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Formerly Utilized Sites Remedial Action Program (FUSRAP)
Contract No. DE-AC05-81OR20722

# HAZARD ASSESSMENT FOR RADIOACTIVE CONTAMINATION IN AND BENEATH CERTAIN BUILDINGS AT THE ALBANY RESEARCH CENTER

## Albany, Oregon

September 1989

Bechtel National, Inc.

# HAZARD ASSESSMENT FOR RADIOACTIVE CONTAMINATION IN AND BENEATH CERTAIN BUILDINGS AT THE ALBANY RESEARCH CENTER ALBANY, OREGON

SEPTEMBER 1989

Prepared for

UNITED STATES DEPARTMENT OF ENERGY

OAK RIDGE OPERATIONS OFFICE

Under Contract No. DE-AC05-81OR20722

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## ABBREVIATIONS

| | |
|---|---|
| cm | centimeter |
| cpm | counts per minute |
| dpm | disintegrations per minute |
| ft | foot |
| FY | fiscal year |
| g | gram |
| h | hour |
| in. | inch |
| kg | kilogram |
| m | meter |
| mrem | millirem |
| mrem/yr | millirems per year |
| μR | microroentgen |
| pCi | picocuries |
| rem | roentgen equivalent (in) man |
| wk | week |
| yd | yard |
| yr | yr |

## ACRONYMS

| | |
|---|---|
| AEC | Atomic Energy Commission |
| ARC | Albany Research Center |
| CFR | Code of Federal Regulations |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FUSRAP | Formerly Utilized Sites Remedial Action Program |
| MED | Manhattan Engineer District |

# 1.0 INTRODUCTION AND SUMMARY

## 1.1 OBJECTIVE AND SCOPE

The objective of this report is to evaluate the risks associated with the residual radioactive material at several specific locations at the Albany Research Center (ARC) in Albany, Oregon. This report provides an assessment of the risks of potential exposure at these locations, the methodology used to estimate the exposures from this contamination, and estimates of the cost for remediating these areas.

U.S. Department of Energy (DOE) protocol provides for the release of property without radiological restrictions in cases where residual radioactive material may exceed generic guidelines but where the contamination does not pose a potential present or future exposure risk and where the cost of remedial action is unreasonably high relative to the long-term benefits (Ref. 1). Most of the contamination subject to the Formerly Utilized Sites Remedial Action Program (FUSRAP) remedial activities at ARC has been or will be removed. However, there are several areas at ARC where the application of supplemental limits would seem justifiable without posing an undue exposure risk to workers or members of the general public. The specific locations addressed by this hazard assessment are:

| Building | Location |
|---|---|
| 4 | Room 105 piping from manholes |
| 17 | Subfloor soils |
| 28 | Floor drains and interconnecting piping |
| 29 | Drain pipes under floor |
| 30 | Floor drains and interconnecting piping |
| 31 | Drain header under main hallway |

## 1.2 BACKGROUND

During Manhattan Engineer District/Atomic Energy Commission (MED/AEC) activities, work involving radioactive materials was performed at the Albany Research Center of the U.S. Bureau of Mines in Albany, Oregon (Figure 1-1). From 1954 to 1956 and from 1960 to 1971, operations at the site involved melting, machining, welding, and producing thorium alloys. MED/AEC activity was terminated in 1978. Although some work with ores containing radioactive constituents continues at ARC, none of it is done under contract to DOE. Records indicate that as MED/AEC activities were terminated, structures were released in accordance with existing applicable guidelines (Ref. 2). Those guidelines were not as stringent as current guidelines; subsequently, DOE has conducted radiological surveys to determine the radiological condition of the site. Surveys completed in 1982 established that contamination in excess of guidelines existed at the site (Refs. 2 and 3). A follow-up radiological survey was performed in 1984 to define the locations and boundaries of the contamination identified in the 1982 surveys (Ref. 4). The radiological surveys performed indicated that the major contaminant at ARC was thorium-232 and its decay products. Subsequently, remedial action activities were performed on the grounds and in eleven buildings and included decontaminating the surfaces of floors, walls, structural members, and contaminated equipment in Buildings 2, 4, 5, 17, 19, 23, 27, 28, 29, 30, and 31. These remedial action activities resulted in the release of three buildings (2, 19, and 27) without radiological restrictions. A total of 2,275 $m^3$ (2,976 $yd^3$) of contaminated material generated during remedial action was shipped to DOE's low-level waste disposal site in Hanford, Washington. Contaminated interior areas were decontaminated and restored. Exterior areas that had been excavated were restored.

A follow-up characterization of the buildings, which indicated that several buildings contain additional contamination in excess of guidelines, was conducted in 1987 (Ref. 5). This radiological hazard assessment is based on data from that characterization.

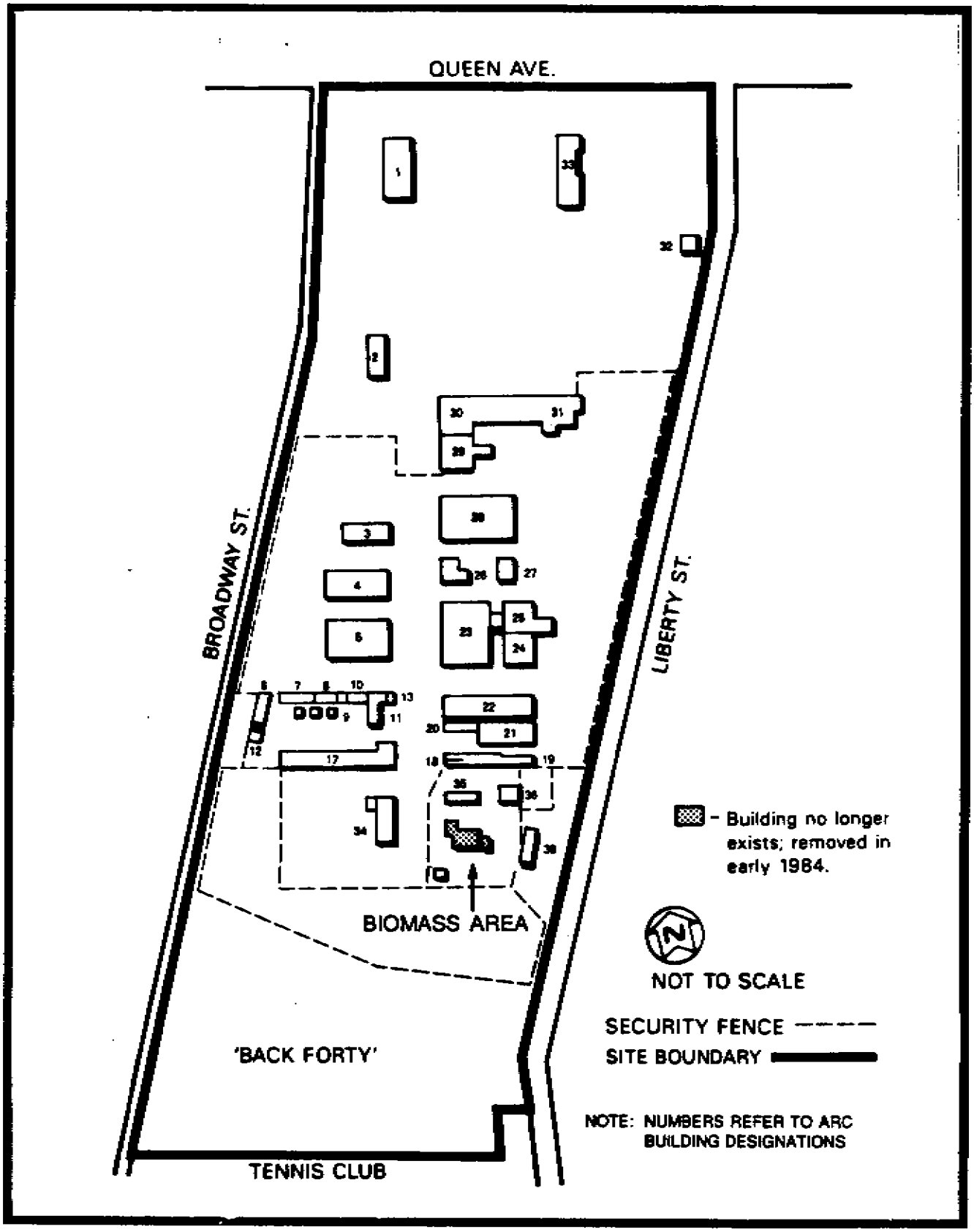



FIGURE 1-1 ALBANY RESEARCH CENTER

The 1987 characterization indicated that additional areas in 15 buildings exceeded applicable DOE guidelines. The areas covered by this hazard assessment are a very small subset of these areas. The other contaminated areas are to be remediated in the future. For additional information covering these areas, see the 1987 characterization report (Ref. 5).

