and the truly advanced reactors now being designed will probably be deployed instead.

The smaller, near-passive advanced LWRs will also likely be ready for deployment before the turn of the century. Such designs include the Westinghouse AP-600 PWR, the General Electric SBWR, and perhaps the ABB-Combustion Engineering PIUS-600 PWR, as well as other designs such as the AECL Technologies CANDU-3 design. These designs generally emphasize modular construction (resulting in shorter construction cycles and better quality control), improved economic performance (high availability and capacity factors), and improved safety (formal emphasis on severe accidents and some near-passive to passive systems). These plants should be more palatable to utility ratepayers and shareholders, as well as to the general public which is concerned about the safety of reactor operation.

Moderate-Term Directions -- Eight to Fifteen Years

Additional smaller reactors should become available beginning around the turn of the century and into the early years of the 21st century. These designs include the ABB-Combustion Engineering PIUS-600 PWR and the Rolls-Royce/ABB-Combustion Engineering Safe Integral Reactor PWR concepts.

Long-Term Directions

For the long-term, truly advanced reactors should be available for deployment. Such designs are expected to be small reactors (of the order of 100-200MWe), modular in concept, and making extensive use of passive safety concepts. These designs include the General Atomics Modular High Temperature Gas-Cooled Reactor (MHTGR) and the General Electric Power Reactor Innovative Small Module (PRISM) liquid metal reactor.

If nuclear power is to have a long-term future, and/or play a significant role in reducing acid rain problems and greenhouse gas emissions, it seems evident that breeder reactors must eventually be deployed. This suggests a role for the PRISM-type plant, as well as possibly a breeding variant of MHTGR.

What Attributes are Needed for a Successful Advanced Reactor?

Based on the considerations discussed above as well as the experience of the author, it is suggested that the following attributes are needed for a successful advanced reactor:

(a) A design which explicitly accounts for severe accidents, including severe external events (not necessarily limited to contemporary design basis events), and which results in a frequency of severe core damage substantially lower than in current plants. The goal for the frequency of severe core damage should reflect a reasonable assurance that a severe core damage accident will not occur during the operating lifetime of a "fleet" of such plants. Considering the availability of experience with existing plants (including a wealth of severe accident vulnerability knowledge) and an emphasis on passive or near passive safety systems, it should be possible to achieve severe core damage frequencies on the order of 1×10^{-5} per reactor-year and perhaps significantly better (in the range of 1×10^{-6} per reactor-year). Modular plants (such as MHTGR or PRISM) may have to achieve lower frequencies on a per-module basis to be equivalent to large units (for example, four MHTGR modules are roughly equivalent to one AP-600 plant).

(b) A design which explicitly accounts for severe accidents in terms of accident mitigation, resulting in a very low conditional likelihood of a substantial fission product release given a severe accident. Smaller reactor sizes (particularly modular reactors) should help significantly in this regard, as should a focus on passive mitigation systems in advanced reactors.

(c) A design which utilizes near-passive and passive concepts (whose safety and reliability are demonstrable by experiment and/or full-scale test) for both accident prevention and accident mitigation to the maximum extent feasible. The design should also explicitly account for the severe accident phenomena relevant to the coolant type (light water, heavy water, helium, liquid sodium, etc.).

(d) A design which allows for a suitably long time between refueling outages, with a balance struck between refueling outage duration and refueling outage frequency so as to optimize both availability and capacity factor performance.

(e) A design which emphasizes modular construction and exceptional quality control.

(f) A design which deemphasizes the importance of maintenance and human reliability more generally to assure that safety functions are performed with acceptable reliability, and to assure that passive safety characteristics are not compromised by design, manufacturing, or installation defects.

In addition to these characteristics, the ability to breed fuel would be most desirable for the long term, provided that related safety and proliferation concerns can be satisfied.

It is further suggested that key factors in gaining public acceptance are the early public availability of design information on advanced reactors and, once there has been time for an initial review of this information, the occurrence of a period of dialogue between the designers and parties concerned with safety issues. This will promote the early identification and resolution of potential safety issues – most importantly, occurring at a time when tradeoffs in design and accommodative design changes are more easily and less expensively accommodated – and the sharpening of the residuum of safety issues for resolution in the design certification rulemaking (to the extent that significant issues remain). Late disclosure of significant design details or outright secrecy, on the other hand, could breed distrust and unnecessarily and profitlessly (for all parties) extend litigation on the advanced reactor designs.

