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The nuclear industry's transition to risk-informed regulation and operation in the United States

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Abstract

This paper summarizes a study of the transition of the United States nuclear industry from a prescriptive regulatory structure to a more risk informed approach to operations and regulations. The transition occurred over a 20 yr period in which gradual changes were made in the fundamental regulations and to the approach to nuclear safety and operations. While the number of actual regulatory changes were few, they are continuing. The utilities that embraced risk informed operations made dramatic changes in the way they approached operations and outage management. Those utilities that used risk in operations showed dramatic improvement in safety based on Institute of Nuclear Power Operations (INPO) performance indicators. It was also shown that the use of risk did not negatively affect safety performance of the plants compared to standard prescriptive approaches. This was despite having greater flexibility in compliance to regulatory standards and the use of the newly instituted risk-informed reactor oversight process.

Key factors affecting the successful transition to a more risk-informed approach to regulations and operations are: strong top management support and leadership both at the regulator and the utility; education and training in risk principles and probabilistic risk Assessment tools for engineers, operators and maintenance staff; a slow and steady introduction of risk initiatives in areas that can show value to both the regulator and the industry; a transparent regulatory foundation built around a safety goal policy and the development of a strong safety culture at the utility to allow for more independence in safety compliance and risk management.

The experience of the United States shows positive results in both safety and economics. The INPO and NRC metrics presented show that the use of risk information in operations and regulation is marginally better with no degradation in safety when plants that have embraced risk-informed approaches are compared to those that have not. The use of risk-informed approaches allows both the regulator and the industry to focus on important safety issues. The transition to risk-informed regulation also required a "culture change" by both the regulators and the utilities. Caution should be taken, however, since the basis of the US transition to risk-informed regulation is founded on a long history of a regulatory structure and practices that have matured the industry to a point where the next step could be taken.

Keywords: Risk-informed regulation; Configuration risk management; Safety metrics

1. Introduction

The objective of this study is to understand the transition to risk-informed regulation in the United States. Since the regulatory systems in many countries are traditionally prescriptive, this study should assist these countries in understanding how and why the transition to risk-informed regulation occurred. This study will provide a deeper understanding of the reasons for the change, the philosophy of risk informed operation and regulation and current practices with specific examples of how these changes were implemented by both the regulator and the utility.

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2. Development of risk informed regulation in the US

The publication of WASH-1400 (The Rasmussen Report or The Reactor Safety Study) [1] in 1975 was the beginning of the process of creating a risk-informed regulatory (RIR) process. The approach developed in WASH-1400 indicated that it was possible to create quantitative measures of plant safety. One of the most important results of WASH-1400 was the determination that there were other accidents than the design basis accidents, much smaller in consequence, but much more likely to occur, that dominated the risks. In particular, the small break LOCA was identified as a dominant accident sequence.

Following the publication of Wash-1400, the Lewis Committee [2] was commissioned to review the Rasmussen Report. The Lewis Committee identified certain shortcomings in the treatment of uncertainties that questioned the readiness to use risk in technical decision making. The sense of the Nuclear Regulatory Commission (NRC) at that point in time was to be cautious and the staff was instructed that the regulatory decision could not be solely based on PRAs [3]. All decisions were required to have deterministic basis. During this period, the NRC staff needed to prove that they never made a decision solely based on PRA.

The reluctance to use PRA in licensing decisions was based on several factors. In addition to the uncertainty concerns expressed by the Lewis Committee, there was the newness of the approach and lack of industry experience. The NRC itself lacked much expertise in the methodology. The TMI accident in 1979 was a watershed event in changing the attractiveness of PRA because the event was similar to a small break LOCA which WASH-1400 identified as a risk dominant type of event. The industry became interested because the physical damage to the plant and economic damage to the owners was very large which prompted their need to better understand the risks of operation.

In response to the TMI event several important initiatives were pursued. The BWR Owners Group, with the collaboration of The Nuclear Energy Institute, began an effort to develop PRAs for BWRs. The nuclear industry created the Industry Degraded Core Rulemaking (IDCOR) program to better understand the likelihood and consequences of events leading to degraded cores. Several other PRAs were completed and these lent support to the usefulness of the approach to better understanding safety. In 1986, the safety goal policy statement [4] was issued as was the Severe Accident Policy statement [5]. By 1988 the NRC had completed an analysis of the use of PRAs and found them to be very useful for insights into risks and problem identification. As a consequence of its findings, the NRC issued Generic Letter 88-20 [6] requested each licensee to conduct an individual plant examination (IPE) that would allow for identification and analysis of plant safety vulnerabilities.

