SELECTION OF AN ANNUAL PERSON-SIEVERT(REM) GOAL WHEN PLANT CONDITIONS ARE CHANGING

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ABSTRACT

The Susquehanna Steam Electric Station (SSES) is a two-unit boiling water reactor station in central eastern Pennsylvania, United States of America. Hydrogen Water Chemistry was implemented at SSES in 1999, to reduce the risk of stress corrosion cracking of reactor system components. A Condensate Filtration System (CFS) had just before been implemented. The CFS was added to reduce feedwater metals (iron) levels and is expected to result in long-term reduction in radiation fields due to reduced concentrations of insoluble radionuclides (a previously dominant source of radiation fields at SSES). Hydrogen injection has resulted in increased radiation fields along the steam path by about a factor of 5; it is expected to result in refueling outage dose rate increases in primary containment (drywell) of on the order of 1.5 – 7. A recirculation system chemical decontamination is planned for the spring 2000 Unit 1 outage, to reduce those in-plant fields and set the stage for reduced radiation fields in the future.

As these changes were evolving, the year 2000 person-Sievert(rem) goal had to be set. Methods used to address non-outage radiation field increases in steam-affected areas, drywell dose rate increases due to movement of "crud", and effectiveness of chemical decontamination will be described. Background information on the relative standing of SSES with respect to the industry will be provided. The goal set by management will be stated as will approaches developed to reduce collective dose. Actual vs. expected dose rates in the drywell and the initial results of the chemical decontamination will be described, to reflect available data from the refueling outage beginning March 18, 2000.

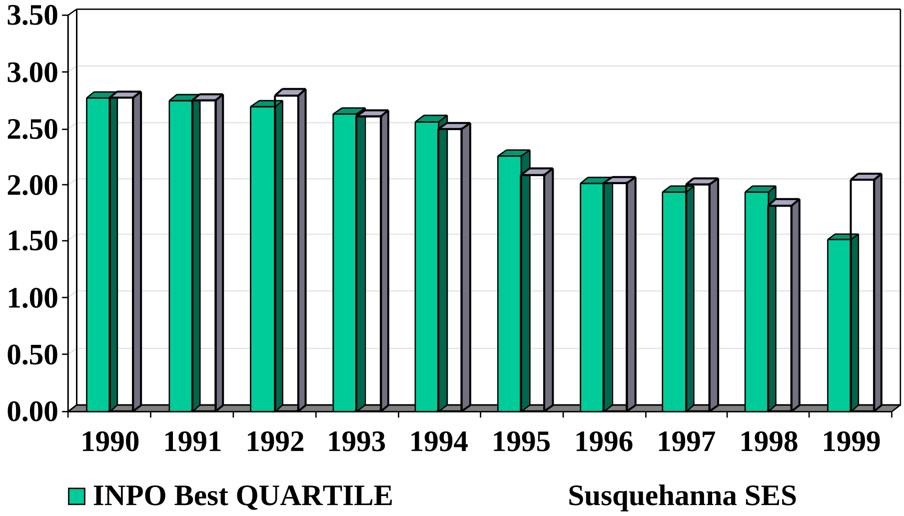
INTRODUCTION

The long-term vision for the Susquehanna Steam Electric Station (SSES), a two-unit Boiling Water Reactor (BWR) station, is to be a "world-class performer". The exact definition of those words is left intentionally vague, and success may be measured in several different ways. Among those measures may be achievement of best-quartile status in important attributes of safety, quality, productivity and/or cost-effectiveness.

Specific to radiation safety, there are still numerous performance indicators which are important relative to justification, optimization, limitations, and reduction of risks or challenges to maintenance of doses within applicable limits. Presuming that doses to individuals remain within limits, collective dose is the indicator most often compared across the nuclear stations in the United States.

As can be seen in Figure 1, collective dose at Susquehanna has reasonably tracked best-quartile status with the widely used INPO three-year rolling average methodology. (INPO is the Institute for Nuclear Power Operations.)