## 1.3 SUMMARY

Most of the residual contamination from MED/AEC activities at ARC has been removed. The remediated areas qualify for release without radiological restrictions according to DOE guidelines. Remedial action is currently planned for areas that still exceed DOE guidelines, with two exceptions. These exceptions are:

- Areas where ongoing activities would result in recontamination (thereby negating any benefits to be derived from the cleanup activities), and
- Areas where supplemental limits can be justified.

To assess potential exposures from residual contamination in areas where supplemental limits are being considered, potential exposures to a worker in the buildings and to a future worker involved in building demolition were calculated. Additionally, the concentrations of radionuclides in debris resulting from possible future building demolition were estimated as a contingency to determine if such rubble would exceed applicable DOE guidelines for release without radiological restrictions. Areas addressed by this assessment include subfloor piping, soils, and drains.

The materials addressed in this report have little or no salvage or recycling value; therefore, the potential for human exposure to materials removed from ARC and used elsewhere was not assessed. Although potential exposures resulting from future building renovation were not evaluated specifically, the conservative estimates calculated for future building demolition workers should provide an upper limit on potential exposures resulting from building renovation.

Potential exposure scenarios were selected for this assessment because they are representative of the current and potential future uses of the ARC buildings. These two scenarios (present work activity and future demolition activity) are described in the following paragraphs. This narrative also provides the general assumptions used for dose estimation. Specific methodology is provided in Appendix A and Reference 6.

### 1.3.1 Present Work Activity

To assess worker exposure from the contaminated areas, gamma and beta-gamma radiation levels in the buildings were monitored. Areas included in this hazard assessment (the drain pipes and subfloor soils) are not easily accessible. Inhalation of this contamination by a worker is not considered a reasonable risk. Accordingly, potential inhalation doses to a present worker were not calculated for these areas.

Estimates of the dose to a worker from each building location are based on the maximum radiation levels measured at each building location. Table 1-1 provides dose estimates that represent the annual exposure a worker could receive working in a particular building location. These estimates do not include naturally occurring background radiation.

### 1.3.2 Future Work Activity

If supplemental limits were used, remedial action would not be performed on select building drain lines and subfloor soils. Therefore, the potential dose to a future worker performing demolition was evaluated. It was assumed that the worker would be exposed to airborne contamination caused by building demolition activities. The calculated dose to a future worker is based solely on inhalation doses. Direct external doses would not be significant because of the short time required for demolition. The time estimated to complete demolition is conservative because the time is calculated as manhours assuming only one person is performing the

work. The actual maximum exposure to any individual worker would be less because, typically, several persons would be involved in such work. The estimated inhalation dose to a future worker is based on the assumption that building demolition is a one-time event. Table 1-1 summarizes the inhalation doses from these activities for each building. A worker involved in demolishing all the contaminated buildings discussed in this report could receive a dose of 4.1 mrem. This cumulative dose estimate assumes that a single worker is involved in the demolition of all buildings assessed, that no respiratory protection is used during demolition, and that during demolition a worker is exposed to the maximum level of airborne particulate permissible under federal law without the use of a respirator (0.015 $g/m^3$). This scenario is highly unlikely, since demolition is normally conducted by a team of several workers protected by respiratory protection equipment. The use of such protective equipment should greatly reduce the inhalation dose. The inhalation dose would also occur if remedial action were performed in the areas covered by this hazard assessment.

### 1.3.3 Conclusion

Based on the calculations performed for this assessment, it is concluded that present or future potential exposures from the subject areas of residual contamination are or would be below the DOE standard for protection of the general public. Specifically, conservative dose estimation techniques indicate that the potential annual dose received by a present worker is well below the DOE standard of 100 mrem/yr for a member of the general public. In addition, the potential dose received by a future worker involved in building demolition is also estimated to be well below the DOE standard for a member of the general public. Calculations also show that debris resulting from demolition of these areas would, in all cases, have average specific activities of less than the applicable DOE guideline for release of soil without radiological restrictions.

TABLE 1-1

SUMMARY OF ESTIMATED RADIATION DOSE TO A PRESENT WORKER IN THE BUILDINGS AND TO A FUTURE WORKER INVOLVED IN BUILDING DEMOLITION AT THE ALBANY RESEARCH CENTER

| Radiation Source | Levels From Which Dose Rates are Calculated (cpm)[a] | Present Worker[b] External Gamma Dose (mrem/yr) | Future Worker[c,d] Inhalation Dose (mrem) |
|---|---|---|---|
| Building 4 | | | 0.075 |
| Piping from manholes | 72[e] | 0.0020 | |
| Building 17 | | | 3.8 |
| Soil under subfloor | 38,464[f] | 7.2 | |
| Building 28 | | | 0.035 |
| Floor drains and drain pipes in basement | 33,771[f] | 0.47 | |
| Building 29 | | | 0.031 |
| Drain pipes under floor | 10,965[f] | $1.9 \times 10^{-5}$ | |
| Building 30 | | | 0.08 |
| Floor drain and pipes | 10,343[f] | 0.58 | |
| Building 31 | | | 0.036 |
| Drain header in hallway | 11,522[f] | $2.3 \times 10^{-5}$ | |

[a]Background has been subtracted from values.

[b]It is assumed that the worker spends 2,000 h per yr within 1 m of the maximum contamination level found in the area assessed.

[c]Conservative doses were estimated assuming that the future worker spends all of the demolition time enshrouded in a particulate cloud composed entirely of contaminated material.

[d]Inhalation dose is estimated for the cumulative exposure resulting from demolition of all areas within a building covered in this assessment.

[e]Instrument used - Geiger-Mueller probe.

[f]Instrument used - scintillometer.

FUSRAP protocol provides for the release of property without radiological restrictions in cases where the contamination may exceed generic guidelines but where the residual radioactive material does not pose a potential present or future exposure risk and where the cost of remedial action for the contaminated material is unreasonably high relative to long-term benefits (Ref. 1).

> Remedial action will generally not be necessary where only minor quantities of residual radioactive materials are involved or where residual radioactive material occurs in an inaccessible location at which site-specific factors limit their hazard and from which they are costly or difficult to remove. Examples include residual radioactive materials under hard surface public roads and sidewalks, around public sewer lines, or in fence post foundations

As shown in this report, none of the areas evaluated in this assessment pose exposure threats that could result in human exposure in excess of the radiation protection standard for the general public. Even under the conservative assumptions used to calculate potential exposures, most of the estimates represent less than one-tenth of the allowable radiation protection standard of 100 mrem/yr. Accordingly, very little health benefit would be derived from remediating these areas.

To place the doses associated with the residual radioactive contamination at ARC in perspective, one can examine the dose incurred from natural background. The average dose from natural background in the United States is 300 mrem/yr, which includes 200 mrem/yr for radon (Ref. 7). Potential exposures from residual contamination at ARC present less than one-thirtieth of the natural background exposure rate.

Although the estimated costs of remediating the contaminated areas addressed in this assessment are low relative to the total FUSRAP budget, they are clearly high when compared to the benefits from remediation. Specific remediation costs and an analysis of the resulting benefits are provided in Section 2.0.

In conclusion, supplemental limits appear to be warranted because the material that would be left in place does not pose a present or future health risk and the cost of remedial action is high relative to the long-term benefits.

## 2.0 REMEDIAL ACTION COST ESTIMATE

This section presents the estimated costs and relative benefits of remediating the subject areas. The specific locations were selected because the residual radioactive materials are not expected to pose a potential present or future hazard (see Section 3.0), and the anticipated cost of remediation is unreasonably high relative to the benefits.

Cost estimates for remedial action at ARC are based on the field experience of removing material during the 1987 remedial action at ARC, on similar work at other facilities, and on engineering experience. These costs include engineering design, construction setup, removal of material, radiation monitoring support, chemical testing, waste transportation and disposal, restoration of the facility, and project support costs associated with removal actions.

Cost estimates do not include the cost of lost productivity at ARC during remedial activities. Remediation of subfloor materials, for example, would be particularly disruptive, as all overlying materials would have to be demolished and excavated to allow access to the residual contamination. Before the location could be restored to its original condition, the independent verification contractor would have to confirm that all above-guideline contamination had been removed. The effort would require relocation of equipment and furniture, and would affect any ongoing ARC activities in the area.

