40 CFR Part 61
National Emission Standards
for Hazardous Pollutants

EPA 402-R-98-009

Background Information Document

ADDENDUM: Risk Assessment for Research and Development Uses of Phosphogypsum

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U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Washington, D.C. 20460

PREFACE

The Environmental Protection Agency (EPA) is promulgating revisions to 40 CFR Part 61, Subpart R, National Emission Standards for Radon Emissions from Phosphogypsum Stacks. This Background Information Document (BID) has been prepared in support of the final rulemaking. This BID contains an introduction, background of phosphogypsum, a general description of phosphogypsum, scope of the reassessment of risks to laboratory researchers, reassessment of the risks from 700 pounds of phosphogypsum, the assessment of risks from multiple activities in the same laboratories, and the summary of the reassessment.

Copies of this BID, in whole or in part, are available to all interested persons. For additional information, contact Eleanor Thornton-Jones at (202) 564-9773 or write to:

Director, Radiation Protection Division
Office of Radiation and Indoor Air (6602J)
U.S. Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

1. Introduction

This risk assessment of phosphogypsum used in laboratory research and development (R&D) activities has been prepared to support the Administrator's decision to conduct a partial reconsideration rulemaking of the NESHAP for phosphogypsum (40 CFR 61, Subpart R).

1.1 BACKGROUND

Phosphogypsum, a waste product from the production of fertilizers derived from phosphate ores, contains concentrations of radium-226 and its decay products that are significantly higher than those found in typical soils and rocks. Pursuant to its mandate under the Clean Air Act, the U.S. Environmental Protection Agency (EPA) has performed a number of risk assessments of potential human exposures to the radiation emitted from phosphogypsum. In 1989, the Agency's assessment of radionuclides emitted to the air from phosphogypsum stacks (waste piles) found that the public's risk was dominated by the potential exposure to radon-222 and its decay products (EPA89). Based on this finding, and its determination that protection of the public's health would be assured with an ample margin of safety if phosphogypsum wastes were confined to stacks or used in the reclamation of mines, the Agency promulgated a NESHAP for phosphogypsum (40 CFR 61, Subpart R). The work practice standard established by the NESHAP effectively prohibited alternative uses of phosphogypsum.

As phosphogypsum is used in agriculture, both as a soil amendment and as a nutrient for certain crops, and the industry was actively pursuing research and development of applications such as road building that would incorporate significant quantities of phosphogypsum, it petitioned the Agency to reconsider the prohibition of alternative uses. In 1990, the Agency granted a limited reconsideration of the phosphogypsum NESHAP. For the reconsideration rulemaking, the Agency broadened the scope of its risk assessment to consider exposures that could be incurred by members of the public from the use of phosphogypsum in agriculture, in road construction, and in research and development activities. The results of these risk assessments (EPA92) show that exposure to direct gamma radiation and to radon and its decay products dominate the risks for all scenarios considered. Based on these risk assessments, the Agency determined that a total ban on all alternative uses of phosphogypsum was not necessary. Therefore, it promulgated amendments to Subpart R, which allow phosphogypsum containing 10 pCi/g or less radium-226 to be used in agriculture and up to 700 pounds of phosphogypsum to be used in research and development activities. The amendments established certain monitoring and recordkeeping requirements, and provided a mechanism for other uses to be approved on a case-by-case basis.

Citing unnecessary restrictions in the Agency's final rule, the Fertilizer Institute (TFI), on behalf of industry, again petitioned for reconsideration, and the Agency has determined that another partial reconsideration is warranted. This reconsideration is limited to a reassessment of the risks for research and development activities conducted in laboratories and certain details of the monitoring and implementation requirements.

1.2 SCOPE OF THE REASSESSMENT OF RISKS TO LABORATORY RESEARCHERS

In the 1990-1992 reconsideration rulemaking, the Agency's risk assessment of research and development activities considered the potential risks that would be incurred by researchers working with phosphogypsum in a laboratory environment. Based on a scenario where phosphogypsum is continuously present in the laboratory, the Agency found that exposure to the direct gamma radiation from the phosphogypsum and inhalation of radon and its decay products dominate the potential risk. It also determined that limiting the total quantity of phosphogypsum used for a single research and development activity to 700 pounds (a single 55-gallon drum) would assure the safety of the researchers. The lifetime risks to a researcher from a single year of exposure in the laboratory, given 700 pounds of phosphogypsum with a Ra-226 concentration of 26 pCi/g, were estimated to be 9.1E-07 from exposure to the direct gamma radiation and 2.1E-05 from exposure to radon and its decay products.