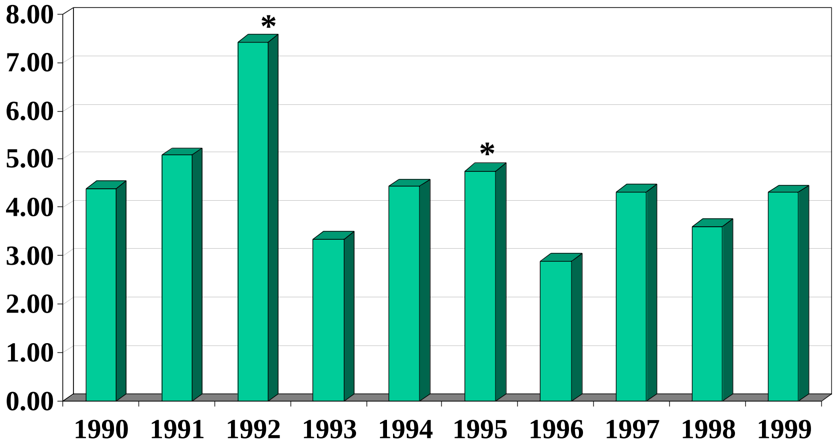
FIGURE 1
COLLECTIVE RADIATION DOSE
THREE-YEAR AVERAGE
INPO BEST QUARTILE vs SUSQUEHANNA SES



Dose Units: Person-Sv per reactor unit

In 1999, Susquehanna's performance moved from first quartile to second-quartile status. A closer evaluation of data underlying the three-year average information reveals that Susquehanna's performance began to deviate from that of the best performers in about 1997. The reason appears to be two-fold: first, an acceptance of "status quo" performance as acceptable performance, and second, physical plant enhancements to address plant appearance and (in 1999) to eliminate insulation of questionable fire protection quality. Figure 2 shows Susquehanna's performance by year over the past 10 years. An admirable performance in 1996 basically masked the trend until 1999. As can also be seen from Figure 2, there is no clearly discernible downward trend in collective dose across the eight single-refueling-outage years shown on the figure.

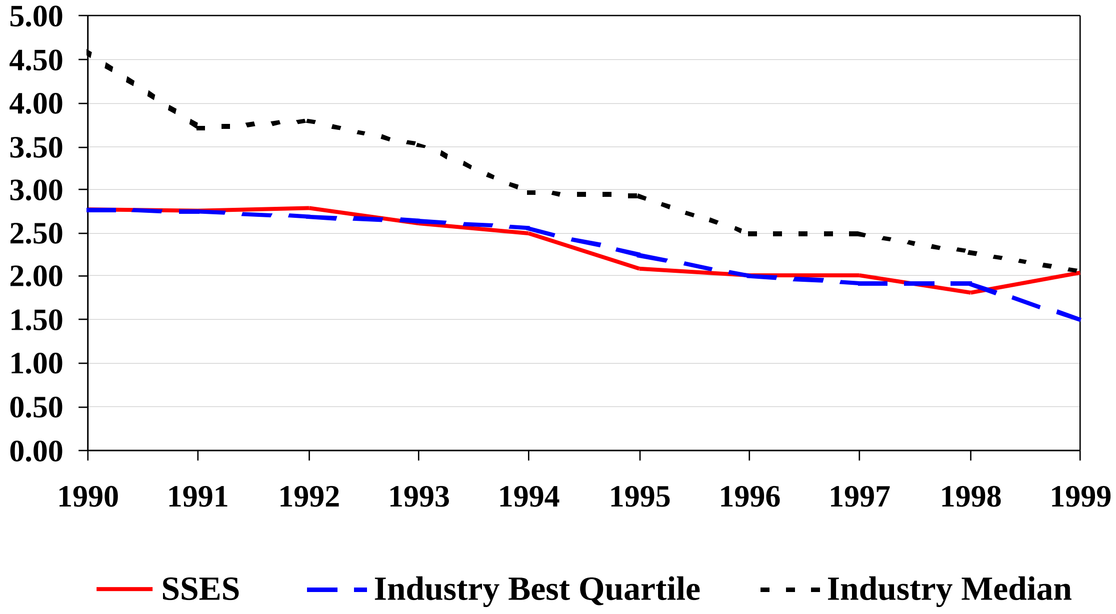
FIGURE 2
SUSQUEHANNA SES COLLECTIVE DOSE



*** Denotes a two-outage year** **Dose Units: Person-Sv for 2 reactor units**

One other figure may be useful in describing Susquehanna's collective dose performance compared to that of its industry peers in the United States. In Figure 3, a reduction in the band width between first quartile and median performance may be seen from the early 1990s through the late 1990s. This reduction implies that even

FIGURE 3
INDUSTRY COMPARISONS
THREE YEAR ROLLING AVERAGES BY UNIT



relatively small changes in overall collective-dose performance can result in a larger change in relative position within the industry.