In 1991, NRC Chairman Dr. Ivan Selin, took the lead in promoting simplification of NRC regulations in response to the request of utilities to consider adjusting regulations to better reflect the safety significance of various systems, structures and components (SSCs). He began a review that ultimately led to the "Maintenance Rule" in 1991 [7] which was one of the first major application of risk insights in regulations. Although risk insights were used in the development of other regulations such as the Station Blackout Rule and Anticipated Transients without Scram requirements in the late 1980s, the Maintenance Rule enabled utilities to take advantage of their IPEs in developing a risk-informed maintenance programs. The interest in risk-informed regulation was also supported by Chairman Jackson, who followed Dr. Selin. The PRA policy statement of 1995 [8] was developed under Chairman Jackson's leadership, and it was a bridge between regulations and the safety goals. The policy statement led to Regulatory Guide 1.174 "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis" [9]. In 1996 the direction from the Commission was to begin to implement the use of PRA. No regulations were changed, but licenses were amended using risk as bases. The positive experience with maintenance rule influenced the pace of the transition to more risk informed approaches.

Some believe that the major drive by the regulator to enter into risk-informed regulation was the direct result of Millstone Nuclear Power Station design basis issues in the early 1990s. It is their view at the time that NRC Chairman Shirley Jackson, with her compliance focused implementation of the regulations in response to Millstone's issues, provided the impetus for the regulator to focus more on those systems that are important to safety rather than everything regardless of safety significance [10].

Following Chairman Jackson, Chairman Richard Meserve, as well as the other commissioners, continued to support the expanded use of risk information in regulatory decision making. During this period many industry "pilot programs" were initiated to take advantage of risk to improve the safety requirements. One of the most ambitious programs implemented recently was the risk informed reactor oversight process (ROP) which allowed the Commission significant regulatory discretion based on the risk significance of the activities being regulated. While in the past, the NRC had significant subjective discretion, the ROP provided the NRC and the licensees an objective measure for assessing the safety significance and thus determining the nature of regulatory response of NRC violations based on safety not subjectivity. It also provided a very publicly transparent process for the monitoring of nuclear power plant operations. The present Commission under Chairman Nils Diaz continues to aggressively expand the use of risk with long-term goals of revising the existing regulatory system to a risk informed system. Currently 10 CFR Part 50.46 (the Emergency Core Cooling System Rule) is being risk informed. It appears that the transition to a risk-informed regulatory system is well underway led largely by the

Chairmen of the NRC and supported by key champions in the industry.

3. Implementation strategies at NRC and the industry

3.1. NRC implementation strategy

The consistent comment from both the NRC and the industry was that without top leadership support in each organization, the introduction of risk-informed regulation could not be done. In addition, there needs to be an over-arching policy guidance in terms of a safety goal or regulatory framework in which to make decisions. One of the biggest obstacles to overcome was that some staff members believed the application of risk information gives away safety margin. Addressing this issue and others is necessary as part of the integration of risk information into regulation. This is a long-term process requiring a great deal of communication between the staff of both the utility and the NRC, training and a transformation of culture.

NRC was struggling to apply more risk-informed methods after the individual plant evaluations (IPE) were performed in the post TMI era. These IPEs were of varying quality but did demonstrate the value of the tool to identify risk vulnerabilities. Based on the success of the IPE program, team leaders within NRC research developed a probabilistic risk assessment policy in the early 1980s and nuclear reactor regulation (NRR) began to implement changes in the 1990s. One of the first major applications of risk in the regulations was the Maintenance Rule in 1991. The Maintenance Rule was NRC's attempt to uniformly introduce the notion of risk into a process of assessing which equipment has high safety significance and establishing appropriate levels of maintenance. While many utilities had reliability centered maintenance programs (RCM), this rule made risk assessments a part of the formal regulatory process.

Based on interviews with NRC staff, they reported that they had an internal struggle with risk-informed regulation since it also required a culture change [11,12]. The NRC staff role was changed from requiring systems that were supposed to work (at least deterministically on paper with no failure assumed except a single failure) to those which provide a high level of assurance considering possible failures for all systems and components. This was a significant change since the staff had a great deal of difficulty in dealing with determining "high level of assurance" as opposed to what they had to do in the past which was to confirm that systems were in place for certain functions with the assumption that they would perform their intended function. While the NRC staff did monitor the effectiveness of equipment to perform its safety function, their role was none the less, changed to assessing the overall consequence of failure if the specific piece of equipment did not operate as designed. In order to gain acceptance by the staff of PRA techniques, NRC management implemented an agency-wide training program for the staff not only on the principles of PRA but also on its applications. This is viewed as an important element in acceptance of the tool.

