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UPDATE TO MILLSTONE 3 ELEVATED pH TEST

C.A. Bergmann and J.D. Perock
Westinghouse Electric Corporation
P.O. Box 355
Pittsburgh, PA 15230 USA

M.J.B. Hudson, R.W. King, and S. Macklin
Northeast Utilities
P.O. Box 270
Hartford, CT 06141 USA

INTRODUCTION AND BACKGROUND

In view of the potential radiological benefits of elevated coolant pH operation, Northeast Utilities (NU), in support of an EPRI-Westinghouse program, agreed to operate the Millstone 3 plant at the start of its second fuel cycle as a demonstration of the effect of elevated coolant pH on out-of-core radiation fields. Operating with an elevated pH is defined as operating with an average lithium concentration of 3.35 ppm, until reaching an end of cycle pH of 7.2 or 7.4. The plant operated during its second and third cycles with an elevated coolant pH. The end of cycle pH during the second cycle was 7.4, and 7.2 during the third cycle. (During the first cycle, operation was with a coordinated pH of 7.0.)

Evaluation of the dose rate trends in Millstone 3 after two cycles of elevated coolant pH operation concluded that an elevated coolant pH resulted in a 15 percent lower component dose rate compared to other plants that operated with coordinated pH 6.9. However, due to a possible increase in fuel clad corrosion, operation during cycle 4 was restricted to pH 6.9 coordinated chemistry, with the exception of the last two months during which the pH increased to 7.35. At the end of cycle 4 (EOC4), there was a greater increase in component and crud trap dose rates than expected. This paper reviews the radiological trends in the plant and discusses the potential causes for the increase in the dose rates at EOC4.

PRESENTATION OF RADIOLOGICAL DATA

Several types of radiological data were taken during the Millstone 3 test. These included: coolant radiocobalt activity data; dose rates at various Electric Power Research Institute-Standard Radiation Monitoring Program (EPRI-SRMP) locations; and nuclide concentrations from two EPRI-SRMP locations representative of ex-core components.

Coolant Radiocobalt Activity

The Millstone 3 primary coolant radiocobalt activities for cycles 2, 3, and 4 of the soluble and insoluble components were averaged on a monthly basis (similar data are not available for cycle 1). Figure 1 shows the trends for the insolubles plotted in months prior to the EOC to discern any effects of the final pH on the activity trends. Observations regarding the trends include:

- A considerable overlap in the insolubles among the three cycles, except for the last five months of cycle 4 operation.

- A reactor trip in the fifth month before the EOC4 (as noted in the figure). After the trip, the average activity in the insolubles started to increase. Three other reactor trips also occurred in previous months. During the month of the trip, the insoluble activity was generally higher compared to prior or subsequent months, however, an increasing trend did not occur after these trips, as it did following the trip in the fifth month before the EOC.

