RECENT DEVELOPMENTS IN RADIATION FIELD CONTROL TECHNOLOGY

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INTRODUCTION

The U.S. nuclear power industry has been remarkably successful in reducing worker radiation exposures over the past ten years. There has been over a fourfold reduction in the person-rem incurred for each MW.year of electric power generated: from 1.8 in 1980, to only 0.39 person-rems in 1991 and 1992. Preliminary data for 1993 are even lower: approximately 0.37 person-rem/MW.year. Despite this substantial improvement, challenges for the industry remain. Individual exposure limits have been tightened in ICRP 60 and there will be increased requirements for special maintenance work as plants age, suggesting that vigorous efforts will be required to meet the industry goals for 1995.

Reducing out-of-core radiation fields offers the best chance of continuing the downward trend in exposures. To assist utilities select the most economic technology for their specific plants, EPRI has published a manual capturing worldwide operating experience with radiation-field control techniques (TR-100265). No one method will suffice, but implementing suitable combinations from this collection will enable utilities to achieve their exposure goals. Radiation reduction is generally cost-effective: outages are shorter, manpower requirements are reduced and work quality is improved. Despite the up front costs, the benefits over the following 1-3 years typically outweigh the expenses.

RADIATION EXPOSURE SOURCES

Occupational exposures are the product of the time spent in the radiation field and the radiation intensity (dose rate). The former is determined by the amount of work to be done, the efficiency with which the task is carried out, and the extent to which remote technology is utilized. Radiation fields result primarily from activated cobalt isotopes; the dose-rate is determined by the amount of cobalt used in valves and materials of construction, control of water chemistry to limit transport and activation of the cobalt, condition of out-of-core surfaces in the primary system, which determines how much cobalt is deposited, and the extent to which decontamination is utilized.

Cobalt isotopes are the main cause of exposure; radioisotopes from failed fuel are but a minor contributor. Cobalt is activated to Co-60, the dominating gamma emitter. The widespread use of cobalt-base hardfacing alloys in U. S. plants and the higher cobalt impurity levels in construction materials are key reasons why U. S. plants have higher radiation fields than Swedish or modern German plants. The first goal of the radiation protection manager is, therefore, to replace cobalt hardfacing alloys whenever possible and to specify low cobalt impurity levels in ordering replacement components.

Cobalt-58, produced by the activation of nickel in corrosion products released by stainless steel and nickel-base alloys, is the second most important exposure source. The impact of both cobalt and nickel sources can be minimized by selecting water chemistry to minimize the release, transport, and activation of wear and corrosion products. In limited areas, such as the chemical volume control system (CVCS) in PWRs, extra-fine filters can be helpful. However, their benefit is more local than circuit-wide.

Activated corrosion products become a problem when they deposit on out-of-core surfaces, particularly in areas such as PWR channel heads and around valves, where inspection and maintenance work is performed. Preconditioning the surfaces of replacement components helps reduce activity pickup. If all else fails, chemical decontamination can typically remove 90% of the deposited corrosion products.

TECHNOLOGY TO HELP REACH FUTURE GOALS

Radiation control technology can be divided conveniently into three categories: established or mature techniques, recently-developed techniques that are now available for plant demonstrations, and the developments that are promised for the future.

Established Techniques

Cobalt Reduction Guidelines

A close look at valve duty in nuclear plants has pinpointed conditions where the use of the cobalt-base Stellites™ as a hardfacing alloy is not warranted. The latest results are described in the *Cobalt Reduction Guidelines, Revision 1*, published in 1993 (TR-103296). Implementation of these findings affords utilities an opportunity to reduce personnel exposures.

The recommendations of the guidelines have been implemented by Niagara Mohawk Power personnel who ordered 150 replacement globe valves with precipitation-hardened stainless steel seating surfaces. These valves are used in manifolds that provide differential pressure measurements. New York Power Authority has replaced major cobalt contributors, such as charging pump check valves, with cobalt-free valves that are performing well.