Cost estimates were developed by defining the specific scope of work to be performed based on the site characterization, an engineering evaluation, and input from the construction superintendent in charge during the 1987 remedial action work. The total volume of material that would be removed from these areas is estimated to be 99 $m^3$ (129 $yd^3$). The cost is given in FY 1989 dollars with no escalation factor for work performed at a later date. The estimates for each area are provided in Table 2-1.

TABLE 2-1

ESTIMATED REMEDIAL ACTION COSTS

| Building | Location | Unit Cost ($/yd$^3$) | Volume (yd$^3$)[a] | Total Cost Per Area ($)[b,c] |
|---|---|---|---|---|
| 4 | Piping from manholes in Room 105 | 27,000 | 2.6 | 69,000 |
| 17 | Subfloor soils | 2,600 | 96 | 250,000 |
| 28 | Floor drains and interconnecting piping | 27,000 | 2.0 | 54,000 |
| 29 | Drain pipes under floor | 27,000 | 6.8 | 181,000 |
| 30 | Floor drains and interconnecting piping | 26,000 | 15.9 | 420,000 |
| 31 | Drain header under main hallway | 26,000 | 5.7 | 150,000 |

[a]Volume includes materials to be remediated.

[b]Excludes cost of lost productivity at ARC during remedial action.

[c]In FY 1989 dollars.

Additionally, cost-effectiveness estimates were calculated in terms of cost per mrem per year of potential exposure avoided and are given in Table 2-2. It should be noted that the methodology used to calculate potential exposures was conservative, which results in an overestimation of the cost-effectiveness of exposure prevention from remediation. The potential dose received by a future demolition worker was not factored into these calculations because these exposures would not be avoided by remediating these areas. Rather, these exposures would simply occur sooner. In either case, demolition or remediation, worker exposures would be small.

The unit cost for remedial action work at the selected locations being evaluated for supplemental limits is estimated to range from $2,600 to $27,000 per cubic yard. The significant difference between the cost of removing residual radioactive material from the subject areas at ARC and the standard cost for the rest of the program indicates that the cost of removing the radioactive material from ARC may be unreasonably high.

From the standpoint of exposure reduction, remediating the subject areas would not be cost-effective when compared to radiation protection measures used by other DOE programs and elsewhere. If such remediation measures were implemented, the unit cost for dose avoided for a present worker at the selected locations would range from $35,000 to $9.5 billion per man-rem per year. Although no specific cost-effectiveness criterion is consistently applied to exposure management strategies, a cost of approximately $1,000 per man-rem avoided per year has been used (Ref. 8). The term man-rem is equivalent to one rem of radiation dose to one person.

TABLE 2-2

COST-EFFECTIVENESS OF REMEDIAL ACTION

| Building | Location | Total Cost Per Area ($)[a,b] | Unit Cost for Dose Avoided for Present Worker ($/mrem/yr)[b] |
|---|---|---|---|
| 4 | Piping from manholes in Room 105 | 69,000 | $3.5 \times 10^7$ |
| 17 | Subfloor soils | 250,000 | 35,000 |
| 28 | Floor drains and interconnecting piping | 54,000 | 115,000 |
| 29 | Drain pipes under floor | 181,000 | $9.5 \times 10^9$ |
| 30 | Floor drains and interconnecting piping | 420,000 | 720,000 |
| 31 | Drain header under main hallway | 150,000 | $6.5 \times 10^9$ |

[a]Excludes cost of lost productivity at ARC during remedial action.

[b]In FY 1989 dollars.

## 3.0 BUILDING ASSESSMENTS

The general methodology used to assess the potential exposures posed by selected contaminated areas in some of the buildings at ARC is included in Appendix A. Specific calculations and assumptions used for each area assessed are provided in Reference 9.

The dose rate to a present worker was calculated as follows: for each assessment, it was assumed that during a 40-h work week the worker remains within 1 m of the contaminated materials during the entire 40 h. Using applicable conversion factors, gamma and beta-gamma survey measurements were used to calculate the specific activity (activity per unit mass) of the contaminated materials. Subsequently, worker exposure rates were calculated using the methods detailed in the supplement to the DOE guidelines (Ref. 6).

Dose calculations, where appropriate, account for the attenuation provided by construction materials overlying the contaminated material (e.g., concrete slab and fill located over contaminated piping). In addition, calculations incorporate the attenuation that occurs between the contaminated material and the worker. Calculations for contaminated areas are based on the highest measurement observed for that specific contaminated area. Dose rates for a present worker are based entirely on external dose calculations.

Exposure rates potentially encountered by a worker involved in the demolition of contaminated portions of ARC were also assessed. Estimates of the inhalation dose resulting from demolition activity assume that the contamination becomes airborne during demolition. A mass loading factor of $1.5 \times 10^{-2}$ g/m$^3$ was used, which is equivalent to the maximum level allowable under current federal law for worker exposure to airborne dust without the use of a respirator (Ref. 10). The duration required for building demolition was estimated on a building-specific basis using standard references (Ref. 11). Additional details on the potential inhalation dose are

provided by calculation sheets in Appendix A and by references cited throughout this document.

The specific activity of debris resulting from the demolition of the ARC buildings was also calculated. For all calculations, it was assumed that contaminated areas are homogenized with overlying noncontaminated materials generated during building demolition. The specific activity of debris generated from demolition was calculated using volume and specific activity data for both contaminated and uncontaminated areas. No further exposure calculations were performed because the contamination level of the building rubble was below applicable guidelines (Ref. 6).

ARC did not have drawings showing the locations of drain piping; therefore, the exact locations and the extent of the drainage systems at ARC are not known with precision. Assumptions have been made based on the locations of drains and outfalls, and on discussions with ARC personnel.

## 3.1 BUILDING 4

### 3.1.1 General Description of Contaminated Areas

Building 4 has a radioactively contaminated trench and connecting drain pipe. Figure 3-1 shows the location of the contaminated piping from manholes. The drain pipe has a diameter of 0.15 m (6 in.) and is 0.6 m (2 ft) beneath the floor surface.

### 3.1.2 Results of the Building 4 Assessment

The external gamma radiation dose to a worker inside Building 4 is 0.0020 mrem/yr from the piping from the manholes. The estimated inhalation dose to a worker involved in the demolition of Building 4 is 0.075 mrem. The specific activity calculated for the debris that would result from the demolition of Building 4 is 0.0022 pCi/g of thorium-232.

