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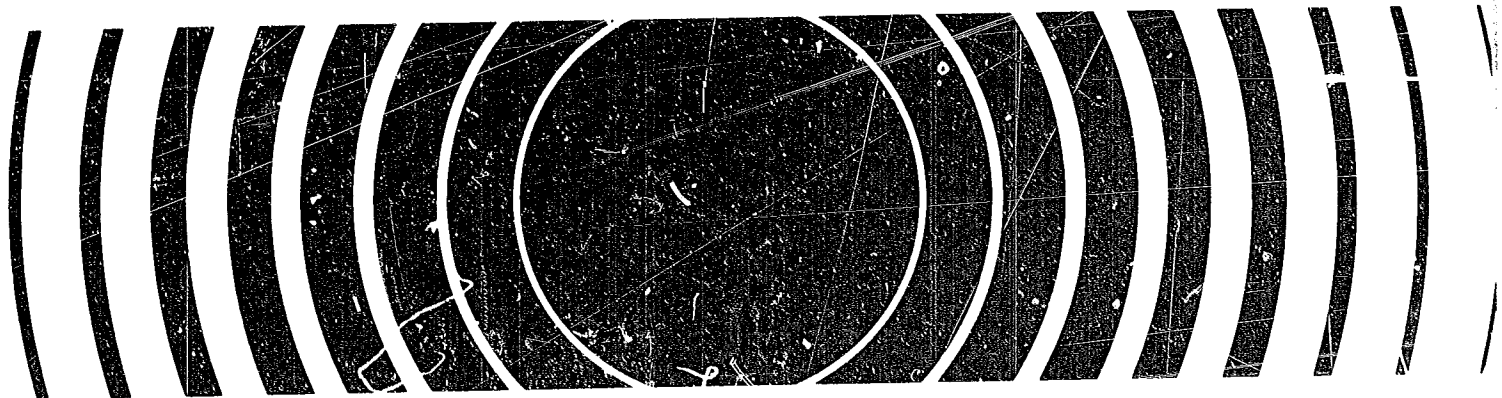
Technical Note  
ORP/TAD-80-7

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Radiation



# Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines



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Technical Note  
ORP/TAD-80-7

# **Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines**

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Prepared under Contract No. 68-02-2616  
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The Office of Radiation Programs, EPA, is developing standards for radioactive air pollutants under the authority of the Clean Air Act, as amended in 1977. Technically enhanced sources of naturally occurring radioactivity, such as underground uranium mines, may release large quantities of radon-222 into the atmosphere. Because of the potential adverse health effects to population groups, underground uranium mines warrant investigation as to the feasibility of reducing the radon-222 releases. This study addresses various control options for a hypothetical mine.

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## Foreword

The Office of Radiation Programs, EPA, is developing standards for radioactive air pollutants under the authority of the Clean Air Act, as amended in 1977. Technically enhanced sources of naturally occurring radioactivity, such as underground uranium mines, may release large quantities of radon-222 into the atmosphere. Because of the potential adverse health effects to population groups, underground uranium mines warrant investigation as to the feasibility of reducing the radon-222 releases. This study addresses various control options for a hypothetical mine.

In sponsoring this study, we have worked closely with the U.S. Bureau of Mines, Department of the Interior, with a common objective of protecting both the underground worker and the surrounding population by reducing the amount of radon-222 released into fresh air pathways, and hence to the environment. Readers of this report are encouraged to comment on its technical merits and conclusions. Additional information is welcome.

Office of Radiation Programs (ANR-458)  
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## ABSTRACT

This report presents the results of a preliminary evaluation of potential radon-222 control technologies for underground uranium mines. The evaluated technologies are (1) use of a sealant coating on exposed ore surfaces; (2) bulkheading of worked-out areas; (3) activated carbon adsorption of radon from contaminated mine air; (4) mine pressurization; and (5) miscellaneous technology (chemical reaction of radon in contaminated mine air).