Summarizing, U.S. BWR industry performance in management of collective dose is getting better. The plants with higher collective doses are improving at a more rapid rate than those with better initial performance. Unfortunately, performance at Susquehanna is not improving at rates consistent with that of its industry peers.

When evaluating Susquehanna performance relative to attainment of world-class status, comparison of SSES performance to BWR performance in other countries is also necessary. As noted in the ISOE report for 1998[1], average BWR performance world-wide is about 1.8 person-Sievert per reactor unit and improving over time. Again, the "message" for Susquehanna personnel is that SSES performance requires a faster rate of improvement.

HYDROGEN WATER CHEMISTRY

To make the issue more challenging to resolve, the decision was reached to implement hydrogen water chemistry at Susquehanna. BWR reactor vessels and their internal components are known to be susceptible to Stress Corrosion Cracking (SCC), particularly in the areas of the fabrication welds. These cracks begin as microscopic cracks in the grain structure of susceptible metals and grow over time to become visible to the eye. Inspection results from the worldwide fleet of BWRs provides evidence that this type of cracking has become increasingly evident in the vessel internal components. Inspections at Susquehanna have identified the start of visible SCC in the welds of the core shroud, a cylindrical structure inside the reactor vessel. Less significant cracking was found in other components such as the steam dryer during prior outages. Our industry has recognized that this problem of SCC in the reactor vessel and its internals is progressive. As such, Reactor Vessel Internals SCC has been identified as a major industry issue needing an organized effort to clearly define the factors contributing to its development and to find effective ways to slow or arrest its development. These organized efforts have been underway for some time.

While repairs of the shroud and many other components are possible, concerns remained about the prospect of the development of SCC in the lower regions of the reactor vessel such as in the core support structures, vessel penetrations (e.g., control rod drives) and internal structural attachment welds to the vessel wall itself. These are of concern because access for inspection is very limited and the methods and technology to repair damage found has not been fully developed and demonstrated. Most importantly, the cost to assess damage and repair it, including generation lost during a protracted outage, direct expenses and the personnel radiation dose accrued, posed a clear threat to the economic viability of Susquehanna SES.

Extensive research by the Electric Power Research Institute, General Electric and lead nuclear plants showed that Hydrogen Water Chemistry (HWC) was the only clear option available in the 1995-97 timeframe to effectively slow or arrest the initiation and growth of SCC in the lower reactor vessel region. Given this, PPL assessed the further risk of SCC for SSES and the economic benefit of installing HWC to reduce that risk. PPL managers concluded that HWC installation (and operation at “moderate” hydrogen injection rates – about 1.6 ppm H_2 in feedwater) was prudent and that HWC should be implemented in the near-term to gain all of the expected benefits. At Susquehanna, adherence to design and installation processes resulted in planned installation in the two units in 1998 and 1999, respectively.

The decision to implement HWC at Susquehanna SES was a step that management concluded they had to take to preserve PPL’s opportunity to operate SSES for its design life of 40 years and potentially for 20 additional years. The decision was made with a full recognition that operating with HWC would significantly add to the sources of radiological dose present at the site. In making the decision to install HWC, management also committed themselves to search for and implement reasonable measures to maintain site workers dose as low as reasonably achievable. (Effects offsite, to members of the general public, were estimated to be very small, warranting no mitigating action.)

Under HWC, hydrogen gas is injected into the water entering the reactor vessel to reduce the corrosiveness of the water. However, adding hydrogen also results in the generation of increased levels of radioactive nitrogen-16 (N-16) gas in the main steam piping. This N-16 gas flows with the steam from the reactor out through the main steam lines to the turbine and eventually is removed from the main condenser by the offgas system. While on route to the condenser, the radioactive decay of N-16 results in release of high energy gamma rays. These gamma rays penetrate the piping and equipment and impact on a wide area. As a result, most of the plant site was expected to be exposed to some increased levels of radiation, primarily from the lightly shielded upper elevation of the Turbine Buildings. Without mitigation, doses to workers inside the Radiological Controlled Area (RCA) due to this source were expected to double, increasing by about 0.2 person-Sievert per year. Mitigation actions were planned, using changed work practices, additional shielding, and 15 additional remote TV camera stations. These actions, if implemented in total, were expected to bring collective doses due to this source almost back to pre-HWC levels. Mitigation measures actually implemented included those modifications required to avoid establishing high radiation areas in frequently accessed areas and those for which the cost-benefit ratio was clearly favorable. Several work practice changes were also implemented. Modifications which were not cost-favorable when evaluated separately, were not implemented. The overall result of the mitigating actions is being quantified. Pre-HWC levels have not been attained.