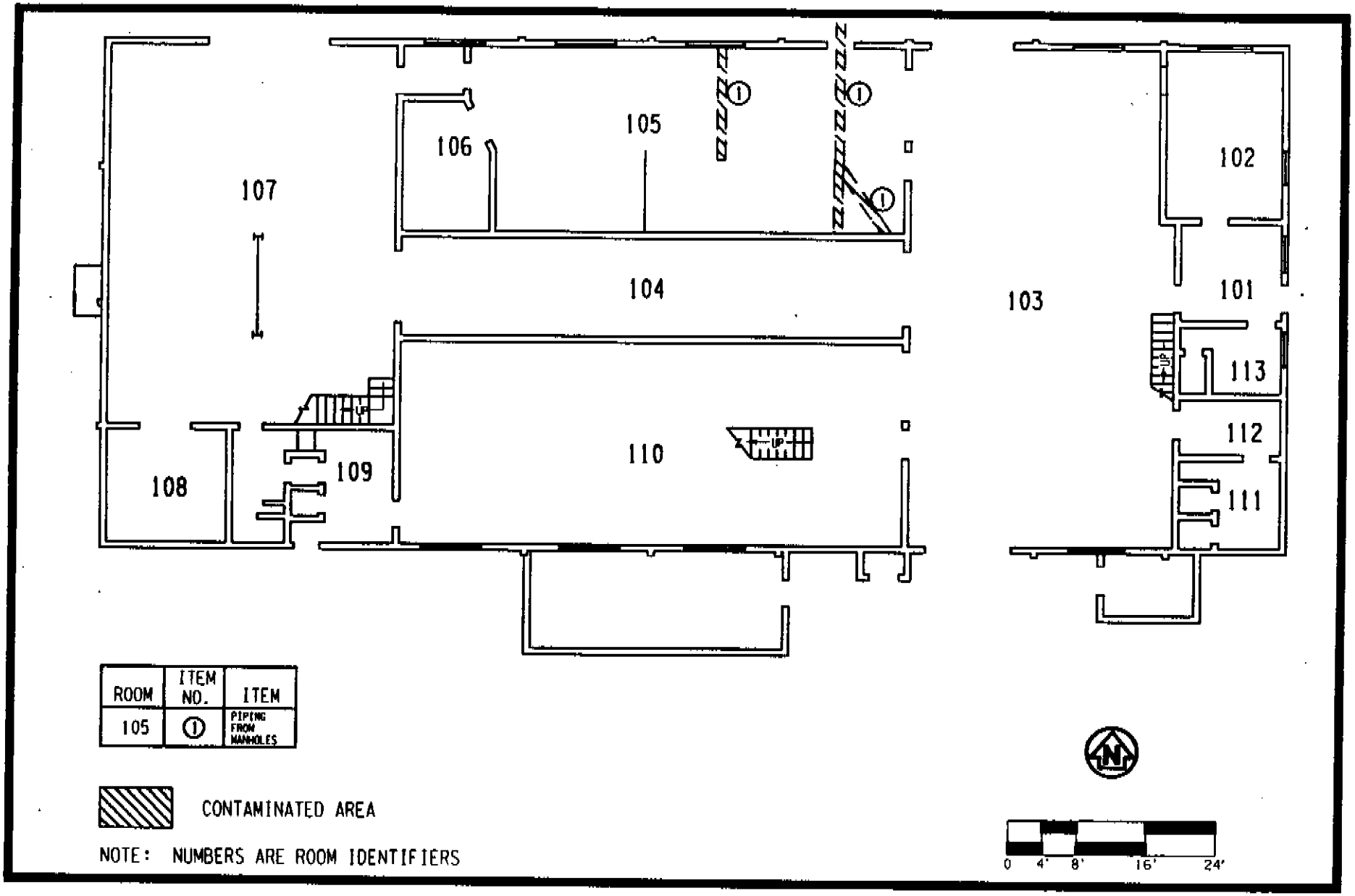



FIGURE 3-1 BUILDING 4

102F009.DGN

## 3.2 BUILDING 17

### 3.2.1 General Description of Contaminated Areas

The location of the contaminated subfloor soils in Building 17 are shown in Figure 3-2.

### 3.2.2 Results of the Building 17 Assessment

The potential dose from the subfloor soils was estimated by choosing the highest instrument reading and applying it to the open storage area in Building 17. The total potential dose to a present worker in the open storage area is 7.2 mrem/yr from subfloor soils. The estimated inhalation dose to a worker involved in the demolition of Building 17 is 3.8 mrem. For the debris that would result from the demolition of Building 17, the specific activity calculated is 2.7 pCi/g of thorium-232.

## 3.3 BUILDING 28

### 3.3.1 General Description of Contaminated Areas

Building 28 is underlain by a run of radioactively contaminated floor drains and connecting drain pipes (Figure 3-3). The drain pipes have a diameter of 0.10-m (4-in.) and are approximately 0.91 m (3 ft) beneath the floor surface.

### 3.3.2 Results of the Building 28 Assessment

The external gamma radiation dose to a worker inside Building 28 from the drain and drain pipes is 0.47 mrem/yr. The estimated inhalation dose to a worker involved in the demolition of Building 28 is 0.035 mrem. For the debris that would result from the demolition of Building 28, the specific activity calculated is $7.7 \times 10^{-4}$ pCi/g for thorium-232.

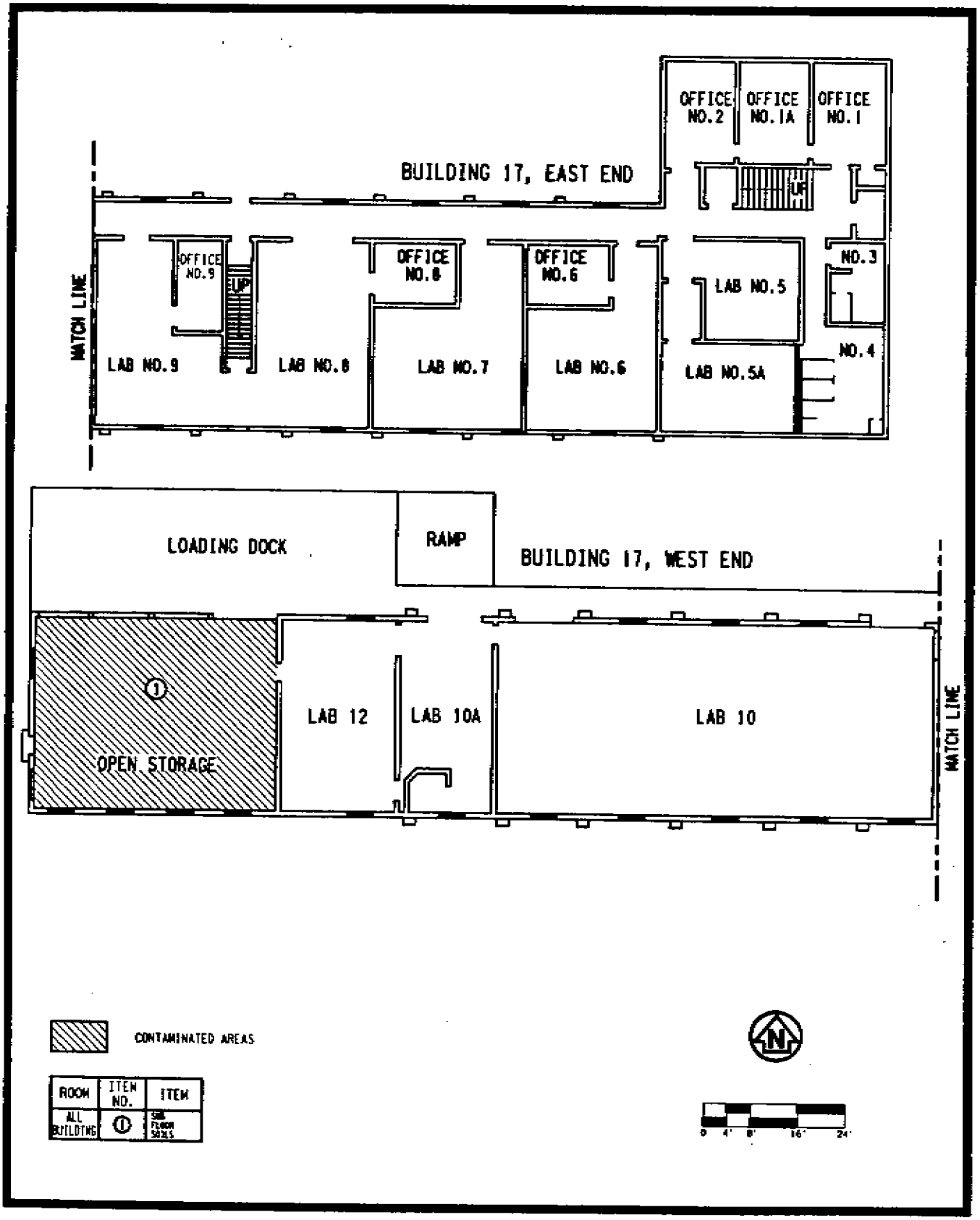
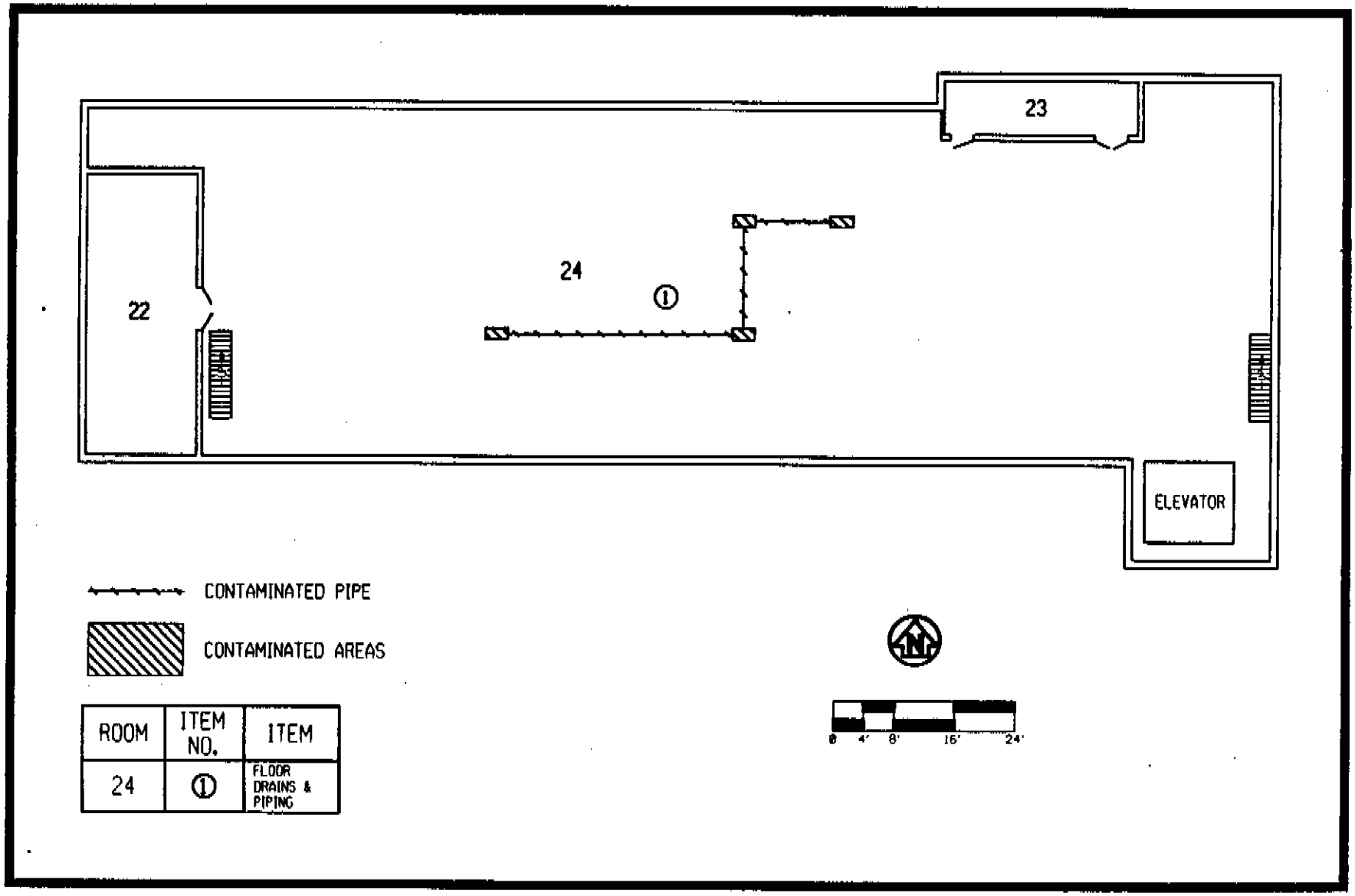



