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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF NIOSH WHITE PAPER, "THE NEUTRON EXPOSURE AT THE PIQUA ORGANIC MODERATED REACTOR," DATED MARCH 3, 2011

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ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission
CAM	Continuous Air Monitor
cc	cubic centimeter
Ci	Curies
cm^2	square centimeter
ER	Evaluation Report
INL	Idaho National Laboratory
mR	milliRoentgen
mrem	millirem
MWt	megawatt thermal
NIOSH	National Institute for Occupational Safety and Health
POMR	Piqua Organic Moderated Reactor
rem	Roentgen equivalent man
SC&A	S. Cohen and Associates
SRDB	Site Research Database

1.0 INTRODUCTION

Prior to the July 8, 2010, meeting of the Work Group for the Piqua Organically Moderated Reactor (POMR), SC&A was asked to perform a cursory review of the Piqua Evaluation Report (ER) (NIOSH 2009). The review consisted only of reading the ER and identifying any areas that appeared to be technically weak or "soft." The review did not include a query of the site research database (SRDB), a check of all the numbers, or a site data capture, including interviews. "Soft" area issues resulting from this review were raised during the meeting of the Work Group on the POMR, held on July 8, 2010.

At the meeting, NIOSH committed to provide a white paper that would evaluate the so-called "soft" areas. These areas included (1) the tritium and carbon-14 assumptions used for the occupational inhalation exposures, related lack of tritium concentration measurements, and the potential difference in exposure between the general plant environment, as measured by Continuous Air Monitors (CAMS) and that experienced by workers who were breaching contaminated systems during activities such as filter change outs, and (2) the assumptions for the dose calculations due to neutron exposure.

NIOSH's white paper, *Tritium and Carbon-14 Organic Moderated Reactors at Piqua and INL* (NIOSH 2010), addressed the tritium/carbon-14 issue. SC&A performed a cursory review of the white paper (SC&A 2010) and agreed with NIOSH's position on the volatility issues of tritium and C-14 as technically defensible.

NIOSH's white paper, *The Neutron Exposure at the Piqua Organic Moderated Reactor* (NIOSH 2011), addressed the neutron exposure issue. SC&A performed a cursory review of the second white paper. The following provides a summary of the issue, the white paper response, and the SC&A conclusion.

2.0 EXTERNAL DOSE FROM NEUTRON EXPOSURE ISSUE

2.1 Evaluation Report Methodology

NIOSH has not located any primary external dosimetry records (e.g., original dosimetry records) for the Piqua workers during the operational period. External data that have been found are in the form of exposure summary reports and monthly and semi-annual operational progress reports for the years 1963 through 1966. Based on the available summary data, the individual data reports [reported to Atomic Energy Commission (AEC) as whole-body radiation exposures to penetrating radiation] would likely have included neutron dose, had any been detected. However, in order to interpret the data in a claimant-favorable manner, NIOSH used paired measurements of neutron and photon doses to establish a neutron-to-photon ratio, and then added the derived neutron dose to the photon dose. In this way, NIOSH ensured that the neutron dose was not overlooked.

Two measured values, each indicated as <0.5 mrem/hr, were taken, one in a location where the concurrent gamma reading was 13.5 mR/hr and the other in a location where the concurrent gamma reading was 11 mR/hr. The first detectable reading had a resulting neutron-to-photon

ratio of 3.7% (0.037 to 1) and the second of 4.5% (0.045 to 1). Based on this information, NIOSH used a neutron-to-photon ratio of 10% as a bounding ratio to assess the bounding neutron dose, given a bounding photon dose.

In turn, the bounding photon dose, according to the ER, can be assessed based on bounding assumptions from the site summary data for external dose. NIOSH explains that the data are sufficient to support bounding whole-body photon estimates for the years 1963 through 1966 from the upper bound of 1 rem for the years 1963 through 1965, and 2 rem for the year 1966.

2.2 SC&A Concern

The SC&A concern lies in the fact that there is no assurance that non-monitored workers could have received higher neutron exposures, or that every worker was monitored. There are surveys in locations where there are indications of neutron streaming and neutrons escaping. Although these locations are outside the containment, SC&A expressed concern that it is uncertain whether a worker could be present inside the containment during operation. In response to that concern expressed during the work group meeting, NIOSH committed to check and verify that personnel had no access to the containment during reactor operation. In general, SC&A indicated that a closer look in the neutron survey data is warranted.

2.3 White Paper Response

NIOSH's draft white paper (NIOSH 2011), responds to SC&A concerns by providing documented answers to the following questions/issues: (1) Was every worker monitored; (2) Did workers have access to containment; (3) What documentation exists on neutron exposure levels; and (4) How is worker exposure estimated from survey data? The following summarize the white paper positions.

(1) Was every worker monitored?