There is, however, a second and larger, increased source of radiation when HWC is implemented – the “crud” source. The term “crud” as used here refers to the fine materials produced by the corrosion of the internal metal surfaces of the reactor vessel and connected primary piping systems and balance of plant piping and components. By far, the largest source of crud in the reactor coolant system is from corrosion products in feedwater. Over time, this crud plates out and becomes fixed on certain surfaces or circulates with the primary water until it deposits in areas of low flow. The Susquehanna plant has a large inventory of fixed crud in the reactor vessel, much of which is plated out on the fuel rods. Crud that remains in the reactor for some time becomes radioactive. The injection of hydrogen into the reactor vessel produces a reduction in the concentration of oxygen and hydrogen peroxide in the reactor water. This results in chemical and physical changes in fixed crud, particularly crud that is plated out on the fuel rods, causing it to become loose and again circulate with the primary water. This additional loose crud is then redistributed to the primary piping, causing a substantial increase in dose that is most notable in the reactor water clean-up and recirculation system piping. If no mitigation steps were taken, a three-fold increase was projected in total person-Sievert dose for outage work performed inside primary containment due to radioactive crud. Such a dose increase could be on the order of 2 person-Sievert per year.

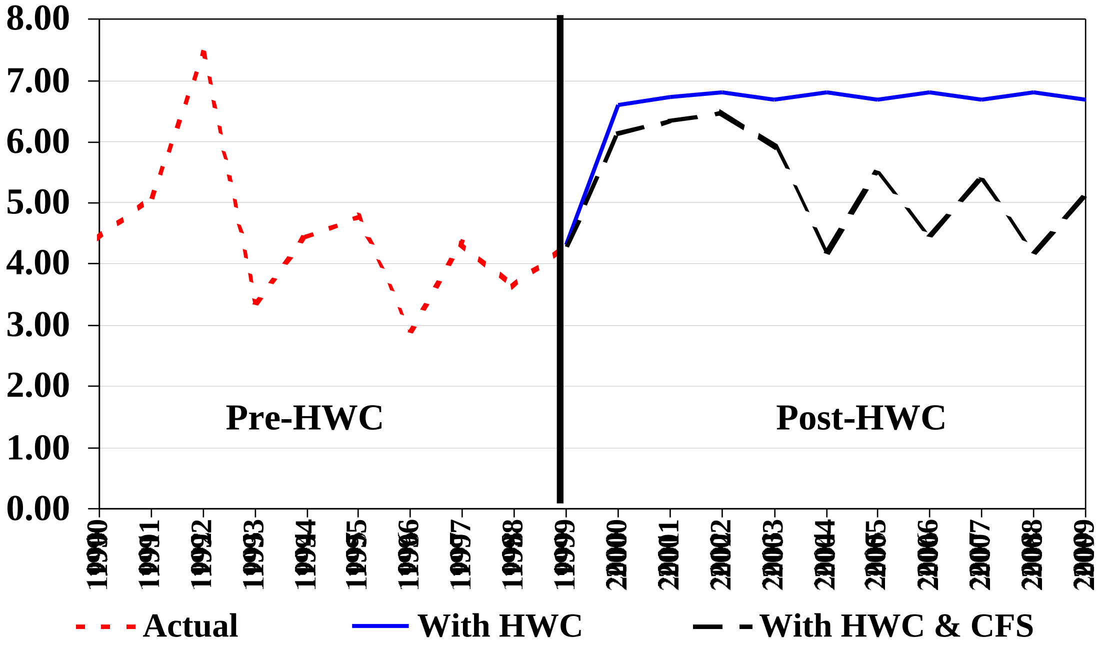
CONDENSATE FILTRATION

PPL concluded that over the long term, the most effective step that could be taken to significantly reduce the shutdown dose was to install full flow filters that were highly efficient at removing the insoluble corrosion products suspended in the condensate water.