FIGURE 3-2 BUILDING 17



DG17C.DGN




| ROOM | ITEM NO. | ITEM |
|---|---|---|
| 24 | 1 | FLOOR DRAINS & PIPING |

**FIGURE 3-3 BUILDING 28**

BLDG28C2.DGN

## 3.4 BUILDING 29

### 3.4.1 General Description of Contaminated Areas

Building 29 is underlain by radioactively contaminated drain pipes. The locations of all contaminated drain lines are shown in Figure 3-4. The drain pipes range in diameter from 0.10 m (4 in.) to 0.15 m (6 in.) and are approximately 1.2 m (4 ft) beneath the floor surface.

### 3.4.2 Results of the Building 29 Assessment

The external gamma radiation dose to a worker inside Building 29 from the drain pipes is $1.9 \times 10^{-5}$ mrem/yr. The estimated inhalation dose to a worker involved in the demolition of Building 29 is 0.031 mrem. The specific activity calculated for the debris that would result from the demolition of Building 29 is 0.002 pCi/g of thorium-232.

## 3.5 BUILDING 30

### 3.5.1 General Description of Contaminated Areas

Building 30 is underlain by a system of radioactively contaminated floor drains and connecting drain pipe. The locations of all contaminated floor drains and drain lines are shown in Figure 3-5. The drain pipes range in diameter from 0.10 m (4 in.) to 0.15 m (6 in.) and are approximately 1.2 m (4 ft) beneath the floor surface.

### 3.5.2 Results of the Building 30 Assessment

The external gamma radiation dose to a worker inside Building 30 from the floor drains and drain pipes is 0.58 mrem/yr. The estimated inhalation dose to a worker involved in the demolition of Building 30 is 0.08 mrem. For the debris that would result from the demolition of Building 30, the specific activity calculated is $1.9 \times 10^{-4}$ pCi/g for thorium-232.

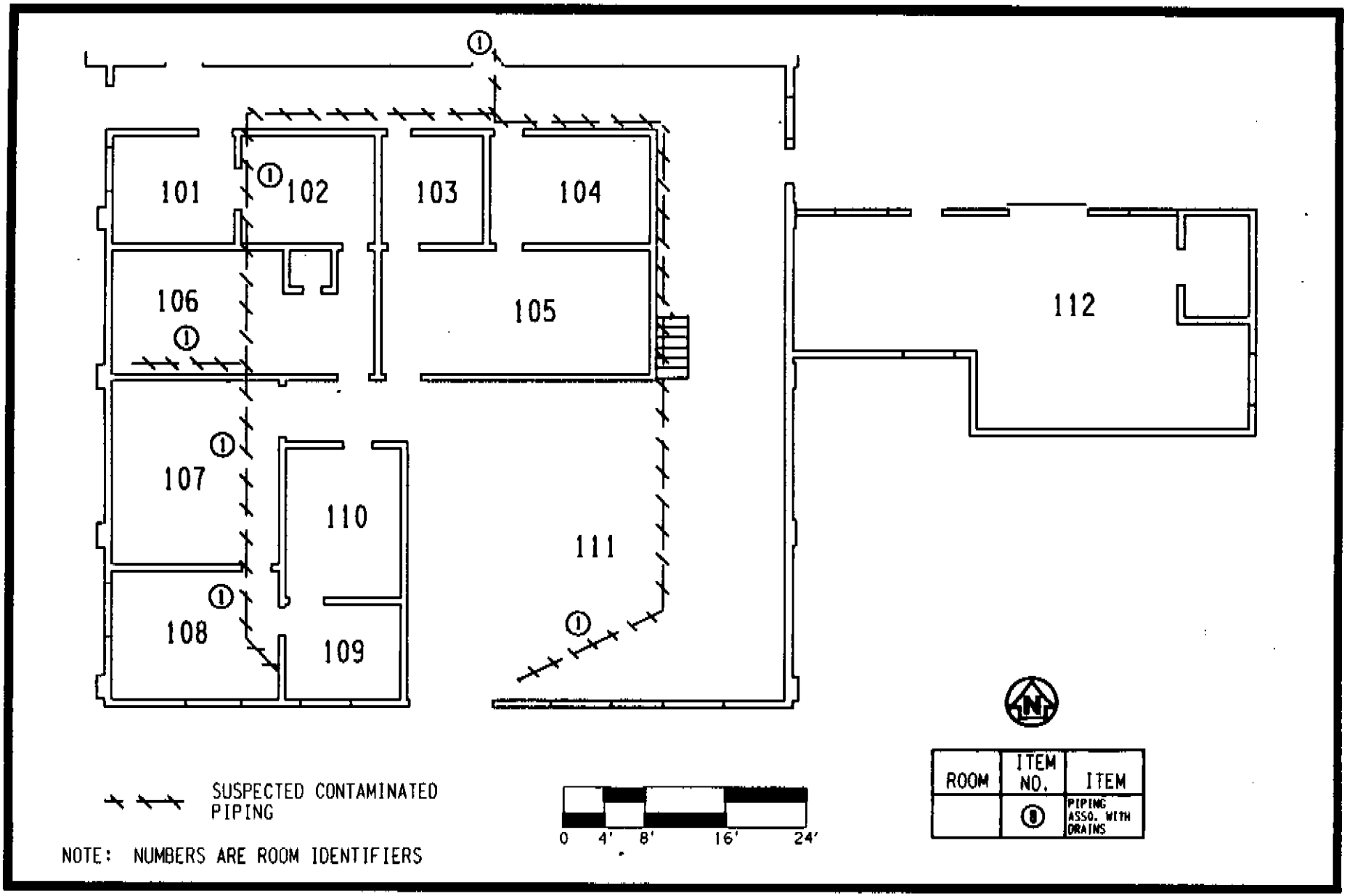
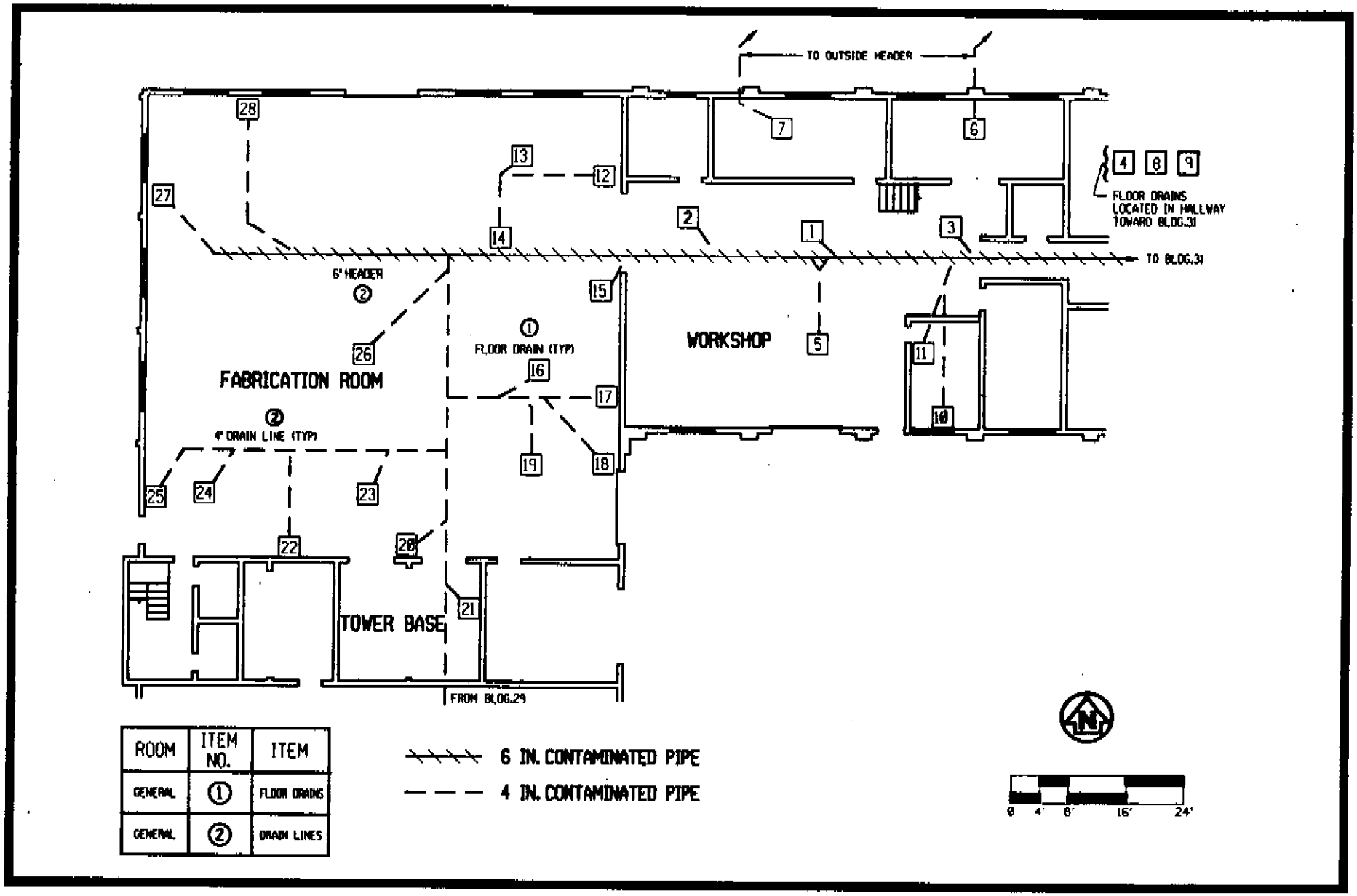