In its petition for reconsideration, TFI contends that the scenario assumed by the EPA in assessing the risks from laboratory exposures to phosphogypsum is unnecessarily conservative in that it assumes virtually complete release of all the radon generated in the phosphogypsum, a very small laboratory with poor ventilation (50 m^3 free air volume and 2 air changes per hour), and ignores basic laboratory safety procedures. In reviewing its risk assessment in light of these contentions, the Agency discovered that the risks from exposure to radon and its decay products cited in EPA92 were erroneously based on five 55-gallon drums of phosphogypsum (approximately 3,500 pounds) rather than a single drum being present in the laboratory and the researcher being present for more than 4,000 hours per year. It also determined that while the assumption that all emanated radon is released to the laboratory is overly conservative, the scenario itself might be non-conservative as it does not address the potential for multiple exposures from more than a single research and development activity being conducted at the same time.

In light of its review, the Agency tasked SC&A with reevaluating the potential risks to researchers from research and development activities involving phosphogypsum in a laboratory setting. In making the reassessment the assumptions and the parameter values used in the original assessment were reviewed and changes have been made to better reflect expected conditions. The laboratory scenario itself has been expanded to assess the potential consequences of multiple research and development activities in a single laboratory and separate research and development activities occurring in multiple laboratories within the same facility. The basis and results of this reassessment are presented in the following sections.

2. Reassessment Of The Risks From 700 Pounds Of Phosphogypsum

As the current NESHAP permits the use of 700 pounds of phosphogypsum, regardless of radium-226 content, in a single research and development activity, the first step of the reassessment is to correct the errors and overly conservative assumptions identified in the previous assessment and re-estimate the risks from exposure to the direct gamma radiation and to radon and its decay products. As exposure to radionuclides via inhalation of airborne dust was shown not to be a significant contributor to the overall risk in the previous assessment, the dust inhalation pathway is eliminated from this reassessment.

2.1 ASSESSMENT OF EXPOSURE AND RISK FROM DIRECT GAMMA RADIATION

The computer code MICROSHIELD (version 3.13) was used to calculate the direct gamma exposure rate. The magnitude of the exposure and the resulting risk from direct gamma radiation depend on the source strength, the source geometry, shielding, the distance from the researcher to the source, and the duration of the exposure. As the NESHAP does not limit the radium-226 content of phosphogypsum used in research and development activities, 26 pCi/g (the highest average radium-226 content of phosphogypsum (EPA89)) is assumed. At 26 pCi/g radium-226, 700 pounds of phosphogypsum would contain about 8.3E-6 Ci of radium-226. As 700 hundred pounds of phosphogypsum is the quantity that can be contained in a single 55-gallon drum, the dimensions of a 55-gallon drum (~60 cm diameter and 74 cm in height) are used for the source geometry. No shielding beyond that provided by the phosphogypsum (bulk density of 1.5 g/cm^3), the 55-gallon drum (mild steel with a wall thickness of 0.121 cm), and the air gap between the source and the researcher is assumed. The distance between the researcher and the source is assumed to be 1 meter.

Based on these inputs, and using the Taylor method to calculate build-up, the MICROSHIELD code estimates the gamma exposure rate to be about 2.5 μrem/hour. Assuming that a researcher spends about half time in the laboratory (1,000 hours per year), the resulting exposure would be 2.5 mrem/year. This estimate is the same as reported in EPA92, and the resulting lifetime fatal cancer risk from a single year of exposure would be 9.1E-7.

2.2 ASSESSMENT OF RISK FROM INHALATION OF RADON AND ITS DECAY PRODUCTS

The EPA uses an indoor exposure risk factor of 4.4E-8 per pCi/m^3 for radon (EPA92). To assess the risk to researchers from radon and its decay products, it is necessary to define the size and ventilation characteristics of the laboratory in which the activity is conducted, the radon emanation coefficient, and the mechanism by which the emanated radon in the phosphogypsum is released to the air, and the duration of the researcher's exposure.