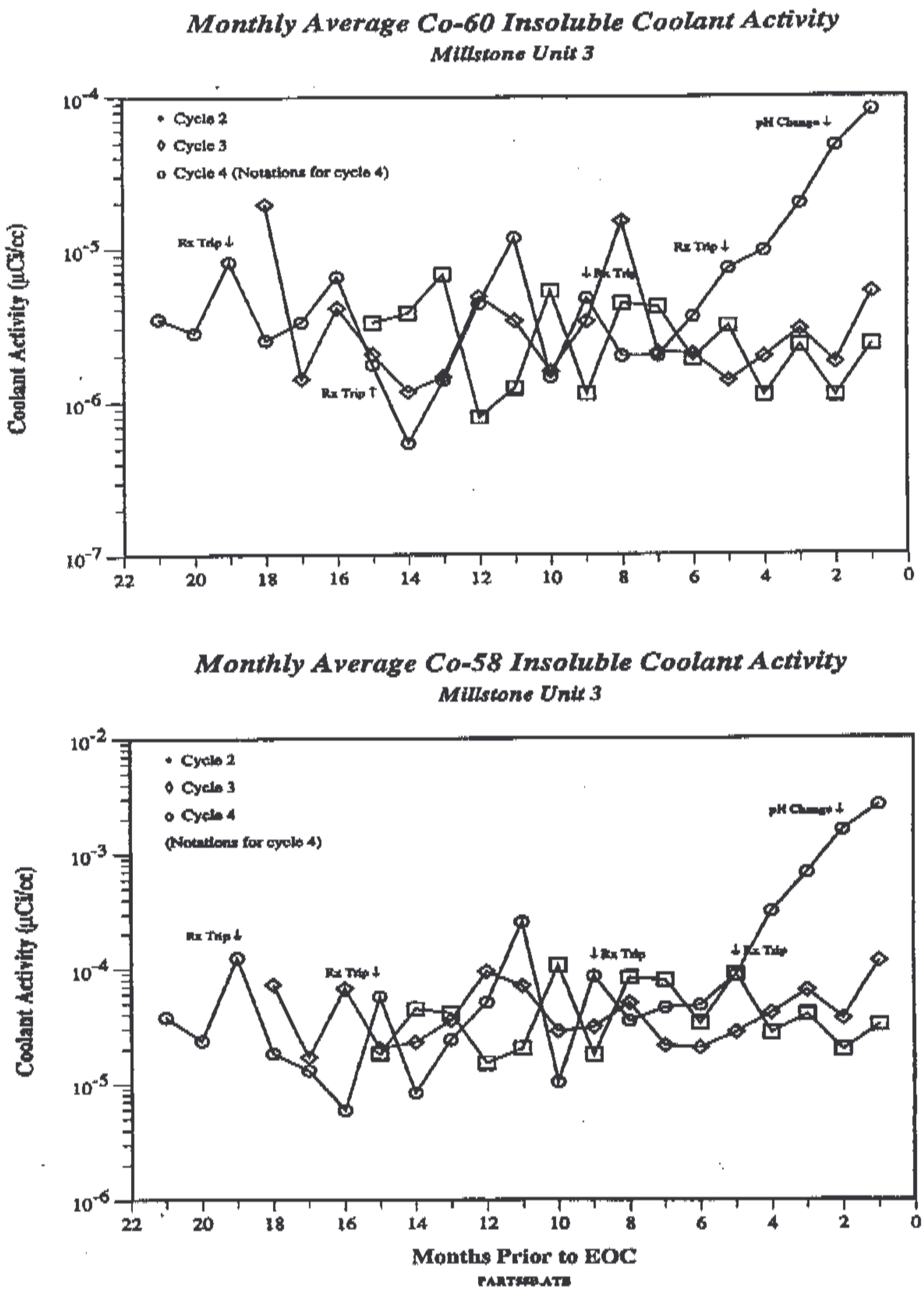


Figure 1. Insoluble Coolant Radiocobalt Activity Trends in Millstone 3 for Cycles 2, 3 and 4

- After the change in pH in the second month before the EOC, the average activity in the insolubles increased again. The absolute activity increase was about a factor of 3 to 5 times greater compared to that observed during the months after the reactor trip.

Measurable total suspended solids were found in the coolant (values of 10 to 25 ppb) during the last two months when the activity in the insolubles was increasing. Prior to this time, the suspended solids were always less than 10 ppb (except for a few times during or soon after a plant shutdown). However, the insoluble activity changes were not entirely consistent with the suspended solids values, thus suggesting that the overall increase in the insoluble activity was at least partially due to an increase in the specific activity of the insolubles, rather than solely an increase in the suspended solids concentration.

No similar increasing trend for the soluble radiocobalts was noted for the last five months before the EOC, thus suggesting that the reactor trip may have loosened insoluble crud from the core or caused it to be more mobile during the ensuing months.

Dose Rates

Figure 2 shows the dose rates of three EPRI-SRMP locations monitored (steam generator channel head, exterior to the steam generator shell, and on the crossover piping) for the Millstone 3, Ringhals 3 and 4, and the comparison group of plants. Ringhals 3 and 4 also operated with an elevated coolant pH. Observations regarding the trends are:

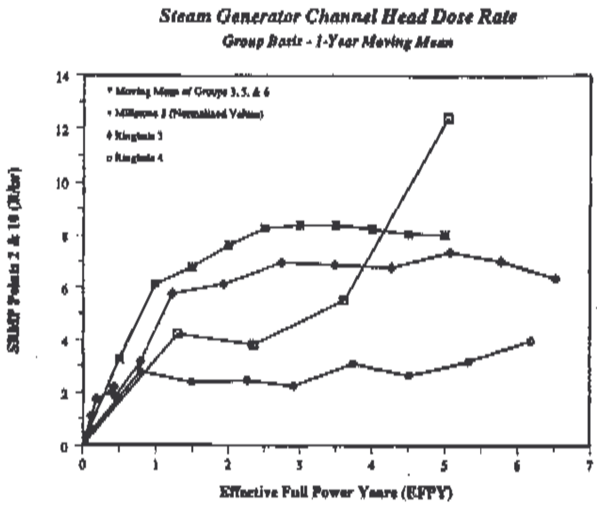
- A considerable increase in the dose rates in Millstone 3, by an average factor of 1.68, from EOC3 to EOC4.

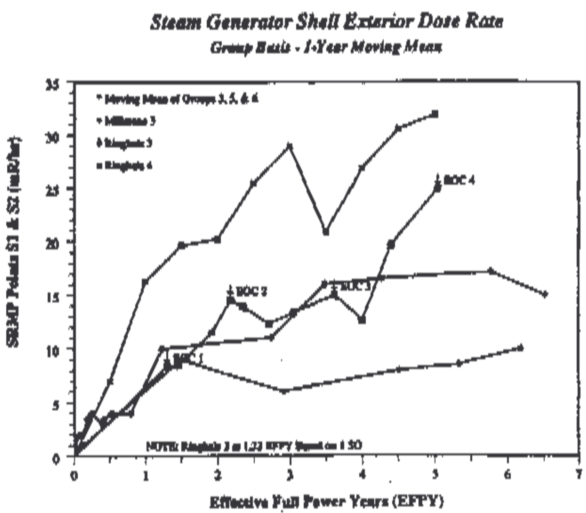
- A similarity between the trends for Millstone 3 and Ringhals 3 and 4 prior to EOC4: an increase up to 1-2 EFPY and then a leveling off. This is in contrast to the trends in the comparison group of plants (which operated with a pH 6.9 coolant chemistry). In these plants, the dose rate trend did not level off until about 3-4 EFPY. In addition, the absolute value of the dose rate in the comparison plants are generally greater than in the other three plants. These trends suggest the radiological benefit of the elevated pH operation.

In addition to the above increase in the component dose rates, increases in the dose rates at other areas shown in Table 1 were noted from EOC3 to EOC4. It was estimated that the increases in dose rates shown in the table contributed to an extra 175 man-rem to the total dose during the cycle 4 outage.

Plant Health Physics personnel also noted an increase in dose rates at certain areas routinely monitored after the reactor trip that occurred five months before the EOC4 (March 31, 1993). Table 2 lists the changes in the average general area dose rates at several locations monitored during the five-month period. The locations monitored are representative of the components of sections of the chemical and volume control system (CVCS) letdown line. The locations near the letdown heat exchanger could be typical of component dose rates, whereas the dose rates near the letdown line could be more typical of component and crud trap dose rates. Note that the dose rates several days after the reactor trip did not change. However, after about one to two weeks, the dose rates increased about a factor of 1.5 to 2. They then continued to increase until they were about another factor of two above the initial increase until near the EOC4. The absolute value of these general area dose rates are subject to some uncertainty due to the nature of taking general area dose rates compared to contact dose rates.

In addition to the above changes, a large increase in dose rates was noted at the EOC4 in the pressurizer cubicle during the shutdown process. During this same period, a particulate crud burst of 1.4 ppm occurred, and the dose rates near the top of the ladder in the pressurizer cubicle increased from 50 mR/hr to 800 mR/hr. The increase was believed to be due primarily to an increase in the dose rates from hot spots in the pressurizer spray line and valves in the pressurizer system.





