Technical Note
ORP/LV-75-1

RADIOACTIVITY IN CONSTRUCTION MATERIALS
A LITERATURE REVIEW AND BIBLIOGRAPHY

Gregory G. Eadie

April 1975

U. S. Environmental Protection Agency
Office of Radiation Programs
Las Vegas Facility
P.O. Box 15027
Las Vegas, Nevada 89114

Technical Note
ORP/LV 75-1

RADIOACTIVITY IN CONSTRUCTION MATERIALS
A LITERATURE REVIEW AND BIBLIOGRAPHY

Gregory G. Eadie

U.S. Environmental Protection Agency
Office of Radiation Programs
Las Vegas Facility
P.O. Box 15027
Las Vegas, Nevada 89114

PREFACE

The Office of Radiation Programs of the Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation, and to promote development of controls necessary to protect the public health and safety. This literature survey was undertaken to assess the extent of the exposure of the population to naturally occurring radionuclides present in building materials and to provide a basis for further studies. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

Donald W. Hendricks

Donald W. Hendricks
Director, Office of
Radiation Programs, LVF

TABLE OF CONTENTS

	Page
INTRODUCTION	1
SUMMARY	2
CONCLUSIONS	3
RADIOACTIVITY IN CONSTRUCTION MATERIALS	5
RADIATION SURVEYS	8
RADON AND RADON DAUGHTER PRODUCT CONCENTRATIONS INSIDE BUILDINGS	14
SURVEY OF BUILDINGS WHERE URANIUM MILL TAILINGS HAS BEEN USED FOR CONSTRUCTION PURPOSES	17
SPECIAL STUDIES IN AREAS OF HIGH RADIATION BACKGROUND	18
BIBLIOGRAPHY	20

LIST OF TABLES

	Page
Table 1. GONADAL DOSE EQUIVALENT TO THE U.S. POPULATION FROM NATURAL RADIATION	9
Table 2. GAMMA EXPOSURE RATES INSIDE BUILDINGS	13

INTRODUCTION

A literature search has been conducted to evaluate the exposure of the population to levels of naturally occurring radionuclides present in construction materials.

A bibliography of pertinent references has been compiled from the bibliographies by Lowder (1965) and Klement (1965 and 1970), and has been supplemented by searching the Nuclear Science Abstracts (NSA) through Volume 31, Number 4 (February 1975).

This bibliography on radioactivity in construction materials contains, to a large extent, articles from the early 1950's to the present, since few surveys were reported in the literature prior to 1950. A brief description of important topics dealt with in each article has been provided with the reference source for those articles which have been reviewed.

SUMMARY

Surveys to determine the radioactive content of specific building materials used in the United States have not been reported in the literature. The external dose to the United States population from exposure to natural radioactive materials (exclusive of uranium mill tailings) contained in United States building materials has not been evaluated, and the possibly significant external exposure from the use of by-product gypsum and fly-ash materials should be evaluated. The effects of various construction materials on the attenuation of cosmic and terrestrial radiation have been evaluated in a limited number of surveys in the urban areas of Boston, New York, and Livermore, California. The measurement of radon and radon daughter product concentrations has only been reported for a few dwellings and several multi-story office buildings in Boston and in several State-owned buildings in North Carolina. This literature search has found a lack of meaningful data for use in evaluating the U.S. population exposure from building materials.

CONCLUSIONS

1. The article by Hamilton (1971) is the only significant report of data on the radioactivity content of specific building materials.

2. Radioactivity in building materials used in the United States has received very little attention. Except for the studies to find construction materials of very low background, there are no reports of radiological surveys of any United States building materials which are used by the general population for construction purposes. Also, there are no reports of United States studies on the possible use of by-product gypsum and fly-ash products for construction materials.

3. The reports by Solon, et al., (1960); Yeates, et al., (1970 and 1972); and Lindeken, et al., (1971 and 1973) provide the only data on radiation measurements made inside United States buildings.

4. The reports by Yeates, et al., (1970 and 1972) and Aldrich and Conners (1974) are the only reported data of radon daughter product concentration measurements made inside United States buildings (exclusive of measurements made to study uranium mill tailings material usage).

5. The documentation of the evaluation of radiological hazards associated with the use of uranium mill tailings material for construction purposes in the United States has not been reported in the open literature [except for the report by Duncan and Eadie (1974)].

6. Dose assessments of radiation exposures inside dwellings and evaluation of the internal dose due to the inhalation of radon daughter products in the air inside dwellings have been reported in a number of articles from foreign countries. These reports indicate that radon and radon daughter product concentrations in air inside dwellings of concrete or granite construction probably exceed a working level value of 0.01, which is the lower limit of the exposure

guideline currently recommended for the remedial action program in Grand Junction, Colorado (JCAE, 1971), where uranium mill tailings material has actually been used for construction purposes.

7. Table 1, taken from Oakley (1972), represents the best summary of the gonadal dose equivalent to the United States population from natural sources and concludes that the total dose equivalent is 88 mrem/yr.

RADIOACTIVITY IN CONSTRUCTION MATERIALS

There are only a few published reports which specifically discuss the concentration of radionuclides in building materials such as brick, gypsum board, concrete, etc. The article by Hamilton (1971) reports the concentrations of potassium, thorium, uranium, and radium for various building materials used in the United Kingdom. The results are expressed in "ppm" and, for comparison purposes, the concentration results were converted to a "radium equivalent" unit. This expresses the summation concentrations of potassium, thorium, and uranium in terms of the concentration of radium which gives the same gamma-ray emission per gram of material. Gypsum board, derived as a by-product of the manufacture of superphosphate fertilizers, had the highest radium equivalent of all building materials, 17.0 picocuries per gram (pCi/g). Natural gypsum products in the United Kingdom had a radium equivalent of 1.2 pCi/g. Clay bricks, the most commonly used building material, had a concentration of 1.4 pCi/g. There is some indication that concrete blocks produced from fly ash (i.e., a mixture of coal clinker, ash, and cement) have a radium equivalent greater than other brick products. As a result of Hamilton's report, the United Kingdom has considered legislation to limit the average concentration of radium in by-product gypsum materials for use in the construction industry to less than 25 pCi/g (O'Riordan, et al., 1972).

In a report to the United Kingdom's National Radiological Protection Board, O'Riordan, et al., (1972), evaluated the dose rate from the use of by-product gypsum material. Considering that the typical radium content of by-product gypsum material is 25 pCi/g, the corresponding gamma-ray dose rate to the gonads and bone marrow of the occupants of a standardized house was calculated to be 30 mrad per year. The beta-ray dose rate to the skin and lens of the eye was less than 20 mrad per year. An evaluation of the lung dose due to radon and radon daughter products produced from the use of the by-product gypsum indicated an annual exposure of 0.04 working level months (WLM). The report summarized that the radiation exposures due to the use of by-product gypsum products are about one-tenth of the annual dose limits for exposure to members of the general public as recommended by the International Commission on Radiological Protection.

Standards for natural radioactive substances in building materials have been established in the Soviet Union and are contained in the Soviet Sanitary Regulations, Numbers 437 through 463. In summary, the maximum permissible concentration of naturally radioactive substances in Soviet building materials is less than 20 pCi of the total radium-228, radium-226, thorium-228, thorium-230, uranium-234, lead-210, and polonium-210 content per gram of material.

The article by Krisyuk, et al., (1974) also discusses gamma-spectrometric analyses of various building materials used in the USSR and predicts exposure rates inside buildings. Suggested permissible concentrations of radium-226, thorium-232, and potassium-40 are 10, 7, and 126 pCi/g, respectively, based on external gamma radiation levels inside structures.

In the article by Afanas'ev and Krisyuk (1967), the exposure of occupants due to increased levels of radon and thorium and their decay products in indoor air is discussed. The article concludes that measurements of specific radon and thorium liberation rates should be evaluated on all new building materials, e.g., by-product gypsum boards. Also, different air-change factors and the influence of paint or sealants on the emission rates inside structures should be considered.

Data on the potassium, uranium, and thorium content of building materials of Taiwan are given in the article by Chang, et al., (1974). The results are expressed in parts per million per kilogram and, from these values, it was estimated that the external gamma radiation from a typical concrete building was 52 milliroentgen per year (mR/y).