While these filters would be very efficient, they could only remove loose radioactive crud that is circulating. As previously noted, much of the large inventory of radioactive crud is fixed on the surface of the fuel rods. This source of fixed radioactive crud would be removed over three refueling outages, one-third being replaced during each outage. Following replacement of the fuel rods, the condensate filter would keep the fuel cleaner. Thus it would take six or more years for the condensate filters to become fully effective in the reduction of radioactive crud dose. The condensate filters would also serve to substantially improve overall feedwater chemistry by removing insoluble feedwater metals.

Figure 4 shows dose projections for the two-unit station, reflecting the implementation of Hydrogen Water Chemistry on both reactor units in 1999, and also the installation of the condensate filters. A dose increase on the order of 2 person-Sievert was projected for the year 2000, about a 50% increase over collective doses incurred in the late 1990s. In making that estimate, several dose mitigation actions had already been credited.

FIGURE 4
DOSE PROJECTIONS USING HWC
(PERSON-SV)



For example, plant modifications using permanent shielding and remote monitoring were completed in the feedwater heater bays and in some locations in the drywell. Also, a "Surrogate Tour" system has been expanded for use by designers and work planners, to minimize time spent in high dose rate areas of the plant.

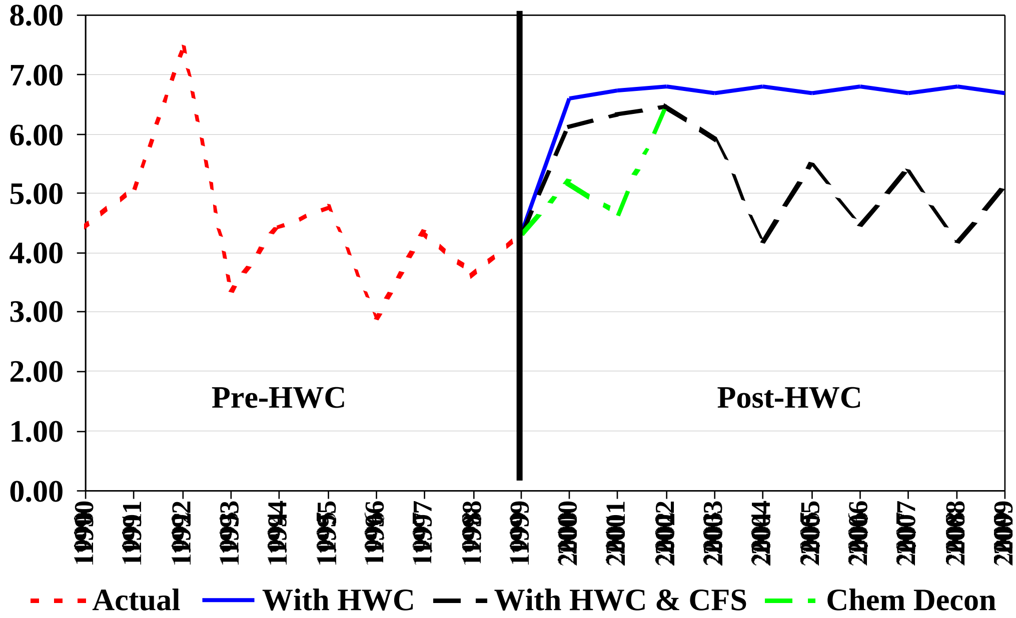
CHEMICAL CLEANING/DECONTAMINATION

Based on the results of other plants using HWC and PPL studies, it was considered reasonably possible that the shutdown crud dose measured in primary containment at the start of the first refueling outage following a period of continuing HWC operation might increase anywhere from a factor of 1.5 up to a factor of 7.0 or more. More detailed evaluations were conducted using software relating Susquehanna reactor water radiochemistry to gamma spectroscopic measurements of primary coolant piping. Estimates of HWC system reliability and profiles of system transients were also considered. The resultant pre-HWC estimate was a factor of 3 increase in the shutdown radiation fields.

Plans were developed to support the staging of all necessary equipment, materials and specialized personnel needed to perform a chemical decontamination of Reactor Recirculation System piping at the beginning of the Unit 1 11th refueling and inspection outage, scheduled to commence in March 2000. The plan is to implement the chemical decontamination. A final determination on whether to commence the process and after how many decontamination steps to stop the process, will be made by applicable management based on radiation survey data in containment, an evaluation of the dose rates, an assessment of process safety and management, and the work to be performed.