Underground uranium mines vary widely in size, shape, depth, ore grade, lithology, layout, and mining method. Accordingly, the radon sources and their emission rates also vary widely from mine to mine. A hypothetical mine was used to estimate the radon emission rates from various sources and to assess the radon control technologies. The hypothetical mine, which has the capacity of 1,000 tons of ore per day and has produced 480,000 tons of uranium ore over two years' operation, has 8.86 Ci/day radon emission into the underground mine air. This includes 4.51 Ci/day from worked-out areas and 4.35 Ci/day from working areas.

The five radon control technologies are evaluated for their application to the hypothetical mine. This includes evaluation of their effectiveness in controlling radon emission, cost, potential problems, safety considerations, and equipment availability. Sealant coating may be applied to the 2.54 Ci/day radon sources and reduce 1.01 Ci/day at a cost of \$1.45 per ton of produced ore. Bulkheading of worked-out areas may be applied to the 4.51 Ci/day radon sources and divert all 4.51 Ci/day radon emission at a cost of \$0.24 per ton of ore produced; 3.25 Ci/day to the exhaust ventilation system, while 1.26 Ci/day is decayed in the bulkheaded areas. (More recent information indicates that as much as 2.95 Ci/day to 3.56 Ci/day of the 4.51 Ci/day of radon from the worked-out areas may decay within the bulkheaded areas.) Activated carbon adsorption, used in conjunction with bulkheading, may be applied to 3.25 Ci/day radon sources and reduce 3.09 Ci/day, which otherwise would be discharged to the surface atmosphere, at a cost of \$4.32 per ton of produced ore.

The concept of mine pressurization to reduce radon emission into the mine air appears to be promising; however, further tests are needed to verify the concept. Use of highly reactive chemical oxidants to react with radon in underground uranium mine air appears possible, but tested chemicals are very corrosive in the presence of humidity, extremely toxic, and not commercially available.

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## SECTION 1

### INTRODUCTION

This is the final report on the study, "Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines," conducted for the Office of Radiation Programs, U. S. Environmental Protection Agency (EPA), under Contract No. 68-02-2616, Task No. 9.

The health hazards of breathing air contaminated with radon-222 and its daughter products have been recognized since the 1940's.<sup>(6)</sup> The concentration of radon daughters in the air of working areas in underground uranium mines is regulated by the Mine Safety and Health Administration (MSHA). The commonly used technique for controlling the concentration of radon daughters in the mine air is forced-air ventilation which dilutes and removes the contaminated air from the mine to the surface atmosphere. At present there is no EPA standard for the concentration of radon and its daughter products in the exhaust ventilation air from an underground mine, or the surface atmospheric air. The U. S. Nuclear Regulatory Commission (NRC) regulations for radon concentrations in air are 30 pCi/L (10 CFR 20.103) and 3 pCi/L (10 CFR 20.106) for restricted and unrestricted areas, respectively.

The Office of Radiation Programs of EPA has the responsibility for setting standards for the airborne emissions of radioactive nuclides under the Clean Air Act as amended in 1977. This includes radon-222 and its daughter products from underground uranium mines. In, in the judgement of EPA, it is not feasible to prescribe an emission standard for controlling radon, EPA may instead promulgate a design, equipment, work practice, operational standard, or a combination thereof, which is adequate to protect the public health.

Because of program requirements, EPA contracted for a two-month quick response task for a preliminary technical evaluation of the potential options for controlling radon-222 released to the surface environment from underground uranium mines based on information and literature supplied by EPA and obtained from other readily available sources.

## OBJECTIVE OF THE STUDY

The purpose of this study is to provide the EPA with some of the necessary information to enable them to make a sound decision on future activities leading to the setting of emission standards or other regulations for the control of radon emissions from underground mines.

This study provides EPA with a first-cut technical assessment of various potential methods of controlling radon from underground uranium mines. The study, based on presently available literature, attempts to characterize the major sources of radon and to review promising methods of controlling radon emissions from those sources. The radon control technologies evaluated were:

- Use of a sealant coating on exposed ore surface
- Systematic bulkheading of worked out areas
- Activated carbon adsorption of radon from highly radon-contaminated air
- Mine pressurization to suppress radon emission
- Use of chemical oxidants to react with radon.

This study is solely aimed at means of preventing radon release to the surface atmosphere. It considers only active underground uranium mines and does not consider completed or inactive mines. This study also does not address open pit mining, subsequent milling and tailings, atmospheric diffusion, the ultimate health effect of diffused radon, or the question of mine workers' protection, except where such means of preventing radon release impinges upon the subject.