Given the experience with existing reactors – which includes both very good and very poor experience, the latter including periodic demonstrations that safety questions remain, overall lower availability and capacity factor performance compared with early predictions, and periodic demonstrations of utility management incompetence – the vendors and their potential customers can scarcely expect their critics to welcome new reactors with open arms if they insist on withholding information on the very design attributes they will wish to assert make these new designs publicly acceptable.[6]

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[6] I hasten to add that the practices of the vendors vary widely in this regard to date. For example, the degree to which significant (albeit preliminary) design information is publicly available on the AP-600, SBWR,and PRISM designs compares rather poorly with that available on the PIUS-600 and CANDU-3 designs.

ADVANCED NUCLEAR POWER OPTIONS: THE DRIVING FORCES AND THEIR RESULTS

DISCUSSION

Much of the discussion of this session focused on the issues of safety and economics of advanced reactors and their interrelations. While some participants held the view that near-term improvements of future technology are likely to be focused upon safety rather than economics, there was a strong contention that achievement of substantial improvements in both areas are in fact compatible. Rather than describe reactors as being economic performance-driven or safety-driven, they could be characterized in terms of time-frames for use, many disparate incremental changes, and evolutionary processes. The view was expressed that large, evolutionary LWRs incorporating some passive safety features would be both safer and more economical than those in current use. This would result from the future advanced LWR program in the United States being based on the Utilities' LWR Requirements Document, a comprehensive compilation of feasible design actions which could make plants cheaper and safer, and also make them easier to operate and maintain. This work is based upon the lessons of past experience.

Considering safety separately, there was some disagreement concerning the best course to achieve improved safety levels. Participation by strong advocates of concepts, variously promising active, semi-passive, passive, and inherent safety brought to light several issues which were discussed further in the session following the papers on Demonstrations of Nuclear Safety and Licensing by Tests (Session 5). Among these was the issue of potential human error, even with passive or semi-passive systems. It was pointed out that design changes have come about to increase the mechanical reliability of essential safety functions, while there has not been corresponding progress in the human influence on those functions. The primary direction of concept evolution has been to remove humans as active components in the immediate response to transients in accidents, yet there remain many subtle (hopefully rare) ways in which humans can have a profound negative impact on reactor operational safety. Examples cited included errors in fabrication and construction, maintenance errors, and the possibility of disabling safety systems when switching between operational modes, such as occurs during with refueling.

It was also stated that, while passive systems may be more forgiving with regard to special accidental events like loss of coolant or loss of heat sink, such as one reactor in the former German Democratic Republic that experienced a six hour loss of heat sink with no severe core damage, they may not be any more forgiving of events like external terrorist aggression. Notably, the general trend with evolution of other technologies is away from passive safety systems and toward more sophisticated active systems involving more electronics and automation.

One participant expressed the expectation that, once a detailed analysis of all of the accident event trees of a new design had been conducted, it might come out that all so-called passive and semi-passive concepts may be defined as being semi-passive. If any consensus was reached, it was that use of a combination of passive and active safety features should and would be the likely path of future technology advancement.

It was interesting to note that in this and later discussions, those participants generally recognized as skeptics of nuclear power, including the session respondent, favored the use of passive or semi-passive safety features for a variety of reasons. These included reducing the uncertainty associated with expected risks and their ability to be tested under demanding conditions.

There was a general reluctance on the part of many participants to accept and use the term "inherent" when discussing reactor safety, as it has led to misunderstandings in public fora in the past, and is in fact considered to be an implausible goal by many technologists. But one participant clarified the issue by pointing out that "inherent" and "absolute" do not mean the same thing, although popular use of the terms in discussion of nuclear safety has tended to make them synonymous, as has the fact that few reactors can claim to meet the criteria of inherent safety. He went on to state that there can be no such thing as absolute safety when dealing with confined energetic, dangerous materials, but that the term "inherent" does have a proper place in the vocabulary. It would apply to a reactor having: 1) fuel that is extremely tolerant of high temperatures, as it would be inherently forgiving of a loss of coolant accident, 2) a coolant that is inherently non-corrosive, and 3) a heat sink which is inherently stable and very large which will have a high tolerance for heat. When you put these all together in a reactor that is sized so that it is inherently unable to go beyond fuel-failure temperatures, you have a concept that is well described as inherently safe.

The discussion of theories of safety led naturally to the issue of determination of safety and risk assessment. As this subject was the focus of Session 5, this issue is not dealt with in depth here, although a few salient points are presented. It was stated by Prof. Golay that, as far as advanced designs are concerned, it is premature to make a statement concerning expected risk values because all potential contributors to risk have not yet been identified thoroughly. Of the two methods of risk assessment discussed in the Conference, probabilistic risk assessment (PRA) and demonstration by test, there was an approximately even split among the technologists and also among the skeptics as to which path to emphasize.