One of the important observations is that not only must the NRC Chairman and the rest of the Commissioners be committed to the change; they must also have people in their organization including senior management who must also share the vision. This transformation is a cultural change in the way people perceive their responsibilities as they implement they oversee the safety of nuclear power stations. It is vital to have an integrated leadership team supporting this transformation since without such a commitment; change would be difficult, if not impossible.

3.2. Industry implementation strategy

Industry adoption of risk analyses was initially driven by the NRC with the IPE program. Some utilities found that the probabilistic safety analysis (PSA) tool was quite useful in understanding plant risk and performance and became champions of the use of the PSA tool in their operations. These utility leaders began to work with similar leaders and champions within the NRC to gain increased use of the tool in regulation and operations.

While there was initial industry opposition to the risk-informed regulation or the use of risk since it was judged to be more of a burden, soon most utilities began to see its value. What happened in the US was that a small group of utilities who were interested in the development of risk-informed technologies and its use in the regulatory arena formed a small owner's group-type organization to further develop not only the technology but also the applications. This small group influenced the overall industry position relative to risk-informed regulation and ultimately provided the focus for the Nuclear Energy Institute (NEI) to begin an active dialog with the regulator on the adoption of the risk-informed regulation and modifications to key rules.

The introduction of risk information started with small initiatives to show early successes leading to other more significant efforts. It is generally agreed that the Maintenance Rule and its application was the first major attempt at using risk information in developing a regulatory compliance strategy. Subsequent pilot programs on specific targeted issues such as graded quality assurance, in-service inspection, integrated leak-rate testing, are all examples of a specific utility taking on the initiative to introduce a risk-informed approach. These pilot programs were used to develop implementation practices for risk-informed approaches and to show that safety would not be compromised by the use of risk information.

The nuclear industry through the NEI is actively participating with the NRC in development and improvement of regulations and guidance using risk principles. The role of NEI is judged to be an important part of the implementation of new regulatory approaches since no individual utility would be subject to any retribution by the regulator. The collective solutions established by NEI and the financial support to pilot plant utilities for the initiatives provided for cost-effective mechanism not only to introduce new changes to regulations but also to share the cost of its deployment.

Typical implementation strategies that utilities used are:

- Early reluctance of the operations staff to accept the risk approach was quickly overcome by showing how this tool could help them manage risky operations. Initially they thought it was just another thing to do and they did not embrace it immediately.
- Utilities found that the development of a risk monitor was an important part of culture transformation. Risk monitors were first used as an aid to the operations department for simple plant status information. The use of the risk monitor was then typically expanded to the maintenance organization. The maintenance department began to use the risk monitor to identify and improve the scheduling of work to minimize risk and vulnerabilities of the plant.
- The acceptance of PSA by the utility was met with some challenges which senior management needed to address. Beyond the resistance of traditional engineers, there was a general lack of understanding of the tool. In response, a site-wide training program was initiated not only on the tool but also how it is to be used. This training was expanded to the general training program for all plant staff.
- To reinforce the importance of risk management, during their morning status reports senior plant management would require a discussion of the risk status of the plant and what quantified changes in risk levels would occur during the day based on plant operations such as taking systems out of service for repair or maintenance.
- Some utilities have included risk performance metrics as part of their employee evaluation and bonus programs. These metrics were used to demonstrate the importance of managing risk to all employees and to have employee ownership in the risk status of the plant. Based on indications, this practice has been successful in transforming the culture of the plant into a more risk-informed way of thinking about their jobs.

4. Metrics on safety and operational performance

The transition to risk-informed regulation and operations can only be accepted if it can be demonstrated that this approach to safety is at least as good, if not better, than the past deterministic standards that have been part of the industry for over 40 yr. Performing this analysis is difficult due to the limited number of serious events in the industry. However, the industry and the regulator have developed operational performance metrics that can be used to make some quantitative comparisons.

The available metrics selected are the INPO performance indicator index [13] and NRC's accident sequence precursor (ASP) index [14]. To assess the impact of the use of risk management in regulations and operations, these metrics are tracked over time for the industry and separately for utilities that have embraced risk as a management tool compared to those that have not to determine whether safety and overall performance are improved by the risk-informed approach.