In Figure 5, the improved collective dose performance expected from a one-time chemical decontamination of recirc system piping on each unit, can be seen. Across a two-year duration, with associated dose mitigation action then planned, the effects of HWC implementation could be substantially but not fully nullified. That is, savings on the order of 1-2 person-Sievert per year may be realized in station dose.

FIGURE 5
DOSE PROJECTIONS USING HWC AND CHEM DECON (PERSON-SV)



DEVELOPMENT OF YEAR 2000 COLLECTIVE DOSE GOAL

PPL staff have traditionally developed annual station collective-dose goals based on an assessment of planned work scope, consideration of known dose-reduction initiatives, and placement of a challenge factor (usually 5-10%) before the organization to further reduce collective dose. In preparing the year 1999 goal, projecting a decline to second-quartile performance, consideration was also given to re-attainment of first quartile status within two years. A challenge factor of about 20% was given to the organization, and the goal was not met. Two situations thwarted that effort. First, emergent work scope (primarily due to some equipment reliability issues) was substantial in 1999. Second, full management commitment to changes in plant culture, work practices, and technology, as reflected in a viable dose reduction plan, was not obtained, within the context of a high station workload.

In developing the year 2000 collective dose goal, there was the added complexity of evaluating for the first full year of operations under HWC and CF, and for a chemical decontamination under evolving reactor water radionuclide concentrations. Further, there had to be sufficient flexibility for management to express its commitment to maintenance of radiation exposures as low as reasonably achievable (ALARA).

The known work scope was used as input to the process. Dose estimates for primary containment (drywell) activities were developed for various dose rate factor increases. Effects of chemical decontamination of reactor recirculation piping were evaluated for each of these increased dose rate scenarios. Figure 6 shows the draft summary of that information. As can be seen, for the current best-estimate increase by a factor of 2.5 in drywell dose rates, an annual collective dose of 5.11 person-Sievert is calculated.

FIGURE 6
2000 PERSON-Sv SUMMARY FOR DOSE RATE INCREASE AND CHEMICAL DECONTAMINATION SCENARIOS
(Rev. 0)

	Baseline		2.5 Increase		3.5 Increase		4.5 Increase	
	w/out decon	With Decon	w/out decon	with decon	w/out decon	with decon	w/out decon	with decon
Non-Outage (Elec. Dos.)								
Routine/Corrective Maintenance	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Planned/Forced Outages	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Special Projects	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Modifications	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Sub-Total Non-Outage	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21
Unit 1 11 RIO (Elec. Dos.)								
Drywell	1.22	0.61	4.20	1.93	5.48	2.51	6.75	3.10
Reactor Building	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Turbine Building	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sub-Total U1 11 Outage	1.65	1.04	4.63	2.36	5.91	2.94	7.18	3.53
Total (person-Sv) via Elec. Dos.	3.86	3.25	6.84	4.57	8.12	5.15	9.39	5.74
Total (person-Sv), TLD	**4.32**	**3.64**	**7.66**	**5.11**	**9.09**	**5.77**	**10.52**	**6.43**

Put into industry (U.S. BWR) perspective, Susquehanna’s three-year rolling average would increase from 2.04 person-Sievert per unit (1999) to 2.16 person-Sievert per unit (2000) versus a 1999 best-quartile value assumed to be about 1.78 person-Sievert per unit and an industry median value of near 2.00 person-Sievert per unit. (In March 2000, the actual best-quartile value of 1.51 person-Sievert per unit was determined, indicating substantial recent improvement among the top-performing U.S. BWR plants.)

Review of the information by the Station ALARA Committee occurred in December 1999. The Committee noted work scope and schedule changes resulting in a reduction of about 0.10 person-Sievert. The members then adopted a challenge factor of 5%, resulting in an interim recommendation to adopt a year 2000 goal of 4.25 person-Sievert as measured by the daily work tracking device – the Pocket Alarming Dosimeter (PAD), a type of electronic dosimeter. The Committee further recommended adoption of a communication plan and a solicitation of means to meet the recommended goal. Further, the Committee noted that, as drywell doses became known during the outage, consideration should be given to adjustment of the goal.