Attendees from the nuclear power industry pointed out that the methods of PRA are not sufficiently mature and standardized that PRA can be used to compare two different types of reactors. The resulting risk values can not be compared validly. Conversely, requiring safety demonstrations by test might introduce a fatal delay of ten to fifteen years in implementation of new technology. Mr. Sholly stated that PRA is the method to use, and that it should be used iteratively throughout the design process in refining a power plant concept.

The most common theme throughout the Conference was the current lack of public acceptance and confidence in the nuclear power program in the U.S. A great deal of discussion focused on probable causes and possible cures. It was generally recognized that one of the goals of advanced reactor development is the restoration of public confidence in the technology. However, several skeptics of the industry pointed out that its problems are institutional as well as technological. One of the skeptics stated that there has been too much secrecy concerning nuclear technologies and their use in the past, although that trend is changing for the better. He cited negative aspects of the DOE's own reactor program coming to light after being held from view for a decade, and becoming part of the public view of how reactors are run. He went on to state that a regulatory system in which we would have total confidence is an absolute requirement for any kind of technology that has the inventories of dangerous materials of the sort that accumulate in reactors.

Discussion in this and subsequent sessions indicated the perception of a lack of confidence in the Nuclear Regulatory Commission on the part of the public [although there were vastly differing perceptions of what that level of confidence is (see the Session 3 discussion)]. One of the causes proposed for that lack of confidence is confusion concerning the NRC's Safety Goals, and whether they would apply to future reactors as well as to those in existence today. A Commissioner of the NRC present at the conference clarified this by explaining that a single version of the Safety Goals will apply to both classes of reactors. These goals include the qualitative goals, the two quantitative health objectives, and the criteria for large release (see Appendix C). He went on to concur with the need for openness in the NRC's activities, stating that there is a requirement for the NRC to review proprietary information which must remain confidential from time to time, but the agency has to be careful that it is not overdone.

Mr. Sholly stated he was aware of the promulgation of the Safety Goals, but did not feel that a reactor designed to meet them would necessarily please anyone, and it also may not be economic in the long run. He saw the goals as a good aiming point in operation of the existing plants, but not as being useful for the advanced plants. In response to this, the Commissioner stated that the NRC has defined "how safe is safe enough" from the standpoint of use of the nation's resources in the effort to reduce risk. Further, the NRC encourages designers and operators to go beyond that standard. However, such encouragement does not mean that the NRC should raise the acceptance requirements in order to reflect technological improvements.

One exchange in this session was particularly important. A participant addressed a member from an environmental protection group regarding Mr. Sholly's criteria: "I particularly wanted to be present at a meeting between those who like nuclear energy and those who do not. And so I was very interested in Mr. Sholly's remarks and would like to address you with the following points. I myself have long felt that the NRC does, by and large, a very good job at establishing standards, and that despite the conformance of American reactors to NRC standards, there are a lot of people in the United States who just do not like nuclear reactors. They think reactors are too dangerous. And so I have argued that the key players, who may not even realize how key they are, are what I have called the 'skeptical elite,' people like Mr. Sholly. I think that the survival and expansion of nuclear energy use, which I feel is very desirable--especially in view of the greenhouse effect--depends upon having the skeptical elite coming around and saying, 'Well, now we have something that we like, and we are going to support nuclear energy.' I think that Dr. Beyea in his U.S. Senate testimony a few years ago said that such statements are more than one could ever expect from this skeptical elite.

"But Mr. Sholly offers an opening here, and I would like to refer to page six of his very excellent paper, where he lists what attributes are needed for a successful advanced reactor. The question I would like to put to you and to the other members of the skeptical elite is this: Suppose these attributes are achieved. Does that mean that your organization would say, 'Yes, we now have something that we accept and will support in view of concerns about the greenhouse effect?' The same question would go to other environmental protection groups."

The response: "I can only speak for my organization. We set out in our public documents the improvements that would make nuclear power acceptable. These include technical improvements of a high order compared to what we have seen in the past. More important would be changing the safety regulatory system, demanding that it operate much closer to the standard of what any regulatory system should do. We have been troubled over the years with not only the nature of the regulations that have been implemented, but also with the fact that the NRC does not enforce its own rules in many cases. We have taken them to court and have won. A regulatory system in which we would have absolute confidence is a requirement for any kind of technology that has the inventories of dangerous materials of the sort that accumulate in reactors.

"Public acceptance is another absolute requirement. A high level of public anxiety has been growing over the years. The percentage of public that thinks nuclear power is desirable has been dropping steadily for over twenty years. In fact, the Three Mile Island accident did not cause a great perturbation in this trend. Now something like half of the people do not want to see an expansion, and a significant population wants to see it phased out. Given satisfaction of these and Mr. Sholly's requirements, I cannot see any deep intellectual problems and personally no moral objections to endorsement of the technology. But whether these goals can be satisfied are really open questions.