## PROJECT METHODOLOGY

To fulfill the objectives of this technical assessment, four major tasks were performed:

- Characterization of radon source
- Definition of a typical mine, "the case mine"
- Conceptual design of radon control systems
- Technical and cost evaluation of control systems.

### Characterization of Radon Sources

The available literature pertaining to the problem, sources,

and emission rate of radon in underground uranium mines, was reviewed. Technical experts in the field were also contacted for consultation<sup>(1)</sup>. It became apparent that information on the radon sources is limited, and that radon emission is a very complex subject which depends on many variables such as the ore characteristics, mining method, climate, and age of mine.

Since this study is a preliminary assessment, it was decided to use a simplified version of the radon source which would allow a generalized assessment of the problem. A discussion of the radon problem and a simplified source is presented in Section 3.

#### Definition of Case Mine

The assessment of radon control technology required a representative underground uranium mine to be used as a model mine (the Case Mine). However, it was quickly realized that all underground uranium mines are different in their size, shape, mining methods, or radon emission. It was not possible to define a typical underground uranium mine. It was decided, with EPA approval, that a simple underground uranium mine of 1,000 tons per day using the modified room-and-pillar mining method would be hypothesized for the purpose of this study. The case mine and its radon source are presented in Section 4.

#### Conceptual Design of Radon Control Systems

Conceptual design of the radon control systems applied to the case mine was necessary for the assessment of these technologies. Available literature on these technologies was reviewed to develop design criteria. There is very little actual experience of these technologies, except for the limited practice of bulkheading and limited test of sealant coating. Each control technology was applied in a manner that was effective for the hypothetical case mine. The conceptual design is presented in Section 5.

#### Technical and Cost Evaluation

Each control system applied to the case mine was evaluated for:

- Effectiveness in radon control
- Capital and operating costs
- Potential problems
- Assessment of operational requirements
- Design and safety consideration

- Availability of material and equipment.

The cost is an approximation based on the conceptual design of the radon control systems applied to the case mine. An estimating method consistent with the conceptual nature of the design was employed for this study. All cost data represent 1978 dollars.

The technical evaluation is based on the application of these technologies to the case mine. Wherever possible, the application to real mines is also discussed. The technical and cost evaluation is presented in Section 5.

## SECTION 2

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The results of this study are summarized in this section. Conclusions and recommendations for future EPA efforts in controlling radon release to the surface environment are also included.

#### RADON SOURCE IN UNDERGROUND URANIUM MINES

The radon source and radon emission rate in underground uranium mines varies considerably depending on the geological characteristics of the ore deposit, ore grade, mining technique, and mine atmosphere. Areas specially noted for radon emission in underground uranium mines are:

- Surface of drifts driven through the ore body
- Exposed surface in extracted area
- Raizes or drifts near the ore body
- Muck piles in working areas
- Ore spills and ore cars in the haulage ways
- Ground water entering mine workings after passing a uranium deposit.

Radon emission rate from an exposed mine surface varies in a range of 10 to 100 pCi/ft<sup>2</sup>-sec depending on the ore grade, mine environment, rock characteristics, and mining activity. For this study, the following approximate emission rates are assumed:

- 55 pCi/ft<sup>2</sup>-sec ( $4.8 \times 10^{-6}$  Ci/ft<sup>2</sup>-day) for a medium grade ore surface (1)
- 28 pCi/ft<sup>2</sup>-sec ( $2.4 \times 10^{-6}$  Ci/ft<sup>2</sup>-day) for a low grade ore area\*
- $2.4 \times 10^{-3}$  Ci/ton-day for ore muck piles.

\*This is in good agreement with a more recent value of 22.4 pCi/ft<sup>2</sup>-sec calculated from information in reference 33.

Groundwater entering a mine working after passing through a uranium deposit, may be one of the major radon sources. However, it is not possible to estimate, based on presently available information, the rate of radon emission from the mine water into the mine air. This study did not include the mine water as a source of radon emission into the mine air.