Soon thereafter, Nuclear Department senior management reviewed all available information. They chose to adopt a still more challenging annual goal of 4.00 person-Sievert. The additional challenge was to reduce collective dose by about 16%, for a total of about 20% from the original estimate. Senior management also maintained the option to adjust the goal depending on radiological conditions actually observed at the beginning of the outage. Overall, this is an example of the expectation of good and improving performance coming “from the top down.”[2]

DOSE REDUCTION PLAN

To meet this "stretch" goal, management needed to be more aggressive in attaining commitment to the goal at all management levels. Further, a more aggressive dose reduction plan needed to be developed and effectively implemented. Quoting again from the OECD Work Management book, "management must be committed to the implementation of the (ALARA Principle), must back up such commitment with time, effort, and monetary support, and must put in place a structure to manage this implementation".

In line with that approach, management first adopted a series of goals to "drive" the implementation of an enhanced exposure reduction plan. The plan was to both result in significant dose savings in the year 2000 and also set the stage for additional substantial savings in future years. The end result was to be reduced collective dose using improved planning and execution of work and appropriate applications of technology. The engagement of all workers in the process was also expected. To provide definition to the process, the goals outlined both broad-based implementing activities and means to monitor progress toward their completion.

Next, radiation safety managers were assigned to identify specific implementing activities, the names of departmental managers to carry out those activities, and the schedules by which the work was to be accomplished. In addition, dose-reduction ideas were solicited from all Nuclear Department employees. All of this work had been done in previous years; the communications plan for HWC design and subsequent installation had, for example, included requests for ideas due to the anticipated dose challenge. The difference was the increased awareness that Susquehanna performance was a) in fact severely challenged by HWC implementation and b) in any case not improving at the rate required for industry competition.

The plan is too lengthy to be fully detailed in this paper. As may be expected, involvement of work group management in review of work is clearly delineated, during all phases of work management. Changes in the ways dose control is effected during work planning, scheduling, and preparation are being implemented. The ideas of workers are being more aggressively solicited and more timely dispositioned.

Review of practices during operational, non-outage periods is receiving substantial emphasis. This is in part due to review of data made available through the ISOE system, and more specifically for Susquehanna, via the North American Technical Center and, separately the BWR Owners Group ALARA committee. Specific benchmarking initiatives are planned resultant from such reviews. As could be seen from Figure 6, almost one-half of the dose at Susquehanna is incurred during plant operations; a lower percentage is likely to be optimal and attainable, even as doses during outage periods are reduced.

The desirability of performing additional recirc system chemical decontaminations is being evaluated, as is the desirability of performing such "decons" on other systems containing high-activity water. Planning for an optimal mix of decons, shielding enhancements, robotic and other non-human "workers", and reactor water chemistry enhancements is underway. For example, the use of noble metals chemical addition has the potential to eliminate the need for injection of hydrogen at the levels now used at Susquehanna.

Changes in Susquehanna's in-service inspection program are anticipated, using the risk-informed process now gaining wider acceptance. ISOE data and analyses assisted in moving that approach along more quickly. Use of other task-specific information will hopefully provide assistance in other areas.

Assessment of the Plan

Annually, a team assesses the performance of Susquehanna in meeting objectives for maintaining doses as low as reasonably achievable. The Dose Reduction Plan was reviewed by this team, which includes industry consultants. The team's comments were generally favorable, and their constructive criticism was incorporated into the plan.

Advantage was also taken of input from the year 2000 North American ALARA Symposium. Elements of the Dose Reduction Plan were compared to those used at the Palo Verde Nuclear Generating Station[3], and differences were evaluated to ensure the Susquehanna plan was comprehensive. Similar comparisons are anticipated to be completed.

Evaluation to date suggests that substantial reductions in collective dose may still be achieved at Susquehanna. Even though collective dose performance at Susquehanna ranks in the better half of station performance among U.S. BWRs per the INPO comparison methodology, estimated savings range up to 70% over a multiple-year period. To accomplish such large savings, plant modifications and other changes would need to successfully meet cost-benefit criteria (the "R" in ALARA). Out-year (2001 and beyond) plans are under review, to tie such cost-benefit evaluations and other ALARA initiatives into the budget planning process.

BWR industry performance has improved by approximately 40% over the past ten years in the United States and 50% across the globe. Specific stations have seen improvements at even higher percentages. CEPN has reported[4] tens of percentage point improvements are feasible as ALARA principles are aggressively implemented into plant maintenance activities.

In summary, substantial gains appear to be feasible. Susquehanna has embarked on the path to achieve those gains and move from "OK" to "world-class" performance.

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