"The big problem which the industry faces is the possibility of an accident. My personal view is that risk of a substantial accident is unacceptably high. Such an accident means, for example, an inadvertent release of radioactivity or an accident on the scale of TMI, or perhaps even a smaller one, would effectively shut down nuclear power for the foreseeable future. My question is: 'Should a country proceed with a program that could have one or a series of very substantial or catastrophic events that could blight its prospects?' I think not, and with some 110 reactors operating, we must bring the risks down."

The participant pressed his point: "If a set of technical criteria as put forth by Mr. Sholly were achieved, would that change your mind?"

The response: "If you simply refer to changes in the technical aspects of reactors, that is not enough. It is not the technical problems that plague this industry, it is the institutional problems. Those problems have to be solved too. These problems are those of a regulatory process in which the 'skeptical elite' do not have confidence. Also, in the nuclear enterprise there has been too much secrecy, although that is been improved. You can see the fruits of this in DOE's own reactor program. After being hidden from view for a decade, the mismanagement comes to light and that knowledge becomes part of the public view of how reactors are run. I personally think it is a mistake to use political muscle to force through something like nuclear technology that the public does not like basically."

The participant then summed up his viewpoint: "The public will not change until the skeptical elite change."

In addition to the criteria presented by Mr. Sholly and those discussed above, other criteria were identified which might be considered to be necessary, although perhaps not sufficient, to gain the support of the skeptics and the public. These include proof of safety by demonstration rather than PRA, creation of a reactor design that would not require evacuation, highly capable mitigation of severe accidents, assurance of reliable transitions between operational modes with associated operator actions, highly reliable quality assurance programs, assurance against flaws in manufacturing, use of automatic monitoring systems that would assure that safety systems will be made available after operational mode switching, and reduced uncertainty in safety and economics.

SESSION TWO

MODULARIZATION AS AN AVENUE TO ECONOMIC COMPETITIVENESS

MODULARIZATION AS AN AVENUE TO ECONOMIC COMPETITIVENESS

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RESPONSE BY

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INTRODUCTION

Session 2 – Modularization as an Avenue to Economic Competitiveness

The purpose of this session is to scrutinize the reality of modularization as a means of improving nuclear power plant economics - both in terms of benefits which it can realistically deliver and potential difficulties. Modularization is particularly important for concepts trying to improve safety by use of passive design features. Because of the limited efficiency of many such features the resulting nuclear power plant concepts typically have low power capacities. Consequently, their expected specific capital costs are unusually high, and may render them uncompetitive. Interestingly, the most difficult design challenge for such technologically innovative concepts is not that of improving safety, it is that of being economically viable.

The main avenues suggested for making such plants economically attractive are simplification and modularization. Simplification is a design strategy of attempting to minimize the amount of hardware in a plant, in a fashion still permitting essential functions to be performed efficiently. The rationale for this design approach is that plant equipment which is not needed does not have to be purchased, or kept reliable, or thought about during operations, or repaired, or considered as a contributor to accidents. The degree to which this strategy will succeed remains to be seen.

The strategy of modularization is suggested more often as a means of reducing the capital cost of a nuclear power plants, regardless of the performance emphasis of the concept. In its most effective form the modularization strategy encompasses three complementary elements:

- Use of a standardized design, as a means of justifying greater investment for factory fabrication of modules and to capture the economies of serial production

- Offsite fabrication of the substantial portions of the plant in the form of modules to be integrated at the plant site

- Use of a factory environment for module fabrication, taking advantage of the higher productivity and work product quality permit in such a setting.

Achieving the benefits of modularization is easier in a stable project planning environment and it requires more initial investment in design planning and fabrication facility investments than with the field-erected construction approach.

Both papers of this session were provided by Vice Presidents for Engineering of large shipyard firms. The keynote paper of this session was presented by James Cottrell of Avondale Industries, Rumson, NJ, and the respondant paper by Patrick Keene of the Pascagoula, MS, shipyard of Litton Industries. These two authors were invited because they were able to discuss their respective experiences in large facility modularization from differing perspectives. Avondale has been a participant in the AP-600 PWR program, and Litton has remained uninvolved in the civilian nuclear power enterprise. Thus, the fact that both papers conclude that modularization holds substantial potential benefits for the future nuclear power program is particularly important.

In the subsequent discussion consensus concerning this conclusion was readily apparent. Consequently, the discussion diverted somewhat from the theme of the session. This occurred particularly in the direction of the topic of public acceptance, reflecting the consensus of the participants that the most important impediment to the future expanded use of nuclear power technology is aversion to nuclear power among the public.