Niagara Mohawk also has purchased and installed at Nine Mile Point Unit 1 replacement control blades and local power range monitors fabricated from stainless steel containing very low levels of cobalt (150 ppm and 250 ppm, respectively). This should lead to reduced fields and reduced low level waste disposal costs.

PWR Primary Chemistry Control

Released Co-59 must be activated in the reactor core by its incorporation into the corrosion products that deposit on fuel rods. A wide range of experiments showed that the amount of activated Co-60 is reduced if the lithium concentration is increased in the primary coolant so that the pH exceeds 6.9. However, laboratory investigations show that very high lithium concentrations can increase the corrosion rate of Zircaloy fuel rod cladding and the susceptibility of Inconel 600 steam generator tubing to intergranular stress corrosion cracking. Thus, the benefits of lower radiation fields must be carefully weighed against possible degradation of critical reactor components. The *PWR Primary Water Chemistry Guidelines: Revision 2* provide a way to avoid the pitfalls (NP-7077). The key point is to operate at or above pH = 6.9 and as close as possible to pH = 7.4 to minimize corrosion-product deposition and accelerated Zircaloy corrosion.

Three new PWRs, Vogtle 1, Comanche Peak 1, and Seabrook have used a modified coolant chemistry regime from startup. Here the pH is maintained at 6.9 early in the cycle until a lithium concentration of 2.2 ppm is reached, which is maintained until a pH of 7.4 is achieved. After about 1 EFPY of operation the average SG channel head dose rate at these units is 4.2 R/h, which compares to a value of 6.4 R/h at other similar PWRs that have operated using pH 6.9 chemistry.

Control of shutdown chemistry using peroxide addition and early boration to minimize activity transients is discussed in *PWR Primary Shutdown and Startup Chemistry Guidelines* (TR-101884).

BWR Zinc Injection

When BWR radiation fields measurements were categorized according to the type of condensate treatment system and the alloy used in the condenser tubing, it was found that soluble zinc inhibited the corrosion of stainless steel and reduced the incorporation of Co-60. The lead utility in applying this technology was Public Service Electricity and Gas, which injected zinc from startup at its Hope Creek unit in 1986. The results of fuel examinations after three fuel cycles on zinc show that the zirconium oxide corrosion thickness on the fuel is in line with other BWR fuel experience. Some units have seen increased fields due to Zn-65 and technology to deal with this problem will be discussed later. Currently ten U. S. units are injecting zinc.

Zinc injection can help minimize the increase in shutdown radiation fields observed in some plants when hydrogen injection is implemented to control intergranular stress corrosion cracking. The *BWR Water Chemistry Guidelines, 1993 Revision* (TR-103515) discusses the options of water chemistry, including zinc injection.

Electropolishing Replacement Components

Laboratory, loop, and plant tests have shown that ex-core components incorporate less radioactivity if the surface is smooth. The earliest application of electropolishing to reactor components was on replacement BWR recirculation piping that was installed at Northern States Power's Monticello plant and Omaha Public Power District's Cooper plant. Subsequently, all BWR replacement recirculation piping has been electropolished.

Replacement PWR steam generator channel heads make use of three structural alloys. Programs to qualify electropolishing investigated prototypical materials and processes used by steam generator fabricators. No adverse results were found, and results on test coupons exposed in European PWRs indicated that electropolishing of representative weld overlay alloys would reduce radioactivity pickup by about a factor of three. In the U. S. channel heads have been electropolished at Northeast Utilities' Millstone-2 and at Consumer Power's Palisades unit. Northeast Utilities expects to avoid at least 18 man-rem per outage.

Part System Decontamination

Decontamination of recirculation systems at BWR plants has become almost routine at many utilities. The number of recirculation system decontaminations has doubled in the past two years, mainly as a result of the increase in fields observed in units that have implemented hydrogen water chemistry as a measure to mitigate IGSCC. The LOMI process has been used for all recent recirculation piping decontaminations. The CAN-DEREM and CITROX processes have been used for other BWR systems and PWR components. Decontamination developments are reviewed in another paper at this workshop.