Other articles dealing specifically with radioactivity in building materials are listed below:

Author	Country
Aten, et al., (1961)	Netherlands
Bergstram and Wahlberg (1967)	Sweden
Kominek (1972)	Czechoslovakia
Krisyuk, et al., (1974)	Soviet Union
Lindell and Peizenstein (1964)	Sweden
Roehnsch (1974)	Germany
Safonov (1972)	Soviet Union
Stretta and del Arenal (1963)	Mexico

Several other articles deal with the use of radioisotopes as tracers in building materials or their use in radiography of construction projects:

Author	Country
Hilaire and Le Gallic (1971)	France
Ramos Rodriquez (1970)	Spain
Toyer (1972)	France

With respect to radioactivity in building materials used in the United States, there are three articles by Wollenberg and Smith (1960, 1962, and 1966) which report the determination of the natural radioactivity content of materials used in concrete or concrete aggregate mixes. These studies were undertaken to determine the lowest background materials for use in constructing a room for a whole-body counting chamber and are, therefore, not representative of typical building materials. Schiager (1974) also discusses the selection of low-background building materials (concrete and aggregate mixes) which were used to construct a photographic film storage facility having an exposure rate less than 11 microroentgens per hour (μR/h).

Other articles which report the natural radioactivity content of various rocks and soils of the United States are listed in the bibliography. The articles by Harley and Lowder (1971) and Oakley (1972) provide good summary reports of the natural radionuclide content and dose rates from common rocks and soils, but these conditions are representative only of outdoor terrestrial exposures.

Although extensive surveys have been conducted in the United States to determine the radioactivty of water supplies and foodstuffs, very little information on the radioactivity analysis and the radiation exposure conditions of specific United States building materials, such as gypsum products, concrete, brick, etc., has been reported in the literature. No reports were found which correlate the radioactivity content of the building materials to the radiological exposure conditions measured inside the buildings.

RADIATION SURVEYS

The following references are concerned with surveys of the outdoor measurement of cosmic and terrestrial background radiation exposure for different sections of the United States:

Author	Area of Survey
Beck, et al., (1964)	Southeast, Central, & Western U.S.
Golden, Jr. (1968)	Florida
Harley and Lowder (1971)	General
Keefer and Dauer (1970)	Florida
Kinsman (1958)	General
Levin and Stoms (1969)	Michigan, Colorado, & Minnesota
Lindeken, et al., (1971, 1972, & 1973)	California
Lowder, et al., (1964)	New England states
McLaughlin (1972)	General
Moxham (1963)	Maryland
Oakley (1972)	General
Patterson, et al., (1958)	San Francisco Bay area
Pinkerton, et al., (1964)	Maryland
Segall and Reed (1963)	New England states
Solon (1958)	General
Stephens and Patterson (1961)	San Francisco Bay area
Wollenberg and Smith (1960)	San Francisco Bay area

Oakley (1972) summarized the results of studies of cosmic and terrestrial radiation exposure rates in the United States. The average dose equivalent to the United States population, considering the population distribution with respect to elevation, the influence of housing and biological shielding, and the contribution from internal emitters, are presented in table 1, from his report.

Oakley based his calculations of the terrestrial component of the United States background exposure rate on the results of the Aerial Radiological Measurement Surveys (ARMS), which were conducted from 1958 to 1963 by the U.S. Geological Survey and EG&G, Inc., under U.S. AEC sponsorship.

Table 1. GONADAL DOSE EQUIVALENT TO THE U.S. POPULATION FROM NATURAL RADIATION

SOURCE	DOSE EQUIVALENT (mrem/yr)
External	
Terrestrial	26
Housing factor = 0.80 Screening factor = 0.80	
Cosmic	44
Internal	
Potassium-40	16
Other nuclides	2
Total	88

*Taken from D. T. Oakley (1972).

The effects of different building materials on the attenuation of the natural background radiation was taken into account by introducing a "housing factor" which was defined as the average factor by which indoor living reduces man's exposure to natural external radiation. Oakley reviewed the available literature which includes both U.S. and foreign surveys, and concluded that the ratio of the indoor to outdoor dose rates for wood structures ranged from 70 to 82 percent. Similar ratios for homes of masonry construction ranged from 72 to 106 percent. Oakley therefore assumed that the ratio of inside to outside dose rates for wood dwellings was 70 percent and for masonry buildings it was 100 percent. Other conditions were also considered in the selection of parameters for the calculation of the housing factor. The type of housing (single-family versus multiple-family dwellings), type of construction (wood versus masonry structure), and occupancy time estimates for at-home versus away-from-home activities were considered in the derivation of the average housing factor of 0.8.

The following articles report the results of surveys conducted to evaluate the radiation exposure rates inside United States buildings:

Author	Area of Survey
Jones, et al., (1971)	California
Lindeken, et al., (1971 & 1973)	Livermore, California
Lowder and Condon (1965)	Vermont, New Hampshire
McLaughlin (1972)	General
Neher (1957)	General
Oakley (1972)	General
Solon, et al., (1960)	New York City
Yeates, et al., (1970 & 1972)	Boston

Neher (1957) reported the results of measurements made inside various buildings using an ionization chamber. The average exposure rate (cosmic radiation contribution subtracted) was 60 mR/yr for wood structures and 130 mR/yr for concrete buildings.

Solon, et al., (1960) also used an ionization chamber to survey dwellings in the metropolitan New York area and reported the results of the survey as cosmic plus terrestrial radiation. Measurements on the first floor of wood-frame dwellings (for three dwellings surveyed) showed a range of 76 to 97 mR/yr. Measurements on the first floor of brick and stone structures (for six dwellings surveyed) ranged from 70 to 84 mR/yr. Radiation measurements were also made in the upper floors of a brick apartment building,

but it is difficult to reach a definite conclusion from the data reported. Radiation levels outside of the surveyed structures were also reported and it appears that, in general, the radiation level inside the structure was somewhat lower than outside.

The article by Lowder and Condon (1965) discusses radiation surveys conducted in Vermont and New Hampshire, but only the results of outdoor measurement are reported. Although the authors present the conclusion that "the mean indoor levels were close to 70 percent of the corresponding outdoor levels in each area," no data were reported for the measurements made inside structures and it is, therefore, difficult to verify this conclusion.

The report by Yeates, et al., (1970) concludes that the ratio of the indoor to outdoor dose rates for wood structures is 82 percent (for five dwellings, first floor measurements), and a range of 87 to 106 percent for steel and concrete office buildings (for four structures surveyed). Yeates, et al., (1972) also discussed data from the 1970 report and has included data of gamma exposure rates inside single- and multiple-family dwellings and for several multi-story office buildings in Boston. The dose rates inside wooden single-family dwellings were from 25 to 50 percent lower than outdoor levels. For masonry multiple-family dwellings, the inside dose rate was about 10 percent lower than the outside measurement. The gamma exposure rates in multi-story office buildings were reported, but the data fail to show any significant change of the radiation level with height inside the building.

Lindeken, et al., (1971 and 1973) used TLD dosimeters to record the background radiation exposure in about 100 residences (mostly wood-frame structures) in the vicinity of Livermore, California. A median annual exposure rate of 63 mR, with a range of 52 to 120 mR/yr, was reported. Radiation levels on the second floor of the dwellings were slightly lower than the ground floor levels. Jones, et al., (1971) also reported TLD gamma surveys inside dwellings.

The article, "Radiation Levels Inside and Outside Buildings," by Goldin is included in the reference of McLaughlin (1972). Goldin summarizes the work in the United States by Yeates and presents a summary table of the radiation measurements inside dwellings in Sweden, East Germany, and Scotland. Some discussion of radon daughter concentration measurements inside buildings is reported by Hultquist (Sweden) and Yeates (United States).

The Second Workshop on the Natural Radiation Environment, W. M. Lowder, ed., (1974), contains several articles which discuss environmental gamma radiation surveys and also radon/ radon daughter evaluations made indoors in Grand Junction, Colorado.

In summary, the analysis of the few reported United States surveys can only lead to general conclusions regarding the attenuation of background radiation by United States building materials. Wood structures tend to have lower radiation levels inside compared to the outside levels. Single-story concrete or brick structures may have inside radiation levels higher than the outside levels due to the presence of natural radioactivity in the construction materials. The second floor of any type of structure (i.e., wood or masonry construction) seems to have a slightly lower radiation level than does the first floor. The ground-level floors of multi-story buildings have higher radiation levels inside than outside; but, in the higher stories, the radiation levels inside the building may be less than the outside radiation levels.