4.1. INPO performance indicators

Trend of INPO performance indicator index [13] from 1995 to 2004 are compared for US nuclear power stations. INPO has formulated a performance indicator index for use in tracking overall plant performance. The index is calculated using a weighted combination of INPO performance indicators and has a value between 0 and 100. *Stations with higher indices generally have better performance in areas monitored by these indicators.*

The following indicators are used in the index calculation:

- Unit capability factor.
- Forced loss rate.
- Unplanned automatic scrams per 7,000 hours critical.
- Safety system performance indicator.
- PWR high pressure safety injection system.
- PWR auxiliary feedwater system.
- BWR high pressure injection/heat removal system.
- BWR residual heat removal system.
- Emergency AC power system.
- Fuel reliability.
- Collective radiation exposure.
- Chemistry performance indicator.

The performance indicator index for a unit is calculated as follows:

(1) Based on unit performance, a value between 0 and 100 is assigned for each indicator using the performance ranges and formulas that is determined in "INPO Performance Indicator Index—2003."
(2) The point value for each indicator is multiplied by the corresponding weighting factor to determine the indicator's contribution to the unit index.
(3) Weighted point values for individual indicators are summed to determine the overall index for the unit.

For this analysis, a determination of whether trends existed was attempted. To evaluate the trend, the slope of index during recent 10 yr was calculated using the least squares method. The average index during recent 5 yr are calculated for each result.

These metrics are grouped into two groups—utilities that have adopted aggressive risk management practices (risk active) and those that have not incorporated risk informed management techniques (risk inactive).

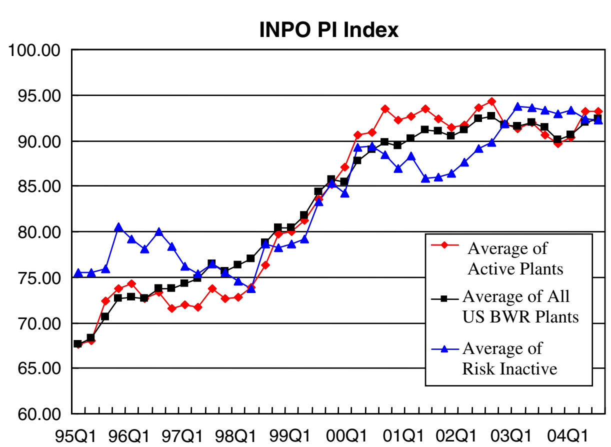
There are 35 plants that are judged to be implementing risk information (active). A total of 19 plants are judged not to be using risk information aggressively in operations (inactive). There are also utilities in which no conclusion could be reached about the degree of adoption of risk-informed approaches but are included in the overall averages.

From the results of these analyses, both safety and operational performances in risk active plants proved to have been more drastically improved than those of all US plants and risk inactive plants. While the risk inactive plants also had significant improvement but the risk active plants showed more dramatic gains because, as a group they started at lower INPO PI levels. Shown on Figs. 1–3 are the INPO standard performance indicators for all US plants, BWRs and PWRs, respectively as categorized by the level of use of risk in operations.

In reviewing these results, several additional observations can by made. In the US, significant pressure was placed on the plant operators to improve performance due to competition and, in some regions, economic deregulation. These pressures motivated the management of the plants to increase operational efficiencies by reducing outage lengths and focusing on preventive maintenance to reduce forced outage rates. NRC's ROP was implemented for all licensees which provided a more risk informed focus on operations. Reliability centered maintenance programs were also introduced by all utilities. During this period, the NRC changed regulatory practices employing more risk informed approaches. When one combines both the regulatory and the industry risk informed efforts, the conclusion that can be reached is that the introduction of risk informed approaches by both the regulator and the industry did not reduce safety as some believed would have happened.