FIGURE 3-4 BUILDING 29

102F010.DGN




| ROOM | ITEM NO. | ITEM |
|---|---|---|
| GENERAL | 1 | FLOOR DRAINS |
| GENERAL | 2 | DRAIN LINES |

FIGURE 3-5 BUILDING 30

BLDG3082.DGN

## 3.6 BUILDING 31

### 3.6.1 General Description of Contaminated Areas

Building 31 is underlain by a radioactively contaminated drain header (Figure 3-6). The drain header has a diameter of 0.15 m (6 in.) and is approximately 1.2 m (4 ft) beneath the floor surface.

### 3.6.2 Results of the Building 31 Assessment

The external gamma radiation dose to a worker inside Building 31 from the drain header is $2.3 \times 10^{-5}$ mrem/yr. The estimated inhalation dose to a worker involved in the demolition of Building 31 is 0.036 mrem. For the debris that would result from the demolition of Building 31, the specific activity calculated is $8.0 \times 10^{-4}$ pCi/g for thorium-232.

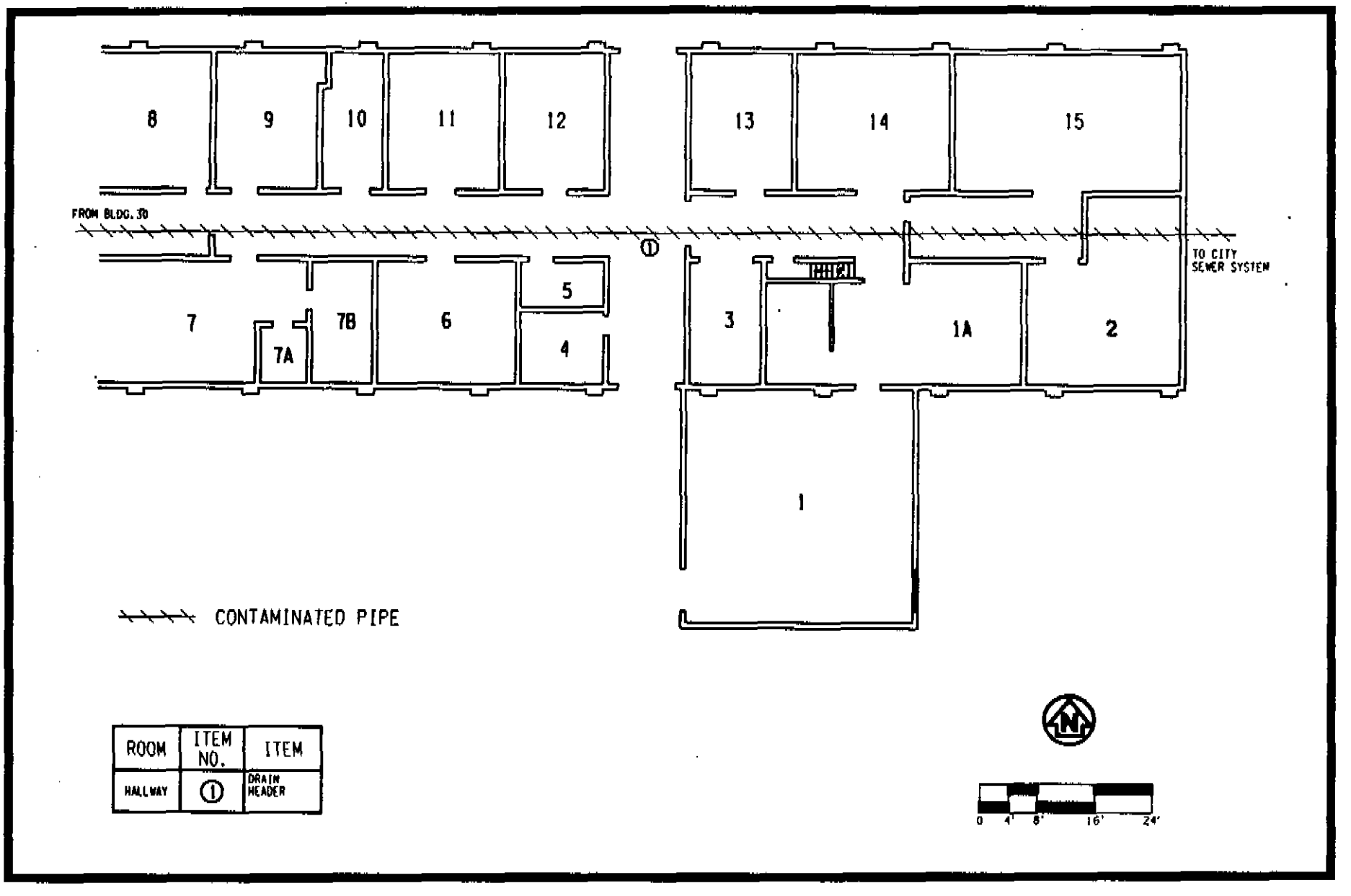



FIGURE 3-6 BUILDING 31

BLDG31B2.DGN

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# APPENDIX A

# GENERIC CALCULATIONS

## General Methodology Used to Perform Exposure Calculations

This appendix provides the general methodology used to perform exposure calculations for select areas of residual contamination at ARC. These examples provide sufficient information for the reviewer to follow the basic approach used to estimate the exposures provided in Table 1-1. Actual calculations and detailed information on the specific assumptions used for each area are provided in Reference A1.