In EPA92, a small laboratory with relatively poor ventilation (50 m^3 free volume and 2 air changes per hour) was assumed; assumptions that were challenged as overly conservative in TFI's petition for reconsideration. While recognizing that a typical laboratory would likely be larger and have a higher the ventilation rate, the Agency believes that it is not inappropriate when developing a generic exemption to select parameter values which reflect unfavorable rather than typical exposure conditions. Therefore, for the reassessment, the laboratory size and ventilation rate are changed only marginally. The laboratory is defined as 4 m wide by 6 m long by 3 m high with a free air volume of about 58 m^3. The assumption of 2 air changes per hour is retained.

A radon emanation coefficient of 0.2 is used in this reassessment, which is smaller than the coefficient of 0.3 used in EPA92. The revision reflects the dependence of the emanation coefficient on the moisture content of the phosphogypsum and the Agency's belief that phosphogypsum used in laboratory research and development activities will have a significantly lower moisture content than phosphogypsum exposed to ambient outdoor conditions. Similarly, the mechanism for the release of the emanated radon from the phosphogypsum has been revised. In EPA92, the simple assumption was made that all emanated radon was released to the laboratory air. This would be possible if the phosphogypsum was continuously stirred or aerated or if dry phosphogypsum was spread widely throughout the laboratory. While such mechanisms are plausible, the Agency believes that release of the radon by diffusion from its storage container (a 55-gallon drum) is a much more likely mechanism.

To estimate the concentration of radon in the laboratory, we assumed that the 55-gallon drum containing the phosphogypsum is left uncovered and that, on average, the drum is half full. Under these assumptions, the rate at which radon enters the laboratory air can be estimated using the following equation taken from NRC84:

$$J = 10^4 R \rho E \sqrt{\lambda D} \tanh\left(X\sqrt{\frac{\lambda}{D}}\right)$$

where,

10^4	= cm^2/m^2
R	= pCi Ra-226/g phosphogypsum
	= bulk density of phosphogypsum, g/cm^3
E	= emanation coefficient, dimensionless
	= Rn-222 decay constant, sec^{-1}
D	= radon diffusion coefficient, cm^2/sec
X	= diffusion distance, cm.

The following values were used for these parameters:

$R = 26$ pCi/g
$\rho = 1.5$ g/cm^3
$E = 0.2$
$\lambda = 2.1 \times 10^{6}$ sec^{-1}
$D = 0.08$ cm^2/sec
$X = 37$ cm.

The steady state room air concentration is given by:

$$C = \frac{JA_D}{Q + \lambda V}$$

where,

A_D = drum cross-sectional area, m^2
Q = volumetric flow rate from room (= aV)
a = air changes per second, sec^{-1}
V = free room volume, m^3.

Based on the values presented previously for the size and ventilation rate of the laboratory, the estimated concentration of radon in the laboratory is 53 pCi/m^3. In terms of risk, using the same radon risk coefficient (4.4E-8 per pCi/m^3) as was used in the 1992 assessment, and assuming 1,000 hours per year exposure, the lifetime risk to a researcher from one year of exposure at 53 pCi/m^3 would be about 2.7E-7.

2.3 SUMMARY OF THE RISKS FROM 700 POUNDS OF PHOSPHOGYPSUM

Summing the risks from the direct gamma exposure and the inhalation of radon and its decay products yields a lifetime risk per year of exposure of 1.2E-6. Under the same assumption as was used in the 1992 reconsideration rulemaking that a researcher might be exposed to these levels for 10 years, the total risk would be about 1E-5.

3. Assessment Of The Risks From Multiple R&D Activities

Since the lifetime risk from a single R&D activity involving 700 pounds of phosphogypsum is an order of magnitude lower than the presumptively acceptable level of about 1E-4, the next step of the reassessment was to evaluate the potential for exposures that could occur if multiple R&D activities were conducted in the same laboratory or if separate activities were conducted in multiple laboratories within the same facility. The following subsections address the potential risks from multiple exposures.

3.1 ASSESSMENT OF RISKS FROM MULTIPLE ACTIVITIES IN THE SAME LABORATORY

The exposures that could result from the conduct of multiple research activities within a single laboratory will depend upon the total quantity of phosphogypsum present in the laboratory, the storage configuration of the 55- gallon drums, and distance from the source to the receptor. As a single 55- gallon drum is estimated to result in risks about an order of magnitude lower than the presumptively safe lifetime risk level of 1E-4, the potential risks from 10 55-gallon drums (7,000 pounds) of phosphogypsum are assessed.