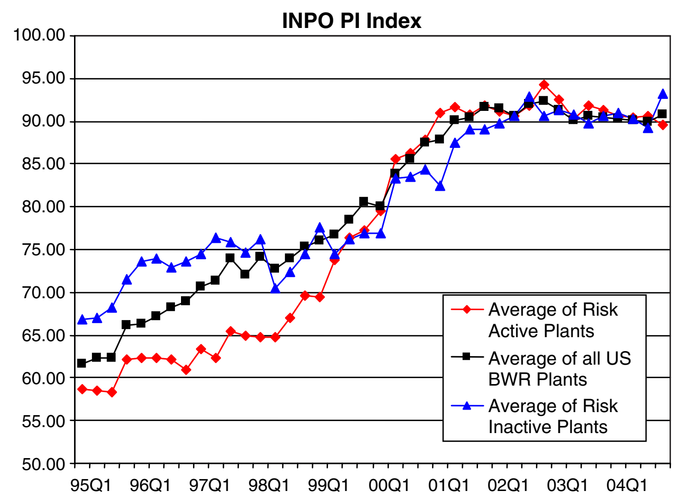
4.2. NRC accident precursor index

Accident precursors are also indicators of safety performance. The NRC has tracked accident precursors since 1979. The NRC systematically evaluates US nuclear power plant operating experience to identify, document and rank the operating events that were most likely to lead



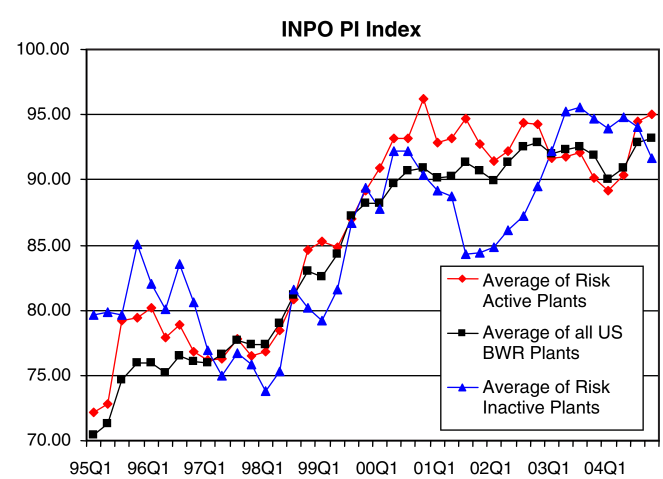
	Slope (1995-2004)	Average Index (2000-2004)
Risk Active Plants	0.73	91.80
All US BWR Plants	0.68	90.61
Risk Inactive Plants	0.52	89.74

Fig. 1. Standard INPO performance indicator indices of all US plants.



	Slope (1995-2004)	Average Index (2000-2004)
Risk Active Plants	1.07	90.00
All US BWR Plants	0.84	89.36
Risk Inactive Plants	0.68	88.31

Fig. 2. Standard INPO performance indicator indices of BWRs.



	Slope (1995-2004)	Average Index (2000-2004)
Risk Active Plants	0.56	92.69
All US BWR Plants	0.60	91.22
Risk Inactive Plants	0.44	90.45

Fig. 3. Standard INPO performance indicator indices of PWRs.

to inadequate core cooling and severe core damage (precursors). Trend of annual ASP index [14] from 1996 to 2003 are compared.

Fig. 4 depicts trends of the annual ASP indices of risk active plants, all US plants, and risk inactive plants. Annual ASP index represents a total conditional core damage probability (CCDP) of all precursors in a given year divided by the total number of plants, which means smaller ASP index is better.

The peak of risk active plants in 1996 is due mainly to the loss of offsite power (LOOP) with emergency diesel-generator B unavailable in Catawba 2. The peak of risk inactive plants in 2001 is mainly because of the potential common-mode failure of all auxiliary feedwater (AFW) in Point Beach.

The peak of all US plants in 2002 is mainly due to the cracking of control rod drive mechanism (CRDM) nozzle in Davis-Besse. The peak of all precursors in 2003 is due to the reactor trip and loss of offsite power occurred as a result of the power blackout of northeast United States. The ongoing analyses of events involving cracks in the CRDM housings are included into 2000–2002. And there are 22 precursors in 2003 for which preliminary analysis is underway and not included in Fig. 4.

For risk inactive plants, there are few precursors during 1997–2000. However, during 2001–2003, ASP indices are over $10^{-5}\,\mathrm{RY}^{-1}$. For risk active plants, the annual ASP indices are below $10^{-5}\,\mathrm{RY}^{-1}$ except 1996.

The number of important precursors that influence each index is limited, and each index does not necessarily represent the performance of each group. The accident precursor data is quite limited and is dominate by high visibility events thus no significant differentiators exist between risk active and inactive plants. However, from this limited data, we can at least conclude that the safety levels in risk active plants are not degraded compared to those of risk inactive plants.