Three types of calculations were performed:

- The potential exposure received by a present worker
- The potential exposure received by a worker involved in the demolition of the buildings in which there are contaminated areas
- The specific activity of debris that may result from demolition of buildings in which there are contaminated areas

For areas with both shielded and unshielded contaminated material, the calculated exposure rates were combined to provide a total dose estimate.

The methodologies for each of these types of calculations are provided in examples on the following pages.

EXAMPLE A-1

CALCULATION: Dose calculation based on scintillometer readings from unshielded contaminated material

Calculation for pCi/g

Scintillometer reading = Y cpm

To convert the direct readings from cpm to pCi/g, a conversion factor is required. The conversion factor is determined by multiplying the μR/h of the entire thorium-232 decay chain by the average cpm/(μR/h) for the instrument (Ref. A2). The decay of the thorium-232 chain produces 2.82 (μR/h)/(pCi/g).

Conversion factor =

$$\frac{(2.82\ \mu R/h)}{(\text{pCi/g of Th-232 decay at equilibrium})}\ (1{,}200\ \text{cpm}/\mu R/h)$$

$$= 3{,}380\ \text{cpm/pCi/g}$$

$$\text{pCi/g} = \frac{Y\ \text{cpm}}{3{,}380\ \text{cpm/pCi/g}} = \text{Specific Activity (SA) pCi/g}$$

(Ref. A3)

Specific activity of contaminated material = SA pCi/g

Calculation of dose at 1 m from the contaminated material

Dose(at 1 m) = (Specific activity of contaminated material) · (Effective dose equivalent conversion factor) · (Density of material) · (Area factor [AF]) · (Occupancy factor) (Ref. A4)

The effective dose equivalent conversion factor ($DCF_i$) is the radiation exposure received from the radionuclide$_i$ present at unit concentration from an infinitely thick source of infinite lateral extent. The radiation field is assumed to be equal to radiation at a distance of 1 m above the surface. The thorium-232 decay chain is assumed to be in secular equilibrium. This generates a $DCF_t$ of:

$$DCF_t = DCF_1 + DCF_2 + DCF_3$$

where

$$DCF_1 = DCF_{(Th-232)} = 6.04 \times 10^{-4} \text{ (mrem/yr)/(pCi/cm}^3\text{)}$$

$$DCF_2 = DCF_{(Ra-228 + \text{ daughters less than 1 year})}$$

$$= 4.51 \text{ (mrem/yr)/(pCi/cm}^3\text{)}$$

$$DCF_3 = DCF_{(Th-228 + \text{ all other decay chain daughters})}$$

$$= 7.36 \text{ (mrem/yr)/(pCi/cm}^3\text{)}$$

therefore,

$$DCF_t = (6.04 \times 10^{-4}) + 4.51 + 7.36 = 11.9 \frac{\text{mrem/yr}}{\text{pCi/cm}^3} \quad \text{(Ref. A4)}$$

Areas assessed were comprised of compacted soils, ceramic material, or concrete. The density of these types of material range from approximately 1.4 to 2.2 g/cm$^3$. The density used is the average of the above, or 1.8 g/cm$^3$ (Ref. A5).

The area factor provides for the adjustment of the effective dose equivalent conversion factor from an infinite lateral extent to the actual area of the contamination. Reference A4 provides a table with the area factors calculated for several areas and suggests interpolating area factors for areas between the given values.

Area factors for disk-shaped surfaces were used. The assumption of disk-shaped contamination is conservative because the potential exposure to a given individual would be increased due to the concentration of the contaminated material into a disk.

The occupancy factor takes into account the fraction of the time that an area is likely to be occupied by a given individual (Ref. A6). It was assumed that workers would spend all of their working time within 1 m of the contamination. Accordingly:

$$\text{Occupancy factor} = \frac{(40 \text{ h/wk})(50 \text{ wk/yr})}{(24 \text{ h/day})(365 \text{ day/yr})} = 0.23$$

Therefore, the dose at 1 m from the contaminated material is:

$$\text{Dose} = (\text{SA pCi/g})(11.9 \frac{\text{mrem/yr}}{\text{pCi/cm}^3})(1.8 \text{ g/cm}^3)(\text{AF})(0.23)$$

$$= \text{DS mrem/yr}$$

## EXAMPLE A-2

<u>CALCULATION</u>: Dose calculation based on a scintillometer reading of shielded contaminated material

Calculating doses from shielded contaminated materials requires incorporation of a Depth Factor (DF) into the dose estimation methodology used in Example A-1.

<u>Calculation of dose at 1 m from the contaminated material</u>

Dose(at 1 m) = (Specific activity of contaminated material) · (Effective dose equivalent conversion factor) · (Density of material) · (Area factor [AF]) · (Occupancy factor) · (Depth factor) (Ref. A4)

The depth factor is calculated for a specified cover depth of clean material and contaminated zone thickness. The depth factor is approximated by the formula:

$$DF_i[C,T,d] = \exp(-kdC)[1 - \exp(-kdT)]$$

where

- T = thickness of the layer of soil contaminated with the principal radionuclide = T m
- C = uncontaminated clean cover depth = C m
- k = mass attenuation coefficient ($m^2/kg$)
- d = bulk density of soil material in the contaminated zone = 1,800 $kg/m^3$ (Ref. A4)

The empirical constant is determined from the interpolation formula:

$$k(d) = \frac{-\ln[1 - DF(0,0.15,d)]}{0.15d}$$

The k(d) is determined, using Reference A4, by selecting a DF(0,0.15,d) for thorium-228 and the remaining daughters in the decay chain. Thorium-228 including daughters was selected because it has the most energy in the decay chain. The value of DF(0,0.15,d) provided by Reference A4 is 0.75.

$$k(1,800) = \frac{-\ln(1 - 0.75)}{0.15(1,800)} = 0.0051\ m^2/kg$$

k(d) is subsequently substituted into the equation for $DF_i$ to obtain the depth factor.

$$DF_i[C\ m,\ T\ m,\ 1{,}800\ g/m^3]$$

$$= \exp[-0.0051(1{,}800)(C)](1 - \exp[-0.0051(1{,}800)(T)])$$

Therefore, the dose at 1 m from the contaminated material is:

$$\text{Dose} = (SA\ pCi/g)(11.9\ \frac{mrem/yr}{pCi/cm^3})(1.8\ g/cm^3)(AF)(0.23)(DF)$$

$$= DS\ mrem/yr$$

EXAMPLE A-3

CALCULATION: Inhalation dose calculation

Calculation for pCi/g

Scintillometer reading = Y cpm

To convert direct readings from cpm to pCi/g, a conversion factor is required. The conversion factor is determined by multiplying the μR/h of the entire thorium-232 decay chain by the average cpm/(μR/h) for the instrument (Ref. A2). The decay of the thorium-232 chain produces 2.82 (μR/h)/(pCi/g).

Conversion Factor =

$$\frac{(2.82\ \mu R/h)}{(\text{pCi/g of Th-232 decay at equilibrium})}\ (1{,}200\ \text{cpm}/\mu R/h)$$

$$= 3{,}380\ \text{cpm/pCi/g}$$

$$\text{pCi/g} = \frac{Y\ \text{cpm}}{3{,}380\ \text{cpm/pCi/g}} = SA\ \text{pCi/g} \qquad \text{(Ref. A3)}$$

Specific activity of contaminated material = SA pCi/g

Calculation of committed effective dose equivalent from the inhalation of contaminated materials

Dose(at 1 m) = (Specific activity of contaminated material) · (Mass loading factor) · (Occupancy factor) · (Inhalation rate) · (Committed effective dose equivalent conversion factor for inhalation) (Ref. A4)

The mass loading factor used in this assessment is equivalent to the maximum level to which a worker may be exposed without a respirator under existing Federal law.

Mass Loading Factor = 0.015 $g/m^3$ (Ref. A6)

The occupancy factor takes into account the time that an area is likely to be occupied by an individual. It is assumed that the demolition worker would be enshrouded in a cloud of particulate matter made up entirely of contaminated material during the period required for demolition of the contaminated areas. The time for demolition of the contaminated area is based on a rate of 0.141 man-hours/$m^3$ of demolition debris (Ref. A8). The volume (V $m^3$) used is based on the volume of contaminated material including 0.15 m on each side of the contaminated material.

Time of demolition = (V $m^3$)(0.141 man-hours/$m^3$) = TM man-hours

$$\text{Occupancy Factor} = \frac{\text{TM h}}{(24\ \text{h/day})(365\ \text{day/yr})} = \text{OF}$$

The inhalation rate is based on reference man in ICRP 23 for light activity at a rate of 20 l/min (Ref. A7).