The following references report the results of surveys conducted to evaluate the radiation exposure rates inside dwellings in several foreign countries:

Author	Country
Cardinale, et al., (1971)	Italy
Gustafsson (1969)	Finland
Hultquist (1956 & 1965) (in Swedish)	Sweden
Kametani, et al., (1970) (in Japanese)	Japan
Kurokawa (1971) (in Japanese)	Japan
Ohlsen (1969 & 1970) (in German)	East Germany
Pensko, et al., (1969) (in Polish)	Poland
Spiers (1960)	Scotland
Storruste and Rlinstad (1965)	Norway
Yamashita, et al., (1966)	Japan
Yeates and King (1973)	Western Australia

The results of most of these reports are summarized in table 2.

Table 2. GAMMA EXPOSURE RATES INSIDE BUILDINGS - mR/yr

LOCATION AND REFERENCE	TYPE OF BUILDING	AVERAGE	RANGE	REMARKS
East Germany (Ohlsen, 1970)	Frame (old)	110	30-240	
	Brick (old)	110	40-200	
	Brick (new)	97	40-150	
	Stone (old)	140	40-260	
	Industrial Const. (new)	92	40-150	
Finland (Gaustafsson, 1969)	Wood	81	78-88	(cosmic of 28 mR/yr incl.)
Italy (Cardinale, et al., 1971)	Unclassified	--	105-263	(cosmic of 37 mR/yr incl.)
Norway (Storruste and Reinstad, 1965)	Wood	87	66-118	(cosmic of 25 mR/yr incl.)
	Concrete	117	81-152	
	Brick	129	91-158	
Scotland (Spiers, 1960)	Stone (Edinburgh)	48	25-70	
	Stone (Dundee)	64	45-80	
	Granite (Aberdeen)	85	70-110	
Sweden (Hultquist, 1956)	Wood	80	70-150	
	Brick	137	70-220	
	Concrete	206	130-520	
W. Australia (Yeates and King, 1973)	Wood	52	--	
	Brick	65	--	
	Concrete	67	53-91	(office bldg.)

---

*Parts of this table were taken from the article by A. S. Goldin in the report by J. E. McLaughlin (1972).

RADON AND RADON DAUGHTER PRODUCT CONCENTRATIONS INSIDE BUILDINGS

The only reported radon and radon daughter product concentrations measured inside United States buildings are contained in the articles by Yeates, et al., (1970 and 1972), and Aldrich and Conners (1974). Yeates measured the radon daughter product concentrations inside dwellings and inside multi-story buildings and compared the results to the outside measurements. The radon daughter product concentrations measured inside the dwellings (first and second floors) were comparable to the outdoor concentrations, but the concentrations in the basements were about a factor of five higher than outside. In the office buildings, the radon daughter product concentrations were low due to the effectiveness of the ventilation system for changing and filtering the air.

In the article by Aldrich and Conners (1974), data are reported on evaluations of the indoor radon daughter product concentrations for 32 State-owned office buildings in North Carolina. Only 5 out of 32 structures surveyed had working level values in excess of 0.01 WL; the highest value being 0.028 WL for the Old Senate Chamber of the State Capitol Building (granite, marble construction with no ventilation system).

Other authors [Barton, et al., (1973); Bunce (1966); Gesell (1973); Harley (1973); and Johnson, et al., (1973)] have considered the exposure of inhabitants of dwellings as a result of unvented combustion products from the use of natural gas in unvented appliances. The average concentrations of radon in natural gas were estimated to be about 20 pCi/l, whereas maximum concentrations of about 1,000 pCi/l have been measured. Other articles dealing with radon in natural gas are to be published in the Proceedings of the Noble Gases Symposium which was held in September 1973 in Las Vegas, Nevada.

Oakley (1972) also considers the internal exposure of organs, other than the lung, of an individual due to the inhalation of radon daughter products in the air inside a dwelling. Based on the UNSCEAR Report (1966), Oakley concluded that the internal exposure from the inhalation of radon daughter products would be less than 2 mrem/yr, gonadal dose equivalent.

Auxier, et al., (1974) describe a study on the effects of using plaster, asphalt, or paint on concrete surfaces to reduce the radon emission rates. Plaster and asphalt coatings did not reduce the radon emission rate. Epoxy paints did reduce the emission rate; however, this resulted in a buildup of radon daughter products at the paint to concrete interface which resulted in an increased gamma exposure rate. This study does not discuss the radioactivity content of building materials.

Kerr, et al., (1974) report on alpha-particle spectrometer measurements of indoor radon daughter products in Grand Junction, Colorado. This study was conducted to evaluate the remedial action program in nine structures where uranium mill tailings material had been used for construction purposes.

Hultquist (1969) reported the results of radon concentration measurements inside Swedish dwellings. For wooden structures (for eight buildings surveyed), a mean radon level of 0.53 pCi/l (ranging from 0.18 to 0.90 pCi/l) was measured. Brick structures (25 surveyed) had a mean radon level of 0.91 pCi/l (ranging from 0.18 to 4.1 pCi/l). Dwellings built mostly of concrete (28 surveyed) had a mean radon level of 1.86 pCi/l (ranging from 0.28 to 5.8 pCi/l).

Sievert (1965) reported results of surveys of the radon and thoron content of air inside Swedish houses of different construction types. Measurements were made before and then after the room was ventilated. The data presented by Sievert are given as the percentage of dwellings (by construction type) which were found in various radon concentration ranges (ranging from less than 0.5 pCi/l to the range of 15 to 30 pCi/l). Therefore, it appears that poor ventilation leads to high concentrations of radon inside dwellings regardless of construction type, and that concrete structures have a higher radon content than do brick dwellings, with wooden structures having the lowest radon content of any type of dwelling surveyed.

Toth (1972) reported on the determination of short-lived radon decay products in the air of unventilated living rooms in Hungary. Analyses for 841 locations completed in 14 different towns indicated mean concentrations for Ra-A, Ra-B, and Ra-C of 3.05, 2.64, and 2.49 pCi/l, respectively. On the basis of these radon daughter product concentrations, and of certain assumptions concerning occupancy time and dose conversion factors, Toth estimated that the Hungarian population receives a dose of 800 mrem/yr to the bronchial epithelium and 120 mrem/yr to the whole lungs.

Hague and Collinson (1967) also reported annual doses for different parts of the respiratory system for various radon and radon daughter concentrations in dwellings surveyed in London [Hague, et al., (1965)].

Four other articles concerned with the measurement of radon concentrations inside dwellings in foreign countries have also been reported:

Author	Country
Mikhaylov, et al., (1967)	Bulgaria
Shem'i-zade (1970)	Soviet Union
Toth (1968)	Hungary
Truelle (1971)	Czechoslovakia

Another report of possible interest, Snihs (1973), is to be published in the Proceedings of the Noble Gases Symposium held in Las Vegas, Nevada, in September 1973.

SURVEY OF BUILDINGS WHERE URANIUM MILL TAILINGS MATERIAL HAS BEEN USED FOR CONSTRUCTION PURPOSES

The extensive radiological surveys conducted by State and Federal agencies (e.g., U.S PHS, U.S. AEC, U.S. EPA, and the State of Colorado) to evaluate the hazards associated with the use of uranium mill tailings material for construction purposes have not been published in the open literature. Detailed reports have been issued to each State where tailings material has been determined to have been used for construction purposes. These State reports include the results of a mobile gamma-scanning survey (used to denote locations with suspected tailings use) and the results of portable instrument radiation surveys completed inside and outside of selected dwellings. For some dwellings, where the use of tailings material could not be completely evaluated from the gamma radiation surveys only, measurements of the indoor radon and radon daughter product concentrations (reported in units of "Working Level") were made and the results reported in the state reports. The extent of the problem resulting from the use of uranium mill tailings material for construction purposes is recorded in the Hearings by the Joint Committee on Atomic Energy (October 1971).

Auxier (1973) also considered the problems associated with the use of uranium mill tailings for construction purposes. Duncan and Eadie (1974) present data on the evaluation of the indoor working level values and also some indoor gamma radiation survey results for structures built immediately adjacent to a uranium mill tailings pile located in Salt Lake City, Utah.

SPECIAL STUDIES IN AREAS OF HIGH RADIATION BACKGROUND

Several articles are included in the bibliography which discuss radiological surveys conducted in areas (in India and Brazil) which have high natural radiation background. Little information concerning the radiological exposure conditions, which result from the use of sands and rocks of high radioactivity content for construction purposes, has been reported in these articles.