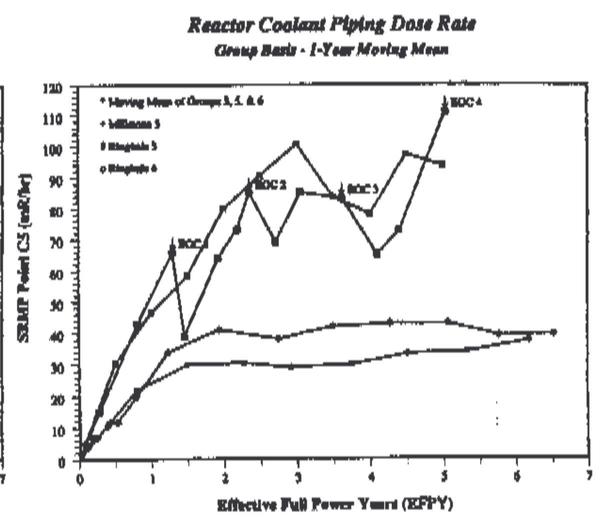


Figure 2. Dose Trends in Millstone 3 and Other Comparable Plants

Table 1
Increases in Dose Rates (mR/hr unless indicated) from Before EOC4 to EOC4

Component	1986-1993 Values	EOC4 Values	Maximum Factor Increase
Pressurizer	30 - 500	100 - 8,000	16
Head Vent Valves	10 - 50	200 - 10,000	200
Refueling Cavity Water	1 - 5	24 - 90	18
Reactor Head/Pit Seal	10 - 30	30 - 300	10
Loop Hot Spots	300 - 500	10 - 200 R/hr	40
Regenerative HX	2 - 3 R/hr	4 - 5 R/hr	1.8
Tri-Nuclear Filters	300 R/hr	1,800 R/hr	6
SG Secondary Side	5 - 7 R/hr	15 - 17 R/hr	2.5

Inspection of average piping and steam generator shell component dose rate trends shown in Figure 3 during the EOC4 shutdown process shows essentially no change during the crud burst, indicating minimal crud/activity deposition on component surfaces. In addition, the amount of activity released in the crud burst is a small fraction of that deposited in the components. Thus, while dose rate increases at some crud traps happened gradually after the reactor trip on March 31, 1993 to the EOC4, increases in the pressurizer cubicle occurred quickly after the crud burst at the EOC4.

Nuclide Surface Concentrations

The nuclide surface concentration on the steam generator tubing and crossover piping was measured in the plant at the end of each cycle using in situ gamma ray spectroscopy techniques. Using these data, the total ex-core activity was calculated and Figure 4 gives the results for the two radiocobalts. Due to the relatively short half-life of cobalt-58, one would expect the activity value to reach equilibrium after a cycle of operation. Note that the amounts of cobalt-58 deposited for each cycle appears to vary depending on the pH (or ending pH) of the coolant, and that there is a minimum at pH 7.4 and a maximum for pH 6.9. For cobalt-60, the rate of activity buildup appears to decrease with time of operation.

PRELIMINARY EVALUATION OF DATA TRENDS

Based on CORA code calculations, an overall increase in dose rates of about a factor of 1.40 would have been expected with operation at pH 6.9, and taking into account a benefit of about a 5 percent reduction in dose rate due to conversion of the fuel to Zircaloy grids. (The CORA-calculated change due to elevated pH operation in lieu of pH 6.9 operation for the fourth cycle was only a few percent less.) The fact that the dose rates increased by about a factor of 1.7 indicates that other factors not accounted for by CORA were in effect. One such factor is changes due to crud bursts, since CORA does not take into account dose rate changes due to these events.

The large increase in cobalt-58 deposited activity at EOC4 compared to a leveling of cobalt-60 activity suggests that the transport of nickel is more influenced by pH operational changes as compared to that of cobalt.