Recently-Developed Techniques

High-Performance Cobalt-Free Hardfacing Alloys

Field tests of a new iron-base hardfacing alloy in key nuclear plant valves have been initiated. PWR utilities, including Consolidated Edison, Union Electric, and Houston Lighting and Power, are using NOREM trim in small gate or globe valves with isolating functions in the chemical and volume control system. The BWR utility, Boston Edison, is using NOREM in a large 12" gate valve that is being used to regulate feedwater flow. Successful performance will provide further confirmation of the extensive laboratory and loop test data showing the EPRI iron-base alloys, designated NOREM, have wear resistance matching the cobalt-base Stellite alloys. Licensees have produced weld consumables in the form of powder and wire, and valve vendors have developed welding procedures for these product forms. In addition to reducing the cobalt inventory, evaluations by the EPRI NDE Center showed that the NOREM alloy wire can be deposited by gas tungsten arc welding on carbon and stainless steel substrates without preheating. This advantage should facilitate valve refurbishing operations in the field, further contributing to exposure reduction.

Replacing Cobalt Pins and Rollers in BWR Control Blades

The first plant demonstration of equipment to replace the upper pins and rollers in BWR control blades took place at Commonwealth Edison's La Salle site in mid-June. These cobalt-bearing sources are a significant dose source because they operate in a high radiation field. The ability to remove these radiation sources in blades with remaining neutronic life is an attractive alternative to their premature discharge. It is expected that up to eight blades could be modified daily using a single work station. Similar equipment designed by GE has been demonstrated recently at KKM Muehlberg. TVA's Browns Ferry Unit 3 plans to change out all blades using this equipment in 1994.

BWR Zinc Injection Using Depleted Zinc-64

The main technical disadvantage associated with zinc injection is the formation of Zn-65 as a result of the activation of naturally-occurring Zn-64. Plant evaluations of zinc injection using zinc depleted in Zn-64 have started. Although depleted zinc is relatively expensive, the technology promises to be cost effective. Plant evaluations are being carried out at New York Power Authority's Fitzpatrick plant and Northern States Power's Monticello plant, both of which have experienced higher radiation fields since adopting hydrogen water chemistry, and other plants, including Millstone 1, operating on normal water chemistry.

PWR Enriched Boric Acid

An alternative way of increasing PWR primary system pH is to use boric acid enriched in B-10. Naturally occurring boric acid contains about 20% B-10, so the same nucleonic effect would be achieved with less boric acid. This, in turn, allows the desired pH to be obtained with less lithium.

As with depleted zinc, the main impediment to the use of enriched boric acid is economics. It is estimated that because of the high start-up costs, benefits will be realized only after several years of operation. However, it appears that enriched boric acid would be economically feasible for PWRs with boron recycle systems, especially at those plants operating on extended fuel cycles that require high boric acid concentrations after refueling.

Full System Decontamination

Current technology requires isolation of the part of the system that is to be decontaminated, such as recirculation piping in BWRs or steam generator channel heads in PWRs. Decontamination of the complete coolant system would provide a number of advantages, including improved decontamination factors, reduced recontamination rates, and lower background fields. Two qualification programs, one for PWR and one for BWRs, have recently been completed by groups of utilities and EPRI. No unresolved safety issues were found, and the economics appears to be feasible for both PWR and BWR applications, particularly for steam generator replacement in PWRs and the removal of in-vessel corrosion products in BWRs, which would otherwise be redistributed to out-of-core surfaces after implementing hydrogen water chemistry. Detailed engineering evaluations are now under way for full system decontamination of Consolidated Edison's Indian Point 2 PWR, the objective being to carry out the first demonstration in 1995.