Bharatwal and Vaza give the results of gamma radiation surveys conducted inside houses in a monazite sand area, and conclude that, irrespective of the construction material used in the dwelling, the gamma exposure rate inside was almost the same as that outside. No studies have been reported which evaluate the radon levels inside dwellings in these areas of high radium and thorium bearing soils.

BIBLIOGRAPHY

Adams, J. A. S., J. K. Osmond, and J. W. Rogers. The geochemistry of thorium and uranium. Physics and Chemistry of the Earth, Ch. 3: pp. 298-348. 1959.

Adams, J. A. S. and W. M. Lowder, (eds.). The Natural Radiation Environment. Proc. International Symposium on the Natural Radiation Environment. Held at Houston, Texas, April 10-13, 1964. Chicago, U. of Chicago Press, 1964. (NSA 18(20)-35727).

Adams, J. A. S., W. M. Lowder, and T. F. Gesell, (eds.). Proc. Second International Symposium on the Natural Radiation Environment. USAEC Symposium Series, 1974.

Afanas'ev, M. K. and E. M. Krisyuk. Standards for natural radioactive substances in building materials. Hygiene and Sanitation. 32(10-12): October-December, 1967. *High radon and thoron indoor concentrations from building materials.*

Akalan, I. and J. L. White. Natural and fission-produced radioactivity in four Indiana soils. Proc. Indiana Acad. Sci. 72:325-329, 1962.

Aldrich, L. K. and D. A. Conners. Evaluation of airborne radon in state owned office buildings. In: Report of the Environmental Radiation Surveillance Program. North Carolina, October 1974. *Data on indoor radon evaluations.*

Aleksakhin, R. M. and V. D. Vasil'yevskaya. Proc. 2nd Inter-Institute Conf. on the Problem of Microelements and Natural Soil Radioactivity in the USSR. Pochvovedeniye. 9:114-115, 1960. (English translation: JPRS-6626; CSO:4902-D).

Alexander, L. T., E. P. Hardy, Jr., and H. L. Hollister. Radioisotopes in soils: particularly with reference to strontium-90. Radioisotopes in Biosphere. R. S. Caldecott and L. A. Snyder (eds.). Minneapolis, U. of Minnesota Printing Dept. 1960. *Includes natural radioactivity.*

Asimov, I. Natural occurrences of short-lived radioisotopes. J. Chem. Educ. 30:616-618, 1953.

Aten, A. H., I. Heertje, and M. C. deJong. Measurements of low-level environmental radiation by means of G-M counters with observations in the Amsterdam area. Physica 27. pp. 809-820. 1961. *External gamma radiation inside buildings and in the building material.*

Auxier, J. A. Contribution of Natural Terrestrial Sources to the Total Radiation Dose to Man. Thesis. Georgia Inst. of Tech. 1973. (NSA 28(6)-13054.) ORNL-TM-4323 (NSA 29(1)-633, September 1973.) *Sources, radon in homes, and uranium mill tailings used for construction purposes.*

Auxier, J. A., W. H. Shinpaugh, G. D. Kerr, and D. J. Christian. Preliminary studies of the effects of sealants on radon emanation from concrete. Health Phys. 27(4):390-392, October 1974. (NSA 31(5)-12113.) *Plaster or asphalt coverings do not reduce radon emission rates; paint reduces emission rate by factor of 4.*

Baranov, V. I., N. G. Morozova, K. G. Kunasheva, and G. I. Grigor'yev. Geochemistry of some natural radioactive elements in soils. (English translation: Soviet Soil Science. 8:733-740, 1964.)

Baranov, V. I. and V. I. Vernadskii. Natural radioactivity of soils. Izv. Akad. Nauk SSSR, Ser. Biol. 29(1):159-163. 1964. (English translation: JPRS-23912; OTS-64-21919.)

Baranovski, R. and J. Bars. The radiometric determination of total potassium in soil, taking into account the radiation effect of components of the uranium and thorium series. Zesz. Nauk. wyg. Szkol. sol. Wroclaw Rol. 12:143-148, 1960. (Soil and Fertilizer. 24(6): abstr. 2991.)

Barr, N. F. Assessments of radiation doses to man from various common sources. Trans. Amer. Nucl. Soc. 15(1):449, June 1972. (NSA 26(18)-43292.) *Sources and dose estimates.*

Barretto, P. M. d. C. Emanation Characteristics of Terrestrial and Lunar Materials and the ^{222}Rn Loss Effect on the U-Pb System Discordance. Thesis. Rice University, 1973. (NSA 29(1)-1272.) *Radon emanation rates from various soils, rocks and minerals.*

Barton, C. J., R. E. Moore, and P. S. Rohwer. Contribution of radon in natural gas to the dose from airborne radon daughters in homes. ORNL-TM--4154, 1973. *Dose estimates.*

Beck, H. L., W. J. Condon, and W. M. Lowder. Environmental radiation measurements in the southeastern, central and western United States, 1962-1963. USAEC Report HASL-145, April 1964. *External gamma background and fallout contribution.*

Beck, H. L., W. J. Condon, and W. M. Lowder. Spectrometric techniques for measuring environmental gamma radiation. USAEC Report HASL-150, 1964.

Beck, H. L., W. M. Lowder, B. G. Bennett, and W. J. Condon. Further studies of external environmental radiation. USAEC Report HASL-170, 1966. (NSA 20(15)-27196.) *Natural radioactivity.*

Beck, H. and G. de Planque. The radiation field in the air due to distributed gamma-ray sources in the ground. USAEC Report HASL-195, 1968.

Beck, H. L. Gamma radiation from radon daughters in the atmosphere. J. Geophys. Res. 79(15):2215-2224, May 1974. (NSA 30(5)-12692.) *Gamma ray flux from radon as function of height in atmosphere.*

Bennett, B. G. Estimation of gonadal absorbed dose due to environmental gamma radiation. Health Phys. 19(6):757-767, December 1970. *Theory to calculate gonadal dose from natural and fallout radioactivity in the environment, screening factor of 0.8 used.*

Bergstrom, S. O. W. and T. Wahlberg. Radium containing construction materials from a radiation protection standpoint. Aktiebolaget Atomenergi. Stockholm, Sweden. p. 24, 1967. *In Swedish.* (NP-17230, NSA 22(7)-12429.)

Bharatwal, D. S. and G. H. Vaze. Radiation dose measurements in the monazite areas of Kerala State in India. Proc. 2nd Int. Conf. Peaceful Uses of Atomic Energy, Geneva. 23:156.

Bharatwal, D. S. and G. H. Vaze. Measurements on the radiation fields in the monazite areas of Kerala in India. United Nations Document A/AC.82--G/R.166. *Thorium sands used in construction materials and exposure rates inside homes.*

Blanchard, R. L. A rapid method for a determination of Pb-210 and Po-210 in environmental samples. Health Phys. 11(8):831, 1965.

Bohn, J. L. Radioactive properties of waters and soils in the Southern California region. Phys. Rev. 31:912, 1928.

Bonka, H. The local average natural radiation exposure of the population in the Federal Republic of Germany. Atomkernenergie. 23(2):137-150. 1974. *In German.* (NSA 30(8)-21368.) *Cosmic and terrestrial exposure estimates for Germany.*

Bonta, J. and T. Predmersky. Technical Hygienical Radiation Protection. Publisher: Muszaaki (Budapest). pp. 102-108, 1962.

Bortoli, M. D. and P. Gaglione. Natural and fallout radioactivity in the soil. Health Phys. 17(5), November 1969. *Good data from Italy on soil content by city; analysis of potassium, radium, thorium, strontium and plutonium reported.*

Bortoli, M. D. and P. Gaglione. Radium-226 in environmental materials and foods. Health Phys. 22(1):43-48, January 1972. *Radium in foods, water; uptake studies in Italy.*

Botset, H. G. and P. Weaver. Radon content of soil gas. Physics. 2:376-385, 1932.