The white paper states that in interviews with former workers, each person interviewed stated that film badges were worn at all times by workers and pocket dosimeters were routinely used. A former health physics technician at the plant stated that workers in the Auxiliary Building wore film badges that were exchanged monthly and later reduced to quarterly. Interviews also indicated that workers in the area always wore their film badges.

(2) Did workers have access to containment?

The white paper provided a figure showing the physical arrangement of the Reactor Building and the Auxiliary Building. The two buildings were adjacent and formed a single structure. The access between the buildings was at the 100-foot level, ground level for the Reactor Building. Double air-locks were used to maintain reduced air pressure in the Reactor Building. The reactor and most of the associated components were below grade to provide additional shielding.

The *Piqua Operating Limits and Controls* (AI 1965) procedures included the following: "No person shall enter the reactor containment shell during periods when the procedure is applicable

without first obtaining permission from the shift leader." Activities were controlled under this manual by Special Work Permits and Extended Work Permits.

A column of ordinary concrete surrounded the reactor vessel and extended upward outside of the reactor vessel to the floor level. This column served both as a biological shielding and as the foundation for the reactor. There was no worker access through this shield. Reactor radial shielding was achieved through (1) an inner thermal shield with 1.5-inch steel, (2) an outer thermal shield with 4.0-inch steel, (3) a reactor vessel wall with 1.125-in steel, and (4) a biological shield with 8 feet and 4 inches of ordinary concrete. Shielding above the reactor was achieved through (1) the upper grid plate with 8-inch steel (2) organic coolant, measuring 17.5 feet, and (3) a reactor vessel head with 8.5-in steel.

(3) What documentation is there on neutron exposure levels?

The white paper responds to this issue by providing documented information on the existing survey data, dosimetry results, interviews with former employees, and a theoretical approach to the neutron flux levels that could have existed outside the biological shield.

Survey Data

According to NIOSH, a series of Post-Critical Operational Tests were performed at several power levels, increasing eventually to full power (45.5 MWt). Twenty-nine (29) points were selected in the Reactor Building prior to power operation and surveyed during each step increase. Measurements taken at the 55% power level showed gamma radiation to be at background levels within the Reactor Building on the main floor, the 100-foot level above the reactor. No neutrons were detected at any location surveyed when testing. During a neutron survey with the reactor at full power, the only detectable neutron levels that were found were within the pump rooms at the two coolant lines where they emerged from the biological shield. The radiation survey data for the full power test, including the neutron results, were presented in the white paper. The only detectable neutron levels were reported as "less than 0.5 mrem/hr."

Dosimetry

A report to the AEC summarized personnel exposures for Atomic International workers who worked at the Piqua Plant. It indicated zero collective neutron exposure for the period April 1963 through August 1965 for those workers.

Interview

During the interviews, a health physics technician stated that neutron surveys were performed routinely, at least monthly, and that extensive surveys were performed whenever the reactor increased power levels. The interview reinforced the assumption that 0.5 mrem/hr was the highest neutron level encountered during the surveys.

Activation in Concrete Shield

According to NIOSH, a 1969 report from Atomics International (Hewson 1969) included estimates of the average lifetime neutron flux within the reactor components and within the inner concrete of the biological shield. A graph of the calculated flux levels, presented in the white paper, showed approximately 107 neutrons/cm^2/second at about 60 centimeters into the concrete shield. Extending the plotted line to the outer edge of the shield at 390 centimeters from the core centerline provides an estimate of 10^{-2} neutrons/cm^2/second at the outer surface. Using the Nuclear Regulatory Commission generic conversion factor for typical nuclear plant neutron spectra (9.0E-6 mrem cm^2), the resulting average exposure due to neutrons would have been about 3 microrem/hr, or approximately 6 mrem/yr for 2,000 working hours per year.

(4) How is worker exposure estimated from survey data?

As discussed in NIOSH's ER methodology above, annual reports were made to the AEC and the data were subsequently published in AEC reports that summarized annual, whole-body exposures. For the years 1963 through 1965, 8 persons were reported to be in the 1 to 2 rem range. This was the maximum range reported. Although it is expected that any neutron exposures would have been included in the values reported to the AEC, the 1 and 2 rem values were assumed to be solely gamma exposure. NIOSH used a neutron-to-photon ratio of 10% as the ratio to assess the bounding neutron dose, given a bounding photon dose. This was based on the assumption that there was no place within the plant during its operation where a worker could receive a neutron dose without also receiving an associated gamma dose.

2.4 SC&A Conclusion

Based on the cursory review of the white paper, SC&A concludes that the position taken by the white paper on the External Dose from Neutron Exposure issue is technically defensible. Moreover, the paper's extensive close look at the data available alleviates SC&A concerns on the uncertainty issues related with neutron exposures at the POMR. SC&A concurs that the approach used in the ER for calculating doses from neutron exposure is bounding and claimant favorable.

3.0 REFERENCES

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