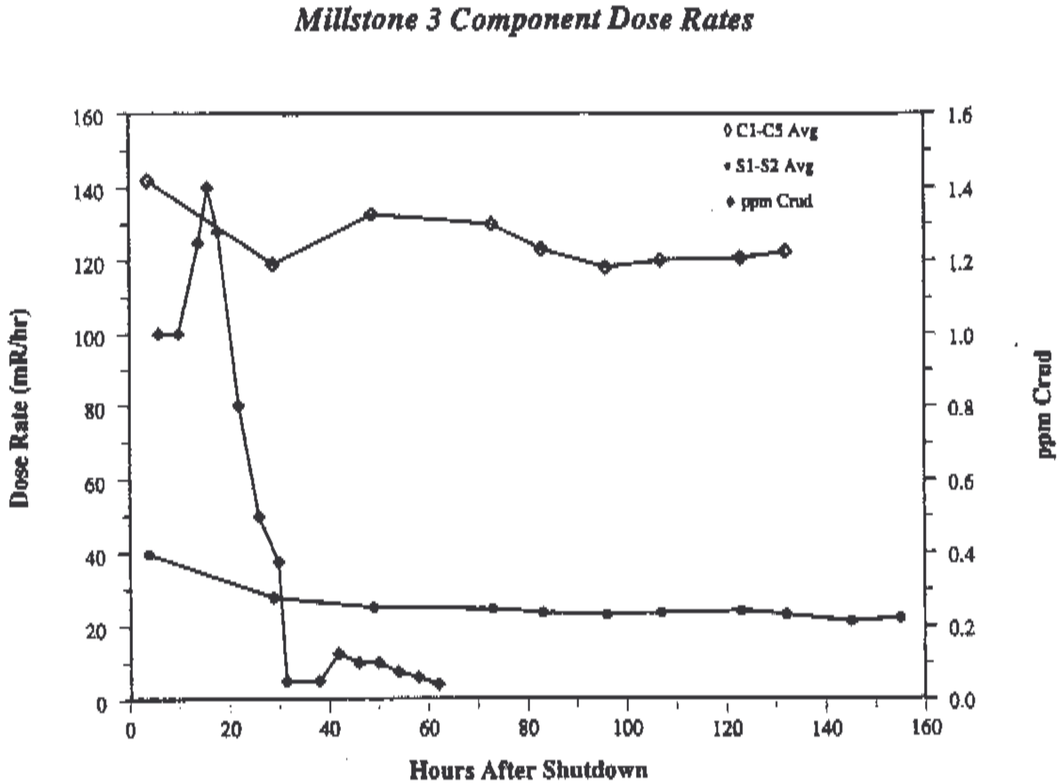


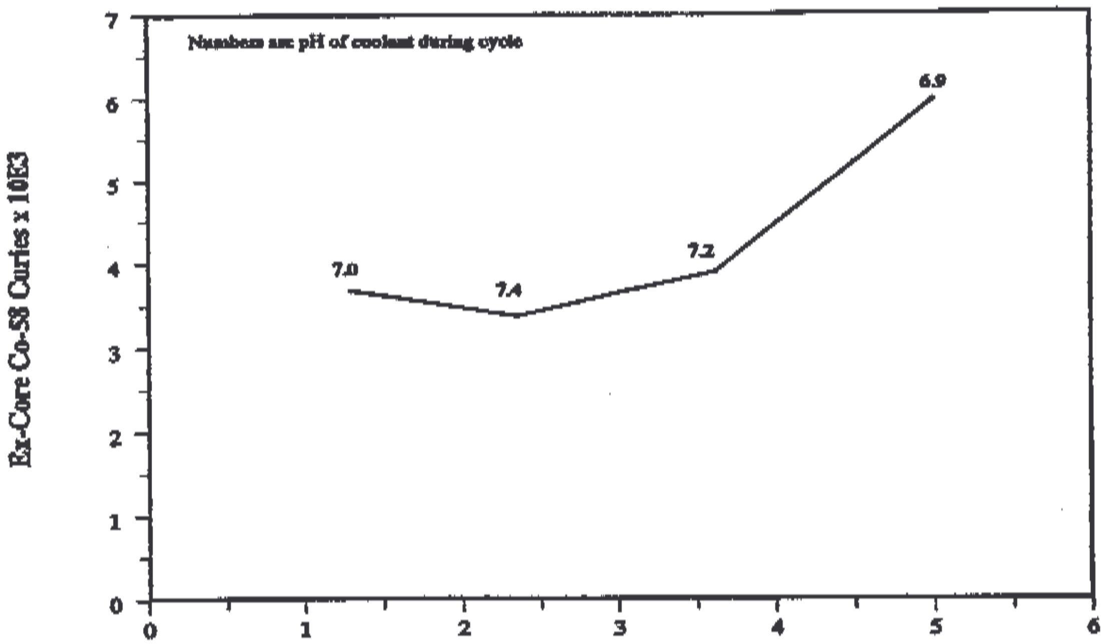
Figure 3. Component Dose Rate Changes During EOC4 Shutdown

As shown in Figure 3, the increase in dose rates at the pressurizer cubicle noted during the crud burst at the EOC4 shutdown did not cause an increase in the component dose rates during this same time period. This suggests that the increase from cycle 3 to 4 for the components usually monitored was due to a long-term change in the plant activity levels and not the short-term change noted at the pressurizer cubicle. The cause of the crud burst during the shutdown period is not known. Based on an evaluation of coolant chemistry and temperature changes during the shutdown process, it was concluded that the cause was not due to coolant chemistry evolutions during the shutdown.