Brill, A. B. and R. E. Johnston. Exposure of man to radiation. CONF-690559. (NSA 25(11)-24430.) *Exposure from all sources.*

Budnitz, R. J. Radon-222 and its daughters--a review of instrumentation for occupational and environmental monitoring. Health Phys. 26(2):145-163, February 1974. (NSA 29(8)-18328.) *Measurement techniques discussed.*

Bunce, L. A. and R. W. Sattler. Radon-222 in natural gas. Rad. Health Data and Rep. 7(8):441-444, 1966. *Room concentrations from unventilated gas appliances.*

Bunker, C. M. and C. A. Bush. Radioelement composition of surface soil in Adams County, Colorado. U.S. Geological Survey, Prof. Paper 600-B, pp. 71-75, 1968. *Thorium, uranium, potassium.*

Evaluation of Radon-222 Near Uranium Tailings Piles. Bureau of Radiological Health. March 1969. PB-188691. (NSA 30(4)-9538.) *Outdoor sampling for radon from tailings piles at 4 locations.*

Burgkhardt, B. and E. Piesch. Use of CaF_2 thermoluminescent dosimeters for measuring the natural background radiation. Kerntechnik. 14(3): 128-134, March 1972. (NSA 26(14)-33455.) *Use of TLD for background radiation measurements.*

Burson, Z. G., P. K. Boyns, and A. E. Fritzsche. Characterizing the terrestrial radiation environment by aerial surveys. CONF-720607. Trans. Amer. Nucl. Sci. 15(1):544, June 1972. (NSA 26(18)-42959.) *Data analysis and method description.*

Bushong, S. C.. The composition and spatial distribution of background radiation. Health Phys. 10(10):731-742, October 1964. *Radium-226 and potassium-40 content of soil at Pittsburgh; variation with depth.*

Cardinale, A., L. Frittelli, and G. Lembo. Studies on the natural background radiation in Italy. Health Phys. 20(3):285-296, March 1971. *Background exposure rates in the open, inside buildings, over roadways in Rome; inside houses=12 to 30 μR/h, outside=19.7 μR/h average over ground.*

Chang, T. Y., W. L. Cheng, and P. S. Weng. Potassium, uranium and thorium content in building material of Taiwan. Health Phys. 27(4): 385-387, October 1974. (NSA 31(3)-5974). *Typical concrete building has exposure rate = 52 mR/year.*

Clark, K. G., M. S. Anderson, and B. T. Shaw. The potash problem in the United States. Agricultural Research Admin., U.S. Dept. of Agriculture, Beltsville, Maryland. 1944.

Clark, R. W. and H. G. Botset. Correlation between radon and heavy mineral content of soils. Bull. Am. Assoc. Petroleum Geol. 16:1349-1356, 1932.

Clark, S. P. Jr., Z. E. Peterman, and K. S. Heier. Abundances of uranium, thorium, and potassium. Handbook of Physical Constants revised edition. Geological Society of America, Inc. (New York). pp. 521-540, 1966.

Clegg, J. W. and D. D. Foley (eds.). Uranium Ore Processing. Massachusetts, Addison-Wesley, 1958.

Clopton, J. C., (ed.). Environmental radioactivity symposium. John Hopkins University. CONF-700124. November 1970. (NSA 28(4)-8133.) *Environmental sources.*

Collinson, A. J. and A. K. Haque. A scintillation counter for the measurement of radon concentrations in air. J. Sci. Instrum. 40: 521-523, 1963. (NSA 18(2)-2049.)

Report on radon and helium occurrences in soil gas. Colorado School of Mines Research Foundation, Inc. Golden, Colorado. Report GJO-928-1. 1967.

Comar, C. L. and J. H. Rust. Natural radioactivity in the biosphere and foodstuffs. Toxicants Occurring Naturally in Foods National Academy of Sciences. 1973. (NSA 30(7)-18627). *Data on rocks, soils, water, foods; exposure estimates.*

Cowan, F. P.. Quantitative summary of natural radiation and naturally occurring isotopes. Brookhaven National Laboratory Report, USAEC Report AECU-1138. 1951. (NSA 5-3465.)

Cowan, F. P.. Every day radiation. Physics Today. 5(10):10, 1952.

Cullen, T. L.. A study of natural radioactivity in Brazil. Univ. Catolica do Rio de Janeiro, Brazil. USAEC Report NYO-2577-8, p. 68. 1967. (NSA 22(13)-25829.)

Curtis, J. T. and R. Dix. Distribution of alpha radioactivity in certain forest types. Science. 123(3201):799-800, 1956.

Curtis, J. T. and R. Dix. The vertical distribution of alpha-emitting radioactive substances in certain forest types. Bull. Ecol. Soc. Am. 36:88, 1955.

Davies, B. L. and J. Forward. Measurement of atmospheric radon in and out of doors. In: abstracts of papers presented at the 2nd International Congress of the International Radiation Protection Association. Brighton, England. May 3-8, 1970.

De Campo, J. A., H. L. Beck, and P. D. Raft. High pressure argon ionization chamber systems for the measurement of environmental radiation exposure rates. USAEC Report HASL-260, December 1972.

De Meijer, R. J.. Concrete with low intrinsic radioactivity. Report EURISOTOP-55. 2:1137-1140, 1973. State Univ. of Utrecht. (NSA 27(12) -27563.) *Measurement methods, but little data and only Utrecht area studied.*

Dick, J. B. and D. A. Thomas. Ventilation research in occupied houses. J. Inst. Heat Vent. Eng. 19:306-326, 1951.

Doke, T., T. Higashimure, and M. Takenchi, et. al. External gamma dose rate from natural radionuclides in Japan. Sci. Papers. 56:40-46, 1962.

Drew, R. T. and M. Eisenbud. The natural radiation dose to indigenous rodents on the Morro DoFerro, Brazil. Health Phys. 12(9):1267-1274, September 1966. *TLD's used to measure radiation exposure of rodents; radon in burrows.*

Druilhet, A. and J. Fontan. Application of radon as indicator of the intensity of exchanges at the soil (0 to 100m). Boundary-Layer Meteorology. 6(3-4):387-411, 1974. *In French* (NSA 30(9)-23992). *French data on radon versus height in atmosphere.*

Duggan, M. J. and D. M. Howell. Method for measuring the concentrations of the short-lived daughter products of radon-222 in the atmosphere. Int. J. Appl. Radiat. Isotopes. 19:865-870, December 1968.

Duncan, D. L. and G. G. Eadie. Environmental surveys of the uranium mill tailings pile and surrounding areas--Salt Lake City, Utah. USEPA Report EPA-520/6-74-006, August 1974. *Indoor and outdoor radiation surveys and working level determinations.*

Eisenbud, M.. Environmental Radioactivity. New York, McGraw-Hill Book Co., 1963. *Sources, activity content of rocks, soils, foods, water; human body burdens.*

Eisenbud, M. Radioactivity in the environment: sources of radioactivity in the environment. Pediatrics. 41(suppl.);;174-195, 1968. (NSA 22(20)-43345.)

Eisenbud, M., H. Petrow, R. T. Drew, F. X. Roser, G. Kegel, and T. L. Cullen. Naturally occurring radionuclides in foods and waters from the Brazilian areas of high radioactivity. The Natural Radiation Environment. pp. 837-854, 1964. (NSA 18(20)-35727.)

Basic approach for safety analysis and control of products containing radionuclides and available to the general public. European Nuclear Energy Agency. (NSA 24(22)-46618.) *Guide for radiation protection.*

Fallout program quarterly summary report. Health and Safety Lab., USAEC Reports HASL-182 and HASL-172. *Lead-210 in rain, water and in fertilizers.*

Ferri, S. and E. J. Baratta. ^{210}Po in tobacco, cigarette smoke and selected human organs. Public Health Reports. 81:121-127, February 1966.

Fisenne, I. M. Distribution of Pb-210 and Ra-226 in soil. Presented at the Proceedings of the 13th Annual Bioassay and Analytical Chemistry Meeting. Held at Lawrence Radiation Laboratory, October 12 and 13, 1967. A. deG. Low-Beer, (ed.). Univ. of Calif., Berkeley. USAEC Report UCRL-18140. pp. 145-158. 1968. (NSA 22(18)-37877.)

Gabrysh, A. F. and F. J. Davis. Radon released from concrete in radiant heating. Nucleonics. 13(1):50, January 1955.

Gabrysh, A. F., N. D. McKee, and H. Eyring. Determination of the radon emanation from carbonate rocks and its potential hazard in building materials. Mater. Res. Stand. 2:265-268, 1962.

Gesell, T. F. Some radiological aspects of radon-222 in natural gas and natural gas products. Proceedings of the Noble Gas Symposium. Las Vegas. September 24-28, 1973. In Press. *Radon content of natural gas and liquid petroleum products reported and its significance to human exposure.*

Geyh, M. and S. Lorch. Determining the concentration of gamma rays to the natural environmental radiation at ground level. The Natural Radiation Environment. pp. 979-988, 1964.