Annual Inhalation Rate = 10,512 $m^3$/yr

The committed effective dose equivalent conversion factor ($DCF_i$) is the committed effective dose equivalent that is incurred by an individual from exposure by inhalation of the radionuclide$_i$ present at unit concentration. The thorium-232 decay chain is assumed to be in secular equilibrium. The dose conversion factor is the 50-year committed effective dose equivalent. Since the lung class for the radionuclides is not known, the largest dose conversion factor for each radionuclide, lung class W, was chosen. This generates a $DCF_t$ of:

$$DCF_t = DCF_1 + DCF_2 + DCF_3$$

where

$$DCF_1 = DCF_{(Th-232)} = 1.64 \text{ mrem/pCi}$$

$$DCF_2 = DCF_{(Ra-228\ +\ \text{daughters less than 1 year})}$$

$$= 4.86 \times 10^{-3} \text{ mrem/pCi}$$

$$DCF_3 = DCF_{(Th-228\ +\ \text{all other decay chain daughters})}$$

$$DCF_3 = 0.342 \text{ mrem/pCi}$$

therefore,

$$DCF_t = 1.64 + (4.86 \times 10^{-3}) + 0.342 = 1.99 \text{ mrem/pCi}$$

(Ref. A4)

The committed effective dose from inhalation of the contaminated material during demolition is:

Dose = (SA pCi/g)(0.015 g/$m^3$)(OF)(10,512 $m^3$/yr)(1.99 mrem/pCi)

= DS mrem/yr

EXAMPLE A-4

CALCULATION: Calculation of specific activity of demolition debris

The specific activity of the demolition debris is found by multiplying the specific activity of the contamination by the mass of the contaminated material and subsequently dividing by the total mass of debris. An example using a drain pipe as the contaminated area is shown below.

Calculation for pCi/g

Scintillometer reading = Y cpm

To convert direct readings from cpm to pCi/g, a conversion factor is required. The conversion factor is determined by multiplying the μR/h of the entire thorium-232 decay chain by the cpm/(μR/h) for the instrument (Ref. A2). The decay of the thorium-232 chain produces 2.82 (μR/h)/(pCi/g).

Conversion Factor =

$$\frac{(2.82\ \mu R/h)}{(\text{pCi/g of Th-232 decay at equilibrium})}\ (1{,}100\ \text{cpm}/\mu R/h)$$

$$= 3{,}100\ \text{cpm/pCi/g}$$

$$\text{pCi/g} = \frac{Y\ \text{cpm}}{3{,}100\ \text{cpm/pCi/g}} = SA\ \text{pCi/g} \qquad \text{(Ref. A3)}$$

It was assumed that the drain pipe consisted of a length of schedule 40 pipe of L m and a diameter of D m which had a cross-sectional area of A $m^2$ (Ref. A9). It was also assumed that the drain pipe was 25 percent full of contaminated material.

Volume = $(L\ m)(A\ m^2)(0.25)(10^6\ cm^3/m^3) = V\ cm^3$

The contaminated material is likely to be primarily floor dirt that has settled into the piping. The density of this type of material ranges from approximately 1.4 to 2.2 $g/cm^3$. The density used is the average of the above, or 1.8 $g/cm^3$ (Ref. A5).

Mass of contaminated material = (density)(volume)

$$= (1.8\ g/cm^3)(V\ cm^3) = M\ g$$

It was assumed that the entire floor area of approximately A $m^2$ and the soil located above the drain pipe (approximate depth of clean overburden is CO m) were mixed with the contaminated trench and drain pipe and the material contained within them.

Total mass of material =

(mass of clean material excavated) + (mass of contaminated material)

Total mass = $(A_2\ m^2)(CO\ m)(1.8\ g/cm^3)(10^6\ cm^3/m^3) + M\ g$

$= M_t\ g$

This assessment assumes that after demolition of the floor area, the contamination originally present in the drain pipe would be homogenized with the floor and the soil mass located above the drain pipe.

Specific activity of post-demolition debris = $\frac{M}{M_t}$(SA pCi/g)

= SAD pCi/g

EXAMPLE A-5

CALCULATION: Dose calculation based on a Geiger-Müller reading

Calculation for pCi/cm$^2$

Geiger-Müller reading on contact with the surface = Y cpm

Conversion of the direct GM reading from cpm to dpm/100 cm$^2$ requires a geometry factor which takes into account the shape and size of the detector. The geometry factor is specific to the instrument type.

$$\text{Geometry Factor for detector} = \frac{1 \text{ dpm}}{(0.155 \text{ cpm})(100 \text{ cm}^2)}$$

In addition, to estimate the actual disintegrations that occur as compared to that detected, an instrument efficiency is needed. The instrument efficiency is specific to each individual instrument.

Instrument Efficiency for detector = IE%

To convert from dpm to pCi, a direct conversion of 2.22 dpm is equal to 1 pCi. This is conservative because it assumes that all activity results from thorium-232; but, in actuality, the activity measured is due to the presence of multiple daughter products. For thorium-232 in secular equilibrium, each thorium-232 disintegration results in more than one disintegration from the daughters.

$$\text{dpm/100 cm}^2 = (\text{Y cpm}) \frac{(1)}{\text{IE}} \frac{(1 \text{ dpm})}{0.155 \text{ cpm } (100 \text{ cm}^2)}$$

$$= \text{Counts per area (AC) dpm/100 cm}^2$$

Applying the conversion factor of 2.22 dpm/pCi converts the number to pCi/100 cm$^2$.

$$\text{pCi/100 cm}^2 = \frac{\text{AC dpm/100 cm}^2}{2.22 \text{ dpm/pCi}} = \text{Activity per area (AA) pCi/100 cm}^2$$

Dividing AA pCi/100 cm$^2$ by 100 converts the number to pCi/cm$^2$

pCi/cm$^2$ = Activity per unit area (AAC) pCi/cm$^2$

Calculation of dose at 1 m from the contaminated material

$$\text{Dose(at 1 m)} = \begin{array}{l}\text{(Activity per area)} \cdot \\ \text{(Effective dose equivalent conversion factor)} \cdot \\ \text{(Area factor)} \cdot \text{(Occupancy factor)}\end{array}$$

(Ref. A4)

The effective dose equivalent conversion factor ($DCF_i$) is the radiation exposure received from the radionuclide$_i$ present at unit concentration from an infinitely thin contaminated surface of infinite lateral extent. The radiation field is assumed to be equal to radiation at a distance of 1 m above the surface. The thorium-232 decay chain is assumed to be in secular equilibrium. This generates a $DCF_t$ of:

$$DCF_t = DCF_1 + DCF_2 + DCF_3$$

where

$$DCF_1 = DCF_{(Th\text{-}232)} = 7.14 \times 10^{-4} \text{ (mrem/yr)/(pCi/cm}^2\text{)}$$

$$DCF_2 = DCF_{(Ra\text{-}228 + \text{daughters less than 1 year})}$$

$$= 0.962 \text{ (mrem/yr)/(pCi/cm}^2\text{)}$$

$$DCF_3 = DCF_{(Th\text{-}228 + \text{all other decay chain daughters})}$$

$$= 1.55 \text{ (mrem/yr)/(pCi/cm}^2\text{)}$$

therefore,

$$DCF_t = (7.14 \times 10^{-4}) + 0.962 + 1.55 = 2.51 \frac{\text{mrem/yr}}{\text{pCi/cm}^2}$$

(Ref. A4)

The area factor provides for the adjustment of the effective dose equivalent conversion factor from an infinite lateral extent to the actual area of the contamination. Reference A4 provides a table with the area factors calculated for several areas and suggests interpolating area factors for areas between the given values.

Area of contaminated material = A $m^2$

Area factors for disk-shaped surfaces were used. The assumption of disk-shaped contamination with an area of A $m^2$ is conservative because the potential exposure to a given individual would be increased due to concentration of the contaminated material into a disk.

The occupancy factor takes into account the fraction of the time that an area is likely to be occupied by a given individual (Ref. A4).

$$\text{Occupancy Factor} = \frac{(40\ \text{h/wk})(50\ \text{wk/yr})}{(24\ \text{h/day})(365\ \text{day/yr})} = 0.23$$

Therefore, the dose at 1 m from the contaminated material is:

$$\text{Dose} = (\text{SA pCi/cm}^2)(2.51\ \frac{\text{mrem/yr}}{\text{pCi/cm}^2})\ (\text{AF})(0.23)$$

$$= \text{DS mrem/yr}$$

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