Obtaining metrics to judge the overall safety impact of risk informed regulation and operations is difficult due to

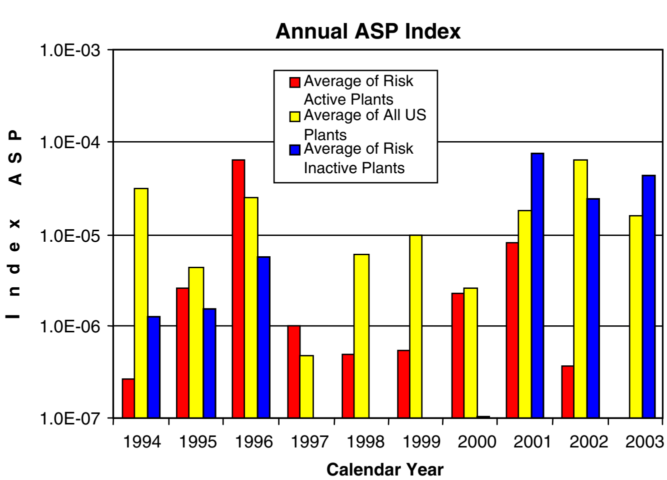


Fig. 4. Accident precursor index comparison.

the limited number of negative events. The available data from the NRC and the Institute of Nuclear Power Operations demonstrates that the use of risk information can improve overall safety and operating performance. What can be concluded was that as the regulatory system moved into more risk informed approaches and as utilities began to use risk management in operations that there was no degradation in safety which is what conventional wisdom would suggest by those that are skeptical of the approach. Thus the lack of degradation in safety is judged to be a significant positive finding.

5. View of public advocacy group and public

In order to gauge the understanding and support for the transition to risk informed regulation in the United States, several public advocacy groups were interviewed as well as a local community oversight organization of a nuclear power station. No attempt is made to dispute their positions or opinions but only to report their views based on the interviews.

5.1. Union of Concerned Scientists (UCS)

The overall position of the UCS [15] is that risk information in regulation can be a useful tool to determine priorities but not to eliminate addressing identified problems. The US Advisory Committee on Reactor Safeguards (ACRS) reviewed the UCS report entitled "Nuclear Plant Risk Studies: Failing the Grade" upon which much of the current position of the UCS is based. In general, the ACRS disagreed with the conclusions of their report regarding the value of using risk in regulations since the UCS's conclusions were based on early Individual Plant Evaluation PRAs. The ACRS's overall position can be best summarized by the concluding line in their letter [16]: "…it would be a disservice to the nation if the agency (NRC) ignored the valuable insights that this (PRA) technology provides."

The major concerns that UCS has with NRC pursuing risk regulation as determined by a recent interview are:

(1) The expansion of the use of pilot plant results to other utilities who may not be as rigorous or knowledgeable in the application of the risk informed approach.
(2) If the application of risk in regulations is voluntary on specific initiatives, it would be extremely difficult to keep track of the licensing basis of the plant. Site inspectors and the Office of Reactor Regulation would need a guide book to monitor which requirements apply to each plant. In UCS's view, using the voluntary approach is acceptable for plants that will only operate to the end of their first 40 yr license, but all plants that enter license renewal should convert to risk informed regulations uniformly.
(3) Should there be another major nuclear plant accident, the application or lack of application of risk

information could be a major factor in the debate over what is the proper role for the regulator—deterministic or risk informed. If it was deterministic as presently, NRC will be criticized for not using risk. If it was risk informed, critics will suggest that the NRC was not strong enough and should have maintained their "tough" rules and not allowed voluntary risk informed applications.

5.2. Nuclear Information Resource Service (NIRS)

The NIRS is a public advocacy group generally opposed to nuclear power. The NIRS opposes NRC's efforts in making the regulations more risk-informed. They view the driving factor to this type of regulation as purely economic and they see little value in it from safety perspective. They are firm believers in defense in depth and the existing prescriptive regulatory structure, which they believe maintains margins to safety that is essential to protect the public health. The definition of defense in depth as a regulatory construct was thoroughly reviewed by Sorensen, Apostolakis, et al in "On the Role of Defense in Depth in Risk-Informed Regulation" [17]. The conclusion of the authors could be summarized as saying that depending on the view of defense in depth, it could be either the primary means for safety assurance in a deterministic approach with PSA being in a secondary supportive role or defense in depth could be used in a supportive role to assure safety based on risk-informed approaches when uncertainties are too hard to quantify for given scenarios and models.

Overall, NIRS's position can be summarized by saying they do not have confidence in the existing condition of the plant and the state of knowledge that would be necessary to use the tool safely. NIRS is concerned that the plant design basis is not well understood and does not reflect the actual condition of the plant.