Geyh, M. and S. Lorch. Measurement of the component of the natural gamma-environmental radiation in the Federal Republic of Germany. Bundesministerium fur Wissenschaftliche Forschung, Bad Godesberg. BMWF-FB-K-66-42. p. 65, 1966. *In German.* (NSA 21(10)-15993.)

Gibbs, H. S. and G. J. McCullum. Natural radioactivity of soils. New Zealand J. Sci. Technol. 37B:354-368, 1955.

Gibson, J. A. B. Measurement of the gamma-radiation background. United Kingdom Atomic Energy Research Est., Harwell. Report AERE-R-4137, 1962. *Cosmic, natural and fallout dose rates.*

Gileadi, M. Joint Radiation Survey Summary. TID-26642, 1974. (NSA 31(4)-8877). *Background radiation survey in Puerto Rico.*

Glauberman, H., A. Breslin, and W. Harris. Environmental radon measurements. USAEC Report NYOO-4861. 1957.

Gold, S., H. W. Barkhau, and B. Kahn. Measurement of naturally occurring radionuclides in air. The Natural Radiation Environment. pp. 369-382, 1964.

Golden, J. C., Jr. Natural background radiation levels in Florida. Sandia Corp. Document SC-RR-68-196, 1968.

Gopal-Ayenger, E. R. Possible areas with sufficiently different background radiation levels to permit detection of differences in mutation rate of "marker" genes. Effect of Radiation on Human Heredity. World Health Org., Geneva. Monograph series:115-124, 1957.

Gorham, E. A comparison of natural and fallout radioactivity in Ontario soils under pine. Can. J. Botany. 41(9):1309-1318, 1963.

Gruneberg, H. Genetical research in an area of high natural radioactivity in South India. Nature. 204:222-224, October 1964. (NSA 19(2)-2131.) *Concludes that no significant genetic changes occurred.*

Gustafsson, M. External and internal irradiation of Swedish reindeer breeders. Health Phys. 17(1):19-34, July 1969. *Radiation levels outdoors and indoors; environmental radiation exposure evaluated; internal emitters assessed.*

Gustafson, P. F. Environmental radiation: past, present, and future. Trans. Nucl. Sci. NS-19(1):104-106, February 1972. (NSA 26(18)-42945.) *Sources.*

Gustafson, P. F., L. D. Marinelli, and S. S. Brar. Natural and fission produced gamma-ray emitting radioactivity in soil. Science. 127: 1240-1242, 1958.

Gustafson, P. F. Measurement of soil radioactivity and calculation of dose therefrom. Radiological Physics Division Semiannual Report. Argonne National Lab. USAEC Report ANL-5967, pp. 156-163, 1959.

Gustafson, P. F. and S. S. Brar. Measurement of gamma-emitting radionuclides in soil and calculation of the dose arising therefrom. The Natural Radiation Environment. pp. 499-512, 1964.

Gutt, W. Manufacture of cement from industrial by-products. Chem. Ind. pp. 189-197, 1971.

Hamilton, E. I. The relative radioactivity of building materials. Amer. Ind. Hyg. Assoc. J. 32(6):398-403, June 1971. (NSA 25-47192.) *Radium, thorium, potassium, uranium in building materials.*

Hamilton, E. I. Distribution of radioactivity in rocks and minerals, and the effect of weathering on determinations of uranium. Nature. 181:697-698, 1958.

Handly, T. H. and C. J. Barton. Home ventilation rates. A literature survey. ORNL-TM-4318. September 1973. (NSA 28(11)-27258.) *Review; 0.5 to 1.5 air changes per hour in average house.*

Hansen, R. O. and P. R. Stout. Isotopic distribution of uranium and thorium in soils. Soil Science. 105(1):45-50, 1968.

Haque, A. K., A. J. Collinson, and C. O. Brooke. Radon concentrations in different environments and the factors influencing it. Physics Med. Biol. 10:505-514, 1965.

Haque, A. K. and A. J. Collinson. Radiation dose to the respiratory system due to radon and its daughter products. Health Phys. 13(5): 431-444, May 1967. *Lung dosimetry from radon and daughter product exposure.*

Harley, N. A., J. H. Harley, and I. M. Fisenne. Measurement of radium-226 and radon-222 in environmental samples. CONF-727. pp. 142-151, 1964. *Radiochemical processes.*

Harley, J. H. and W. M. Lowder. Natural radioactivity and radiation. USAEC Report HASL-242, April 1971. *United States terrestrial dose rates, soil content.*

Harley, J. H. Environmental levels of radon. Proceedings of the Noble Gas Symposium. Las Vegas. September 24-28, 1973. In press. *Radon-222 and daughter exposures, some discussion of radon inside dwellings and its source in building materials.*

Hart, J. C., R. H. Ritchie, and B. S. Varnadore, (eds.). Population Exposures. CONF-741018, October 1974. (NSA 31(1)-821). *Exposure from various sources.*

Havolic, V. Natural radioactive aerosols in the ground level air of a Czechoslovak locality with respect to the radiological exposure of its population. Health Phys. 11(6):553-566, July 1965. *Seasonal variation of radon in atmosphere; dose estimates given.*

Hecht, F., H. Kupper, and W. E. Petraschek. Preliminary remarks in the determination of uranium in Austrian springs and rocks. Proc. 2nd Int. Conf. Peaceful Uses of Atomic Energy. Geneva. 1958. 2:158-160. *Some uranium data.*

Herbst, W. Investigations of environmental radiation and its variability. The Natural Radiation Environment. pp. 781-796, 1964.

Hess, F. L. Industrial Minerals and Rocks. Amer. Inst. Mining and Met. Eng. (New York). 1949. *Radioactivity of beach sands.*

Hess, V. F. and G. A. O'Donnell. The rate of ion formation at ground level and at one meter above the ground. J. Geophys. Res. 56(4): 557-562, 1951.

Hilaire, M. and Y. LeGallic. Nonradioactive reference materials. Bull. Infor. Sci. Tech. Paris. 163:67-72, October 1971. *In French.* (NSA 26-32607.) *Copper, lead and steel; reference source with activity less than 0.001 pCi/g.*

Howell, L. G. Radioactivity of soil gases. Bull. Amer. Assoc. Petroleum Geol. 18:63-68, 1934.

Hoy, J. E. and L. F. Landon. Background radiation measurements in the environs of the Savannah River plant, 1952-1963. Du Pont de Nemours and Co., Savannah River Plant. USAEC Report DPSPU-63-30-8, p. 13, 1963. (NSA 17-18321.) *Natural external gamma radiation surveys.*

Hultquist, B. Studies on naturally occurring ionizing radiation, with special reference to radiation doses in Swedish houses of various types. Kungl. Svenska Vetenskapsakad. Handlingar, Ser. 4, 6(3):1-125, 1956. *In Swedish.*

Hultquist, B. Kungl. Svanska Vetenskapsakademiens Handlingar, Fjard Serien. 6(3):125, 1965. Stockholm, Almqvist-Wilsells Bocktrikeri AB. *In Swedish.*

International Atomic Energy Agency. Proceedings of an International Symposium, Rapid Methods for Measuring Radioactivity in the Environment. Neuherberg, Vienna, July 1971.

International Atomic Energy Agency. Uranium Exploration Methods. November 1973. STI/PUB-334. CONF-720487. (NSA 29(10)-24171). *Radon measurements in various soils to indicate uranium deposits.*

Jackson, M. L. Chemical composition of soils. Chemistry of the Soil. 2nd edition. New York, Reinhold Publishing Corp., 1964. Chapter 2: pp. 71-141.

Jaki, S. L. and V. F. Hess. A study of the distribution of radon, thoron and their decay products above and below the ground. J. Geophys. Res. 63(2):373-390, 1958.