The behavior of the trends in Table 2 also indicate an increase in crud trap and component dose rates during a longer time period than during the shutdown period. As noted in Figure 1, the last reactor trip could have initiated a continuing release of crud from the fuel deposits. The change in the coolant pH during the last two months could have caused a continuation of this process. This fuel crud would have a higher specific activity than that of the normal circulating coolant crud, thus contributing to the overall increase in the insoluble activity. The increase in activity in turn contributed to the increase in the crud trap and component dose rates from the EOC3 to the EOC4.

Based on evaluation of the radiation data to date, the following preliminary conclusions regarding the causes of the unexpected dose rate increase at the EOC4 have been made:

- An increase in the activity and/or concentration level of the coolant particulates during the last five months of operation appeared to be related to a reactor trip that occurred five months before the EOC4 and the pH increase that occurred two months before EOC4. After this increase, the dose rates at certain components and crud traps increased by several factors.



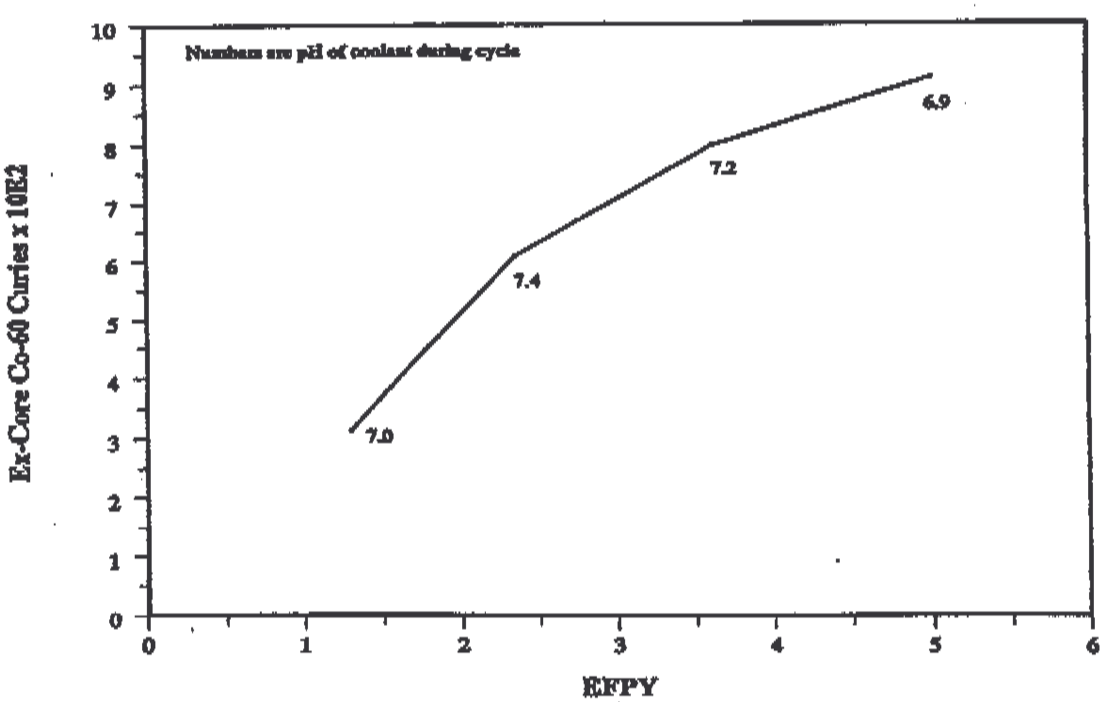


Figure 4. Total Ex-Core Activity

Table 2
Changes in Certain Average General Area Dose Rates (mR/hr) from Mid-March, 1993 to EOC4

Date	Letdown Heat Exchanger Area: Second Level	Letdown Heat Exchanger Area: 4-foot Lower Level
3/22	55	54
3/29	59	46
4/5	44	30
4/9	140	81
4/12	130	101
4/19	183	85
4/26	193	119
6/24	213	123
7/5	153	75
7/19	288	182
8/1	--	221

Date	Near Letdown Line in Auxiliary Building
3/23	17
4/6	20
4/13	26
5/4	27
5/11	33
6/15	73
6/22	61

- A greater proportion of the dose rate increase was due to an increase in cobalt-58 activity rather than increase in cobalt-60 activity.