3.1.1 Potential for Exposure to Direct Gamma Radiation

The potential exposure to the direct gamma radiation from the phosphogypsum depends upon the storage geometry that is assumed. For the purposes of this assessment, two configurations were examined: drums stacked two-high along a single wall; and unstacked drums stored in a V-configuration along two walls. These configurations are depicted graphically in Figures 1 and 2, respectively. For both configurations, assumptions as to the source strength for each drum is the same as evaluated in Subsection 2.1. Again, MICROSHIELD was used to calculate the shielding provided by each configurations and the dose rates to a worker located at 1 meter from the closest drum.

The dose rates for the two configurations are roughly comparable, 16 mrem/yr for the stacked configuration of 10 drums, and 17 mrem/yr for the V-configuration of 10 drums. Risks from a single-year of exposure to these gamma levels would be 5.8E-6 and 6.2E-6, respectively. The less than linear increase in the risk is due to the increase in the average distance from the additional sources. A linear increase would only occur if the worker were ringed with drums, a storage geometry that is not believed to be credible.

3.1.2 Potential for Exposure to Radon and Its Decay Products

The exposure to radon and its decay products, assuming storage of the material in 55-gallon drums, will increase linearly with the number of open drums in the laboratory at any given time. For the stacked storage geometry, it is unreasonable to assume that all drums would be open at the same time - at most, the upper five drums would be open. This would increase the risk from radon by a factor of five. However, for the V-configuration, all 10 drums might be open at the same time. This would result in a 10-fold increase in the risk from inhalation of radon and its decay products.

3.1.3 Summary of the Risks from Multiple Activities in a Single Laboratory

Storage of the 10 drums in a V-configuration is estimated to result in the highest risk for both direct gamma exposure and exposure to radon and its decay products. The 10-fold increase in the quantity of phosphogypsum present in the laboratory is estimated to result in a lifetime risk of about 8.9E-6 from a single years exposure. This is about 7.4 times the risk estimated for a single 55-gallon drum.

3.2 ASSESSMENT OF THE RISKS FROM MULTIPLE LABORATORIES IN THE SAME FACILITY

The additional exposures that could result from R&D activities being conducted in multiple laboratories in the same facility are also relevant to the determination of the quantity of phosphogypsum that can be allowed without jeopardizing the safety of researchers.

To evaluate the potential increase in exposure and risk, a worst case scenario has been evaluated. In this scenario, the research is assumed to be conducted in a multi-story building comprised of identical 4 m by 6 m laboratories that are independently vented. The floor plan for a single floor is shown in Figure 3, and each floor is identical. The corridors are assumed to be 1.5 m wide, and the interior walls are constructed of cinder block (20 cm thick). In this improbable array, a researcher working in the central laboratory in the middle floor could receive additional gamma exposure from the phosphogypsum in the 26 surrounding (8 adjacent, 9 above, and 9 below) laboratories. (Note: the assumption of independent venting of the laboratories implies that no additional risk from exposure to radon released in the other laboratories would occur. While this might seem non- conservative, common venting would result in a lower estimated radon concentration due to dilution with the air volumes in the corridors.)

To evaluate the actual increase in the gamma exposure, the thickness and materials used to construct the floors and walls in the facility would have to be known. While block walls and poured concrete floors are typical of these types of facilities, simple sheet rock partition walls and wood framed floors cannot be totally dismissed. To avoid the uncertainty of the shielding provided by the building materials, a worst case approximation of the increase in the gamma exposure has been made based simply on the distances between the receptor and the various sources.

Given the dimensions cited above, and the fact that the gamma exposure decreases with the square of the distance, the maximum increase in the gamma exposure would be on the order of a factor of two. A two-fold increase in the gamma risk of about 6E-6 combined with the radon risk of about 3E-6 would result in a lifetime risk from a single year of exposure of about 1.5E-5. Assuming 10 years exposure at this level would yield a risk of 1.5E-4.