Jamieson, H. D., C. G. Tripp, and F. L. Sanderson. Environmental ionizing radiation in Dunedin, New Zealand. New Zealand J. Sci. 9:674-683, 1966. (NSA 21(14)-24116.) *External gamma radiation.*

Jaworowski, Z., J. Bilkiewicz, L. Kownacka, and S. Wlodek. Artificial sources of natural radionuclides in the environment. SZS-157, March 1974. Central Lab. for Rad. Prot., Warsaw, Poland. (NSA 31(4)-8618.) *Natural and artificial sources of radium and radon.*

Jeffreys, H. The Earth, 3rd edition. MacMillan, Cambridge Univ. Press, 1952. *Radium and thorium content of rocks.*

Johnson, R. H., D. E. Bernhardt, N. S. Nelson, and H. W. Calley, Jr. Assessment of potential radiological health effects from radon in natural gas. USEPA Report EPA-520/1-73-004, 1973. *Radon exposure in homes from use of natural gas in unvented appliances.*

Use of uranium mill tailings for construction purposes. Joint Committee on Atomic Energy. In: Hearings by the Subcommittee on Raw Materials, JCAE, October 1971. *The problem of elevated radon levels and of increased gamma exposure levels in dwellings in which uranium tailings material has been used for construction.*

Jonassen, N. and E. I. Hayes. Measurement of low concentrations of the short-lived radon-222 daughters in the air by alpha spectroscopy. Health Phys. 26(1):104-110, January 1974. (NSA 29(7)-15317. *Measurement method, data on unventilated basement.*

Jones, D. E., C. L. Lindeken, and R. E. McMillen. Natural radiation background dose measurements with CaF_2:Dy TLD. UCRL-73432, September 1971. (NSA 26(3)-4756.) *TLD measurements inside homes in Livermore, California; 9.6 mR/yr average exposure rate.*

Jones, D. E., C. L. Lindeken, and R. E. McMillen. Natural radiation background dose measurements with CaF_2:Dy TLD. RISO-249, Pt. 3, December 1971. (NSA 27(8)-17375.) *Gamma radiation measurements inside houses.*

Joshi, L. U. and T. N. Mahadevan. Seasonal variations of radium-D in ground level air in India. Health Phys. 15(1), July 1968. *Lead-210 in air and soil.*

Joshi, L. U., C. Rangarjan, and Smt. S. Gopalakrishnan. Investigations of Pb-210 concentrations in various regions of India. Health Phys. 20(6):665-668, June 1971. *Graphical display of lead-210 in air in four cities in India during 1962-1969.*

Kametani, K., A. Hasegawa, et. al. Chemical and hygienic studies on natural radioactive spa. 4. Measurement of external radiation at Misasa and Masutomi Spa areas. Eisei Kagaku. 1:28-31, February 1970. *In Japanese.* (NSA 25(3)-4711.) *Radiation measurements inside buildings.*

Kauranen, P. and J. K. Miettinen. Po-210 and Pb-210 in the Arctic food chain and the natural radiation exposure of Lapps. Health Phys. 16(3), March 1969. *Plant, animal and human uptake.*

Kauranen, P. and J. K. Miettinen. Specific activity of Pb-210 in the environment. COO-3011-1, May 1972. (NSA 26(20)-48055.) *Sample data.*

Keefer, D. H. and M. Dauer. Natural environmental radioactivity in south Florida sands and soils, February-June 1968. Rad. Health Data and Rep. 11:441-448, September 1970.

Kerr, P. F. The natural occurrence of uranium and thorium. Proc. of the International Conference. Peaceful Uses of Atomic Energy, Geneva. 6:5 and 641, 1956. *Worldwide uranium and thorium deposits.*

Kerr, G. D., S. A. Abdullah, J. A. Auxier, *et al.* Measurements of radon daughter concentrations in air. ORNL-4979, pp. 202-207. (NSA 31(3)-5994.) September 1974. *Indoor measurements in Grand Junction, Colorado.*

Kinsman, S. Background radiation exposures of the general population. Amer. Ind. Hyg. Assoc. J. 19(1):8-14, February 1958. *Cosmic, external and internal exposures from terrestrial sources.*

Klechkovskii, V. M., G. G. Polikarpov, and R. M. Aleksakhin, (eds.). Radioecology. New York, 1973. John Wiley and Sons, Inc. (NSA 29(6)-12716.) *Natural radioactivity in soils.*

Klement, A. W., Jr. Natural environmental radioactivity--an annotated bibliography. USAEC Report WASH-1061, July 1965.

Klement, A. W., Jr. Natural environmental radioactivity--an annotated bibliography. USAEC Report WASH-1061(Suppl.), April 1970.

Klement, A. W., Jr., C. R. Miller, R. P. Minx, and B. Shleien. Estimates of ionizing radiation dose in the United States--1960-2000. USEPA Report ORP/CSD-72-1, August 1972. (NSA 26(23)-57893.) *Dose estimates from natural and fallout sources in the USA.*

Kominek, A. Use of radionuclides in building material industry. Radioisotopy. 13(2):415-421, 1972. (NSA 26-28305.) *In Czechoslovakian.*

Krisyuk, E. M., E. P. Lisachenko, S. I. Tarasov, *et al.* Investigation and standardization of the radioactivity of construction materials. CONF-730907-P2, pp. 870-881. February 1974. *In Russian.* (NSA 30(10)-26783.) *Gamma exposure rates and concentration limits for natural radioactivity in Russian building materials.*

Krisyuk, E. M., S. I. Tarasov, *et al.* Study and standardization of the radioactivity of structural materials. SZS-157, March 1974. *In Russian.* (NSA 31(4)-8614.) *Radioactivity analysis data of Russian building materials.*

Kurokawa, Y. Data of natural radioactivity in Japan. Hoken Butsuri. 6(4):192-193, December 1971. *In Japanese.* (NSA 27(1)-310.) *Soils and river waters; some indoor and outdoor exposure rates.*

Kusnetz, H. L. Radon daughters in mine atmospheres--a field method for determining concentrations. Amer. Ind. Hyg. Assoc. Quart. 17(1)::85-88,
March 1956.

Lagunov, L. L. Radioactivity of the rocks in the Far East and its influence on forests. Bull. Far East Branch Acad. Sci. USSR 9:105-109, 1934.

Levin, S. G. and R. K. Stoms. Natural background gamma radiation dose rate measurements in Michigan, Colorado and Minnesota. Amer. Ind. Hyg. Assoc. J. 59(1):102-109, January 1969. *Cosmic and terrestrial background measurements.*

Liboff, A. R. and M. H. Shamos. Ultra low levels of terrestrial ionization. Nature. 217:629-630, 1968. (NSA 22(8)-14583.) *Radiation levels in selected mines.*

Lindeken, C. L., D. E. Jones, and R. E. McMillen. Natural terrestrial background variations between residences. Univ. of California, Document UCRL-72964, 1971.

Lindeken, C. L., K. R. Peterson, D. E. Jones, and R. E. McMillen. Geographical variations in environmental radiation background in the United States. UCRL-73822, March 1972. (NSA 26(20)-48035.) CONF-720805-1. *TLD's used in 107 weather stations; median terrestrial rate = 5.5 μR/h.*

Lindeken, C. L., D. E. Jones, and R. E. McMillen. Environmental radiation background between residences. Health Phys. 24(1):81-86, January 1973. *TLD measurements inside 100 residences in Livermore, California.*

Lindell, B. and D. P. Reizenstein. A Swedish building material for low radioactivity laboratories. Arkiv. f. fyski, 26:65, 1964. *In Swedish.*

Lloyd, R. D., R. C. Pendleton, and T. R. Downard. Radioactivity within a tunnel in granite rock. (Note.) Health Phys. 15(3):274-276, 1968. *Air, water; external gamma radiation, radon-222, radium-226.*

Lough, S. A. and W. M. Lowder. The natural radiation environment. Radiation Biology and Medicine. W. D. Claus, (ed.), Reading, Pa., Addison-Wesley Publ. Co., 1958.

Love, S. K. Natural radioactivity of water. Ind. Eng. Chem. 43:1541-1544, 1951. *Radium, radon and uranium content of rocks, water and seawater.*

Lowder, W. M., W. J. Condon, and H. L. Beck. Field spectrometric investigations of environmental radiation in the United States. The Natural Radiation Environment. pp. 597-616, 1964.

Lowder, W. M., H. L. Beck, and W. J. Condon. Spectrometric determination of dose rates from natural and fallout gamma radiation in the United States, 1962-1963. Nature. 202(4934):745-749, 1964. (NSA 18 (15)-25694.) *Natural and fallout gamma exposure rates in selected United States cities.*

Lowder, W. M., A. Segall, and W. J. Condon. Environmental radiation survey in northern New England. The Natural Radiation Environment. pp. 907-917, 1964. (NSA 18(20)-35727.)

Lowder, W. M. and W. J. Condon. Measurement of the exposure of human populations to environmental radiation. Nature. 206:658-662, 1965.

Lowder, W. M. and L. R. Solon. Background radiation--a literature search. Health and Safety Lab., USAEC Report NYO-4712, 1956.