5.3. Nuclear matters committee in the town of Plymouth

In order to gain insights of what the general public might have regarding the transition to risk-informed regulation, a meeting of the "Nuclear Matters Committee" in the town of Plymouth, Massachusetts was attended during which a discussion of this topic was permitted by the committee. Plymouth is the site of the Pilgrim Nuclear Power Station which is a 670 MWe boiling water reactor which started commercial operation in 1972. The committee consists of approximately 12 members who discuss current issues of the plant with company representatives and amongst themselves to provide improved understanding of the activities of the plant for town officials and the public. The members of the committee are citizens from the town but there have been employees of the plant on the committee. The meetings are open to the public. Based on discussions with the Nuclear Matters Committee the following observations can made:

- Most of the public is unconcerned with the day to day operations of the plant since they have many other things that they worry about in their day to day lives.
- The community relies on the NRC, the federal agency charged with oversight of the plant, to protect them.
- From the perspective of risk informed operation and regulation, this committee has not observed any difference in regulatory effectiveness or interaction.

6. Lesson learned in implementation

The implementation and transformation to a more risk informed regulatory system and operating mode has been a slow and steady process with many lessons learned. The introduction of risk-informed regulation cannot be done overnight due largely to the institutional obstacles that need to be overcome. In the United States, the use of risk information began as early as 1975 with the Rasmussen Report and it is only now being seriously used in utility and regulatory decision making and regulations. The most important observation continues to be that without the support of top management, the introduction and safe use of risk information will be very difficult. Continued top management engagement in the transition and culture change is essential.

The other major observation is that the most useful application of the risk was the maintenance rule since it provided a foundation for making risk and priority determinations for day to day operations. All the basic elements of the risk informed operating style are exemplified in the maintenance rule. The consensus of both the regulatory staff and the utilities interviewed was that the maintenance rule proved to be a very fundamental high value added rule that naturally lends itself to a risk-informed application. The ability to apply risk assessments for prioritizing work in the maintenance area was the needed demonstration of value to utilities who had made considerable investments in IPEs to allow for additional applications in plant operation. The natural follow-on was the development of risk monitors for operations and plant outage planning. It was also observed that utilities who used the risk monitor in operations, maintenance and outage planning were generally more inclined to embrace the value of risk information.

The adoption of the applications of the PSA needs to be tied to plant interests. Normally it is important to show benefits to the plant staff and the management for the adoption of certain PSA initiatives to gain acceptance. Most utilities that are risk informed have undertaken a configuration risk management program. Utilities have used risk assessments to plan and schedule outages to minimize daily and integrated plant risks; to review design changes for risk impacts; proposed design changes to reduce risk further; justified changes in plant specific requirements such as the need to maintain hydrogen gas monitors, develop integrated risk informed responses to Severe Accident Management Alternatives; to name a few of the types of applications that utilities have found to be of value.

There is a large educational effort on site to gain acceptance of the tool. It is quite important to learn the vocabulary and the language of risk and what it actually means. Initially the groups resisting moving towards risk management applications were operations as well as engineering. People have to be trained on the proper use of the tool. Once risk information is incorporated, a heightened level of risk awareness exists at the site. Once active use of PSA is implemented at plants, the impact on how the plant views safety is changed dramatically from only compliance to awareness risk significance of activities. While the plant staff typically knows what systems are risk significant, the use of the risk tools enhances this understanding in a more graphical and numerical way. This is judged to be a positive improvement in safety awareness and safety culture.

It was judged that pilot programs overall were a necessary step to implement many of the risk informed practices. There was a need to identify specific utilities that were willing to undertake the extra burden and cost to test these new initiatives for the rest of the industry. Many were very time consuming but the process provided a means to negotiate and fine tune the final requirements which would be acceptable to both the industry and the NRC.

In a risk-informed regulatory and operating mode, the roles of both the NRC and the utility need to be changed from simply complying to regulatory requirements to a risk management role in which risk is managed in the overall context of safe plant operation. This requires a safety culture in which the emphasis shifts from simply assuring compliance to rules to including safety assessments for plant activities. This requires an open culture of communication and willingness to raise concerns about practices even if they are within the operating envelope of the technical specifications. With the use of risk-informed initiatives that provide more flexibility, there is more responsibility in assuring that the plant actions are well controlled and monitored.