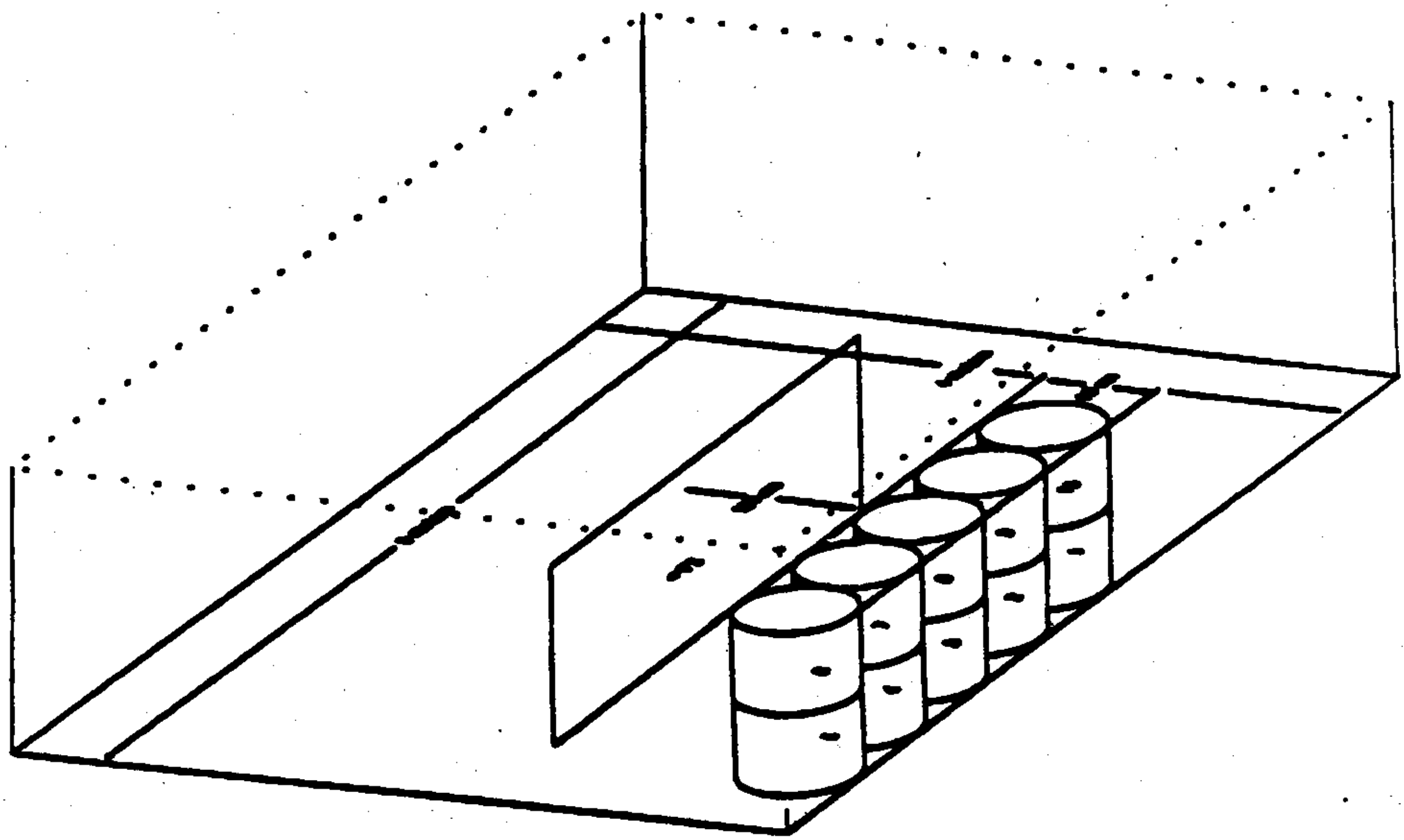

Figure 1: Geometry for Multiple Drum Exposure Scenario - Stacked Drums

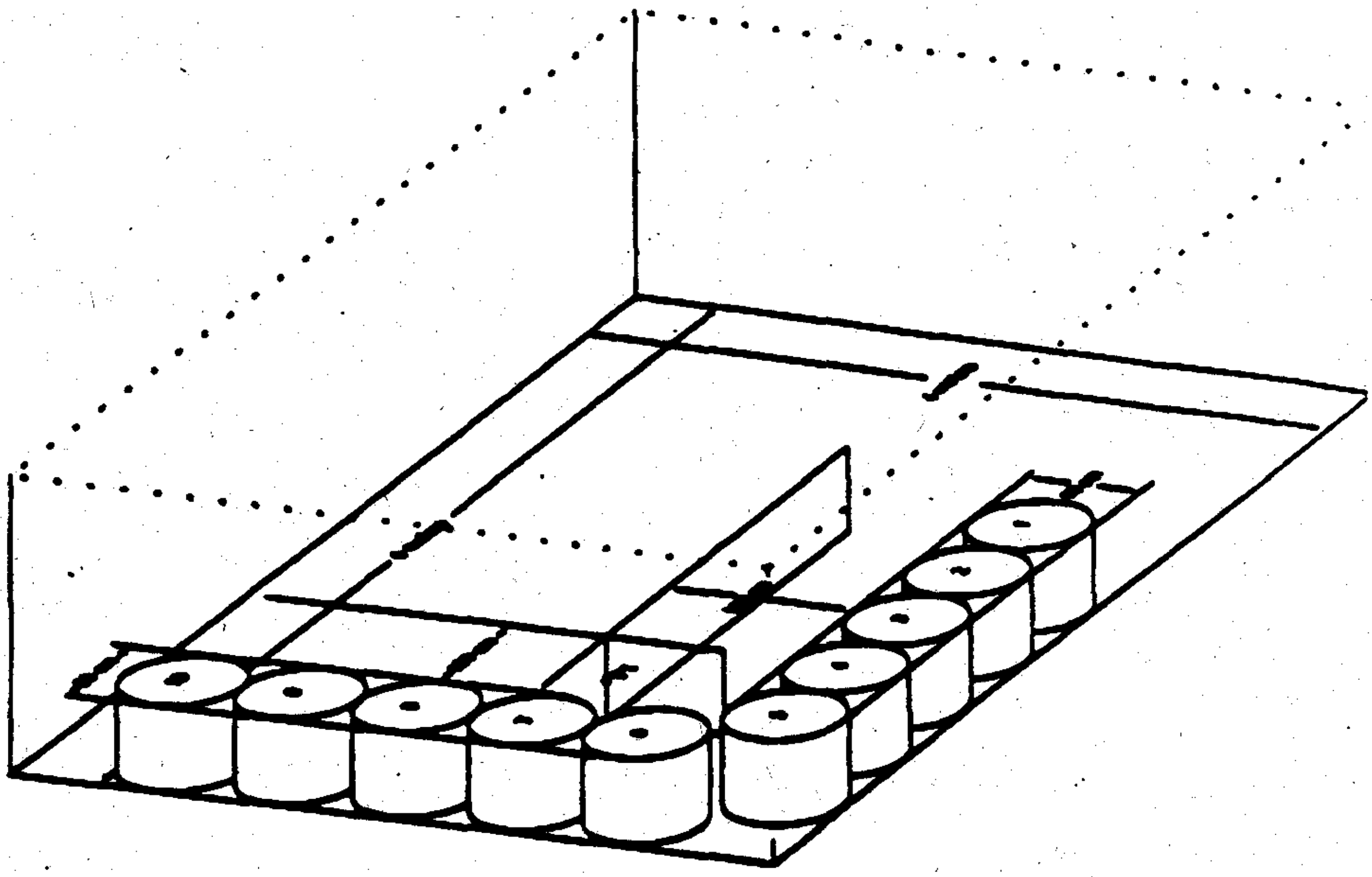

Figure 2: Geometry for Multiple Drum Exposure Scenario - V-Configuration

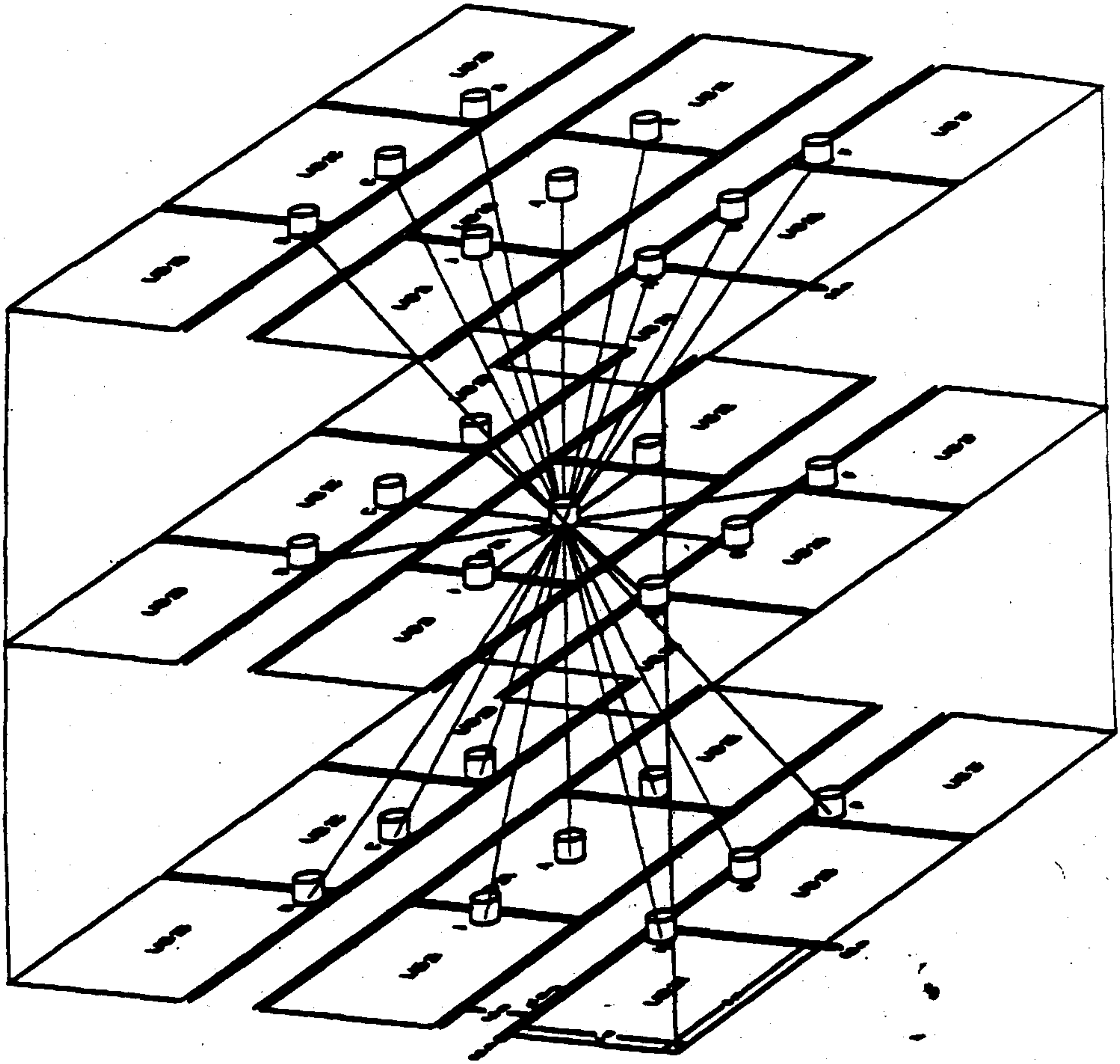

Figure 3: Geometry for Multi-Laboratory Exposure Scenario

4. Summary Of The Reassessment

This reassessment of the potential risks to researchers involved in research and development activities involving phosphogypsum within a laboratory setting corrects errors discovered in the 1992 assessment and expands the evaluation to consider the impacts of multiple activities within the same facility.

For a single R&A activity using 700 pounds of phosphogypsum (the maximum quantity allowed under the current NESHAP), the lifetime risk to a researcher from a