Future Developments

Chromium Coatings

As part of the steam generator replacement project at Millstone 2, Northeast Utilities has installed one of the manway seal plates coated with a thin layer of electroplated chromium followed by pre oxidation in moist air. Activity measurements will be made in 1994. An RHR pipe at Diablo Canyon has also been treated. Chromium coated RWCU pipe sections will be installed at the Peach Bottom BWR units in 1994. The impetus to test this coating is data obtained from small specimens that were similarly coated and attached to the manway seal plates in the Doel 2 PWR. Dose rate measurements show substantial reduction over specimens that had been electropolished and pre oxidized. Thus, this metal coating provides an opportunity to reduce dose rates and hence exposures in the vicinity of channel heads during outages. Other possible applications of chromium coatings include the carbon steel piping that is being replaced in some BWR reactor water cleanup systems.

Zinc Injection for PWRs

Tests in an out-of-reactor loop at Chalk River showed that zinc reduced Co-60 deposition under PWR chemistry conditions, just as it did under BWR chemistry. Other workers followed up on earlier corrosion test results which suggested that the presence of a few ppb zinc reduced intergranular stress corrosion cracking (IGSCC) under BWR normal water chemistry. It appears that zinc additions delay the onset of PWSCC in Alloy 600 and may even reduce crack growth rates. This could be an important benefit of zinc injection in view of the increasing incidence of PWSCC in steam generator tubing and recent observations of degradation of Alloy 600 pressure vessel penetrations. In fact, mitigation of penetration cracking is now the main motivation for a major industry program now underway in the United States.

The concern about PWR zinc injection is that unlike the case with BWRs, no plant data is available the indicates the effect of zinc on the corrosion of Zircaloy fuel rod cladding. PWR applications require similar data, and EPRI and other utility groups have initiated two courses of action: accelerated loop tests at Halden where the effects of both heat flux and neutrons on Zircaloy corrosion can be assessed and a plant demonstration at Farley PWR including fuel surveillance after each cycle, as was done for the elevated lithium evaluation at Millstone 3.

The Farley plant demonstration will use natural zinc. However, the data obtained from Farley should enable a cost/benefit assessment to be carried out on the use of depleted zinc-64 for radiation field control.

Full System Decontamination Including Fuel

Ideally, fuel system decontaminations would be carried out before refueling, as this would significantly reduce recontamination rates and save critical path time. Encouraged by the results from the successful test on Quad Cities BWR fuel, four fuel assemblies from the V.C. Summer PWR were decontaminated during the 1991 outage. Two of these assemblies were reinserted for an additional cycle of exposure and were then examined. No adverse effects were found with either AP/CANDEREM or AP/LOMI. These promising results have prompted industry groups to consider a PWR full system decontamination with the fuel in place, as a follow-on to the 1995 Indian Point-2 fuelout demonstrations.

CONCLUSIONS

Technology developments in radiation field control continue to occur at a rapid pace, with an accelerating rate of implementation at nuclear power plants as utilities move to meet 1995 exposure goals.

Author Biography

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DISCUSSION

Unknown: In some different presentations that I've heard in the past few conferences, and repeated here, we talk about exposures having bottomed out. I was wondering if anyone has been doing any research or compiling any data because I think, that although it's true that we've bottomed out, I still think that we are forgetting about some certain basic things about why it's bottomed out. What I would like to know is are we still looking at exposures due to poor work practices. They're still out there believe it or not. We're still doing some poor things in planning, poor things in scheduling and such. How much exposure is due to what may be termed as "unreasonable regulation" and that type of thing? My feeling is that there is still about 20% reduction due to those things.

Wood: EPRI is not doing any work in that area, but maybe John can answer that.

Baum: Of course, we collect information from the plants as we can, but I don't have any particular response to that question. Does anyone else from the PWR or BWR Owner's Group, for example, who meet frequently on these questions, have an answer?

Cybul: From INPO's perspective, I agree 100% that there is a lot of room for improvement and much yet to be gained in the work practices area. We're putting a lot of emphasis into that. I think we will do that, but we still need to do the technical side.

Baum: The Nuclear Energy Agency held a workshop on that subject about a year ago and there has been a publication on that which you might find helpful.