It was judged that long-term relationships between the utility, NEI and NRC staff were very important to establish the trust and credibility to allow for the implementation of risk-informed regulation. The role of NEI was quite important in gaining NRC support for the use of risk-informed regulation. They provided the forum for meaningful dialogue for how best to develop and implement risk informed rules. While the individual pilot plants undertook the day to day implementation of pilot programs, NEI played a critical role in keeping other utilities informed. NEI played a major interface role with the NRC on problems that were discovered. By representing the entire industry, they were able to speak with a more powerful voice. During interviews with NRC management and staff, it was also noted that they also appreciated a common point for discussion on these critical issues leading to a quicker resolution of any difficulties discovered.

The quality of PRA's is an important factor in the success of risk applications and the use of a peer evaluation program to review PRA's is an important step. The NRC has sponsored that development of PRA standards by the American Nuclear Society and the American Society of Mechanical Engineers which should assist in developing additional confidence in the models developed by the industry. In addition the industry has performed utility peer reviews of the PRAs which were found to be very beneficial to address common concerns. All these initiatives should enhance the overall quality and consistency of PSA's for future application in regulations and operations.

The best way to deal with public and regulatory acceptance of the use of risk informed information is to focus on the safety benefit of such tools and approaches. While there is considerable economic value in using risk management in operations, adoption of risk informed operations and regulations should not be based on economics but on safety. Public acceptance of risk-informed approaches also needs a strong communications program to assure that the public understands the information being provided by the NRC and the utility. NRC provides a very transparent web site on the risk status of each plant using the new ROP which is risk informed. It is quite important to help the public understand the large amount of information provided including the terminology to gain trust in the process.

One of the most important lessons learned is that the transformation to a risk-informed regulatory and operational regime is that management needs to continue to focus on supporting a culture change to be sure that people think in an integrated safety way. This will be difficult for some but continuous management reinforcement and use of risk in communications will be very important for success.

7. Conclusions

Risk-informed initiatives allowed both the regulatory body and the utilities to focus on real safety issues. From the utility perspective, without the support of the chief nuclear officer, the transition to risk-informed operations or management is not likely. This is important because the introduction of risk in operational decisions requires training, leadership and a change management program. It requires culture change and it requires consistency of the message. Without such leadership introduction of risk into operations or regulatory decisions will not be successful.

Generally, there are significant advantages to the plant from an economic perspective by using risk assessment tools to identify the risk significance of systems. The purpose of this paper is not to focus on the economic incentives but many were mentioned during the interviews with utility representatives. More progressive utilities use risk monitors and risk assessment tools in outage planning as well as day to day operations when systems are taken out of service. The use of risk in the operation of the plant forces people to think on an integrated basis and their questions are focused more on overall plant safety and vulnerability than they are on straight compliance to regulations. This is judged to be a very positive aspect of the introduction of risk into operations.

During the course of this study, many examples were cited in which risk tools supported design activities in terms of identifying improved design options. Those utilities that that applied risk information found it to be quite beneficial. In addition to the examples cited earlier, some utilities found that the investment in risk assessment tools and applications were beneficial in license renewal applications, power uprates, increasing allowed outage times for equipment maintenance and repair, control room redesign efforts, and as a tool to focus safety discussions with the regulator about events and license amendment requests being proposed by the utility. Whether these utilities will invest in upgrading their PRAs to the new ASME and ANS standards will depend on whether the NRC allows them to take advantage of these new models in future regulatory decisions. Utilities will be making these investments based on what they believe will enhance their economic and safety performance.

A safety-goal policy is an important but not sufficient condition for the introduction of Risk-Informed Regulation. In true risk-informed space, the safety goal only provides the fundamental high-level architecture for implementation of safety philosophy. There are many other aspects that need to be incorporated to allow for its implementation in the context of regulations and regulatory practices. The implementation of risk-informed regulation should be performed with a clear phased in plan to gain acceptance by the staff, the utilities and the public. Each stakeholder has concerns about change but if properly implemented by establishing a risk-informed architecture and a step-wise plan for its introduction, the objections and challenges that any change poses can be met successfully.

The experience of the United States shows positive results in both safety and economics. The metrics presented show that the use of risk approaches is marginally better with no degradation in safety. The use of risk-informed approaches allows both the regulator and the industry to focus on important safety issues. The transition to risk-informed regulation also required a "culture change" by both the regulators and the utilities. Caution should be taken, however, since the basis of the US transition to risk-informed regulation is founded on a long history of a regulatory structure and practices that have matured the industry to a point where the next step could be taken.

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