#### UNDERGROUND URANIUM MINES AND CASE MINE

Because uranium ore deposits are erratic in size, shape, and lithology, every mine has a different layout and a different mining method. Defining a typical underground uranium mine was not possible. For this study, a hypothetical mine, defined only by major radon sources, is selected and used for evaluation of the radon control technology.

#### The Case Mine

The Case Mine has a large uniform tabular ore body which is mined by modified room-and-pillar stoping method. The case mine has:

- Eight developing stopes at various stages of development (250 TPD ore from eight developing stopes)
- Two developed stopes ready for extraction
- Five extracting stopes at various stages of extraction (750 TPD ore from five extracting stopes)
- Twenty-five completed stopes
- A total of 240,000 tons per year from 12.5 stopes per year
- Each completed stope has 77,000 ft<sup>2</sup> of exposed surface and 300,000 ft<sup>3</sup> of air space
- Ventilation rate of 240,000 CFM.

#### The Radon Emission Rates in the Case Mine

In the case mine, 51 percent of the radon is emitted from 25 extracted stopes (mined out area), while the remaining 49 percent is emitted from active working areas (see Table 2). Not all of the radon emitted into the underground mine space is discharged to the surface environment. Some of the radon, especially that emitted into an isolated space such as a bulkheaded mined out stope, will be trapped and subsequently decayed.

Radon sources and emission rates in the case mine are summarized as follows:

<u>Radon Sources</u>	<u>Emission Rate Ci/day</u>
8 Developing Stopes	
Drifts	1.43
Muck piles	0.38
2 Developed Stopes	
Drifts	0.71
5 Extracting Stopes	
Drifts & extracted areas	1.35
Muck piles	0.48
25 Extracted Stopes	
Extracted areas	<u>4.51</u>
	8.86

#### ASSESSMENT OF RADON CONTROL TECHNOLOGIES

Five radon control technologies are applied to the Case Mine and evaluated for their cost, effectiveness, operational requirements, and potential problems. An assessment of radon control technologies is summarized in Table 1.

##### Use of Sealant Coating

In the Case Mine, only drifts of developing stopes are coated. Annually, 530,000 ft<sup>2</sup> of drifts are coated using 2,400 cubic yards of Shotcrete, 69,600 gal of HydroEpoxy 156, and 17,000 gal of HydroEpoxy 300, at a total cost of \$344,300 (see Section 5 for details). The cost per ton of ore is \$1.45. The sealant coating reduces radon emission from drifts of the developing stopes by 1.01 Ci/day; 11 percent reduction of the total radon source.

##### Bulkheading of Extracted Stopes

Every extracted stope in the case mine is sealed using eight bulkheads as soon as it is completed. All of the bulkheaded stopes are connected to the exhaust ventilation system using bleeder pipes. The systematic bulkheading of the 12.5 stopes per year, with 100 CFM\* bleeding from each stope, will divert all 2.25 Ci/day radon source in 12.5 completed stopes and discharge 1.62 Ci/day to the surface. The bulkheading cost of 12.5 worked-out stopes is \$80,000 per year (\$0.34 per ton of ore).

\*More recent information indicates that flow rates of 10-20 CFM are sufficient to maintain the bulkheads at negative pressure<sup>(32)</sup>.

TABLE 1. ASSESSMENT OF RADON CONTROL TECHNOLOGIES SUMMARY

	Applicability		Radon Reduction		Cost \$/Ton of Ore
	Ci/Day	% of Total(1)	Ci/Day	% of Total (1)	
Sealant Coating	2.54	29	1.01	11	1.45
Bulkheading	4.51	51	1.26(2) (4.51)	14 (51)	0.34
Activated Carbon	3.25(2)	37	3.09	35	4.32
Mine Pressurization (3)	--	--	--	--	--
Miscellaneous Technology (3) (Use of chemical oxidants)	--	--	--	--	--

- NOTES: (1) Based on 8.86 Ci/day radon emission from the case mine.  
 (2) Diversion of 4.51 Ci/day from 25 worked out stopes, 1.26 Ci/day decay in bulkheaded worked out stopes, and emission of 3.25 Ci/day into the exhaust ventilation system.  
 (3) Available information was not enough to evaluate the effectiveness and cost.