- The large particulate crud burst that occurred several hours after shutdown did not contribute to the EOC 3 to EOC 4 component dose rate increase. However, it could have contributed to increases at certain crud traps. The cause of the crud burst is not known but was not due to coolant chemistry evolutions during the shutdown.

Additional data evaluation is continuing to further define the causes of the increase in dose rates.

Author Biography

Carl A. Bergmann is a Principal Engineer in the Radiation and Engineering Analyses Group in the Nuclear Technology Division of Westinghouse Electric Corporation. He has over thirty years of experience in the nuclear field and has been the lead engineer for the research, development and application of dose-reduction techniques to PWR nuclear plants for fourteen years. Dose-reduction techniques include the application of coolant additives such as zinc and enhanced amounts of lithium to the primary coolant. He also led a study to evaluate sources of cobalt in Westinghouse-designed plants. Mr. Bergmann holds a B.S. Degree in Chemical Engineering and a Masters in Business Administration.

Westinghouse Nuclear Technology Division
Energy Center East 478
P.O. Box 355
Pittsburgh, PA 15230

Phone: 412 374 5166
Fax: 412 374 4697

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DISCUSSION

Wood: So your recommendation, Carl, will be that plants then go back to pH 6.9?

Bergmann: We are still trying to sort out whether or not the pH 6.9 operation caused the whole problem, but you can certainly speculate that pH 6.9 caused more crud to be generated and deposited on the core, thus being available for further activation. On this basis, it looks like you shouldn't go back to pH 6.9 after operating at an elevated or modified pH.

Wood: It seems pretty obvious to me that you've got a lot more crud due to the going back to pH 6.9 and that's being released from the core for whatever reason. The key point is that you are obviously forming a lot more crud in the core, which is a bad thing.

Bergmann: Yes.

Wood: Perhaps the co-chair, Krister Egnér, would like to comment.

Egnér: No.

Riess: Could you explain a little about the fuel cladding and the reason why you went to pH 6.9?

Bergmann: There were a number of people concerned from the fuel viewpoint, that when you operated with an elevated or modified pH you have more exposure to lithium. If you can plot the lithium days, the days of certain lithium concentration vs. the time period during the cycle, you have more lithium days operating at a modified or elevated pH than you would have if you operated at a coordinated pH of 6.9. Since lithium is the culprit in terms of fuel cladding corrosion, it is desirable to minimize the lithium days.

Riess: Yesterday I think I heard someone say that there was no evidence of additional fuel cladding corrosion.

Bergmann: That analysis was done after the decision was made to operate at pH 6.9. For this cycle, the plant is planning to operate with modified chemistry. I guess one reason is because most of the fuel is Zirlo fuel, which has less susceptibility to lithium corrosion.

Wood: We did a comparison between Millstone 3 and North Anna, which had operated on pH 6.9. The Millstone 3 data suggested that zircaloy corrosion could be about 14% higher. That whole cycle was the reason for the concern. Then we went back and looked at more detail. Just looking at the Millstone 3 data, we actually thought that the elevated lithium had reduced zircaloy corrosion, comparing cycle 1 with the fuel that went into cycle 2 onwards. So at the moment, we don't believe that there is an adverse lithium effect. We are looking now at the cycle 4 data, which is going back to 6.9, and that will give us a direct comparison. So we can directly compare the pH 6.9 data with or without elevated lithium. Hopefully, in the next few months we will have a better picture on the zircaloy data.

Bergmann: Millstone cycles are 18 months. So in addition to having the higher lithium levels, the higher burnup was also a factor.

Wood: I should have made the point that the first cycle was only 12 months, and we had a problem comparing that with the later ones. The cycle 4, of course, was 18 months, the same as the elevated lithium cycle, so that should help our evaluation.