single year of exposure is estimated to be about 1.2E-6; about 9.1E-7 from exposure to the direct gamma radiation and about 2.7E-7 from inhalation of radon and its decay products.

An increase in the quantity of phosphogypsum assumed to be present in the laboratory by a factor of 10 (from 700 to 7,000 pounds) is used to evaluate the potential risks from multiple R&D activities being pursued concurrently in the same laboratory. Under the least favorable storage geometry (10 drums storaged in a V-configuration with all drums open) the lifetime risk from a single year of exposure is estimated to be about 8.9E-6, a factor of seven higher than for the single drum scenario.

Finally, the potential for increased expsoure due to R&D activities being conducted in multiple laboratories in the same facility was evaluated. Under the unlikely scenario that activities occur simultaneously in all the laboratories surrounding a central laboratory, the lifetime risk from a single year of exposure is estimated to be 1.5E-5. This is a factor of about 13 greater than the risk from a single 55-gallon drum of phosphogypsum.

REFERENCES

EPA89 U.S. Environmental Protection Agency, Risk Assessments - Environmental Impact Statement NESHAPs for Radionuclides, Background Information Document - Volume 2, EPA/520/1-89-006-1, Washington, D.C., September 1989.

EPA92 U.S. Environmental Protection Agency, Potential Uses of Phosphogypsum and Associated Risks - Background Information Document, 402-R92-002, Washington, D.C., May 1992.

NRC84 U.S. Nuclear Regulatory Commission, Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533, Washington, D.C., April 1984.