Lowder, W. M. and H. L. Beck. Cosmic ray ionization in the lower atmosphere. J. Geophys. Res. 71:4661-4668, 1966.

Lowder, W. M. and J. E. McLaughlin. Environmental radiation in the continental United States. HASL-TM-71-21, November 1971. (NSA 26(14)-33336.) *Environmental surveys; terrestrial gamma = 7 μR/h; cosmic = 3.5 μR/h; total natural background less than 20 μR/h in USA.*

Lowder, W. M., A. C. George, C. V. Gogolak, and A. Blay. Indoor radon daughter and radiation measurements in east Tennessee and central Florida. HASL-TM-71-8, March 1971. *Environmental surveys.*

Lowder, W. M. Second Workshop on the Natural Radiation Environment, February 1974. CONF-740212. HASL-287. September 1974. (NSA 31(2)-3320.) *Radon measurements and use of uranium mill tailings for construction purposes.*

Lynch, D. E. Soil and water uranium and radium survey, progress report. New York Operations Office, USAEC Report NYO-1520, 1950.

Lyon, T. L. and H. O. Buckman. The Nature and Properties of Soils. New York, MacMillan Pub. Co., 1943.

Mahdavi, A. The Thorium, Uranium and Potassium Contents of Atlantic and Gulf Coast Beach Sands. Dissertation, Houston, Texas, Rice Univ., p. 72, 1963. (Univ. Microfilms, Ann Arbor, Mich., 63-7170. Dissertation Abstr. 24:3291-3292.)

Marey, A. N. Ch. 2, Natural Sources of Radiation. Distribution of radioactive substances in nature. Radiation Hygiene, Marey, A. N. (ed.). Moscow, House for Medical Literature(Publ.), Medgiz., 1962. 2:9-10. (CA 59-14861.)

Marsden, E. and C. Watson-Munro. Radioactivity of New Zealand soils and rocks. New Zealand J. Sci. Technol. 26B:99-114, 1944.

Marsden, E. Radioactivity of soils, plants ashes and animal bones. Nature. 183:924-925, 1959. *Total alpha activity in New Zealand soil, plants and animals.*

McCormick, J. F. and D. J. Cotter. Radioactivity on southeastern granite outcrops. Bull. Ga. Acad. Sci. 22(1):20-28, 1964.

McLaughlin, J. E., M. S. Weinstein, A. Shambon, and G. Burke. Preliminary environmental radiation tests with TL dosimetry. HASL-TM-71-22, December 1971. (NSA 26(12)-28166.) *TLD's for low-level exposures; TLD capabilities.*

McLaughlin, J. E. Workshop on natural radiation environment. USAEC Report HASL-269, March 1972. *Aerial surveys; surveys inside and outside buildings.*

Megumi, K. and T. Mamuro. Emanation and exhalation of radon and thoron gases from soil particles. J. Geophys. Res. 79(23):3357-3360, August 1974. (NSA 30(10)-26796.) *Particle size effects on emanation rates.*

Mejdahl, V. Measurement of environmental radiation at archaeological excavation sites. Archaeometry. 12:147-159, August 1970. *TLD's buried at depth in ground to record gamma exposure.*

Menzel, R. G. Uranium, radium and thorium content in phosphate rocks and their possible radiation hazard. J. Agr. Food Chem. 16(2):231-234, 1968. *Fertilizer phosphate sources.*

Mericle, L. W. and R. P. Mercile. Reassessing the biological role of background terrestrial radiation as a constituent of the natural environment. Health Phys. 11(12):1607-1620, December 1965. *Effects on plant life in high radiation area of Colorado.*

Mertie, J. B., Jr. Monazite deposits of the southeastern Atlantic States. U.S. Geological Survey, Circular 237, 1953.

Mikhaylov, M. G., M. Yotov, T. Petkov, and M. Yanachkova. Contamination of the air with decay products of radon in dwellings in a region with an elevated natural radioactivity background. Rentgenol. Radiol. 6:112-120, 1967. *In Bulgarian.* (NSA 22(20)-43342.)

Misty, K. B. and K. G. Barathan. Radioactivity in the diet of the population of the Kerla Coast, including monazite bearing high radiation areas. Health Phys. 19(4), October 1970. *Dietary survey, food consumption; radium and potassium in foods.*

Moiseev, A. A. and V. I. Ivanov. Radiation form natural sources. Protection Against Radiation and Dosimetry. Moscow, Atomizdat, pp. 28-54, 1964. (English translation: JPRS-27535; TT-64-51784, p. 62.)

Moore, R. B. The radioactivity of some typical soils of the United States. Orig. Com. 8th Intern. Congr. Appl. Chem. 15:187-190, 1912.

Moore, R. B. The radioactivity of some type of soils in the United States. J. Ind. Eng. Chem. 6(5):370-374, 1914.

Morley, F. and P. M. Bryant. Basic and derived radiological protection standards for the evaluation of environmental contamination. Environmental Contamination by Radioactive Materials. Vienna, International Atomic Energy Agency. 1969. (NSA 24-7828.)

Moxham, R. M. Natural radioactivity in Washington County, Maryland. Geophysics. 28:262-272, 1963. (CA 59-15072.)

Neher, H. V. Gamma rays from local radioactive sources. Science. 125:1088-1089, 1957. *Environmental background radiation in U.S.*

Nishimura, S. Radioactivity in earth's crust. Siebutsu Kogaku. 25(2): 66-77, July 1973. *In Japanese.* (NSA 30(9)-23970.) *Geological time change in earth's natural radioactivity.*

Novikov, Yu. V. and I. I. Rezanov. Problems of hygiene associated with the study of the effect of an increase in the natural radioactive background of the external environment on the health of a population. Inst. Hygiene Res. Moscow, Ministry of Health, RSFSR, 1962.

Oakley, D. T. Natural radiation exposure in the U. S. U.S. Environmental Protection Agency, Office of Radiation Programs Report ORP/SID 72-1, June 1972. *Evaluation of terrestrial and cosmic exposures; summary of gamma exposures in buildings.*

O'Brien, K., W. M. Lowder, and L. R. Solon. Beta and gamma dose rates from terrestrially distributed sources. HASL-3, October 1957. *Dose rates from uranium, thorium and potassium.*

O'Brien, K. Some variable contributors to natural background. USAEC Report HASL-27, 1958.

O'Brien, K., W. M. Lowder, and L. R. Solon. Beta and gamma dose rates from terrestrially distributed sources. Radiat. Res. 9:216-221, 1958.

Ohlsen, H. Determination of the mean population burden from natural external radiation in the German Democratic Republic, November 1969. *In German. Mean population dose inside house of 106 mR/yr; outside: (terrestrial) 89 mR/yr; (cosmic) 32 mR/yr.*

Ohlsen, H. Determination of the population burden from natural external radiation in the territory of the German Democratic Republic (Measurements in houses). Kernenergie. 13:91-96, March 1970. *In German.* (NSA 24(23)-48532.)

O'Riodran, M. C., M. J. Duggan, W. B. Rose, and G. F. Bradford. The radiological implications of using by-product gypsum as a building material. National Radiological Protection Board, NRPB-R7, December 1972. *Radiation and radon exposure estimates for dwellings with building materials of ^{226}Ra=25 pCi/g.*

Osburn, W. S. Primordial radionuclides: their distribution, movement, and possible effect within terrestrial ecosystems. Health Phys. 11(12):1275-1297, December 1965. *Potassium, radium, uranium and thorium content of rocks and soil, radon emanation discussed; radon in atmosphere.*

Overstreet, W. C. The geologic occurrence of monazite. U.S. Geological Survey. Washington, D. C. 20402, Superintendent of Documents, U.S. Govt. Printing Office. Professional Paper 530, 1967.

Pallister, E. T. and J. H. Green. Environmental radioactivity in New South Wales. Australia, New South Wales Univ. Report NRS-30, 1965. (NSA 19(22)-40805.) *Natural radionuclides in various media.*

Patterson, H. W. and R. Wallace. Report to the World Health Organization on a radiation survey made in Egypt, India and Ceylon in January 1963. Berkeley, Lawrence Radiation Lab., Univ. of California. USAEC Report UCRL-10851. 5:25, 1963. *External gamma surveys.*

Patterson, H. W. and R. Wallace. Report of a radiation survey made in Egypt, India and Ceylon in January 1963. Health Phys. 12(7):935-941, 1966. (NSA 20(19)-35648.) *External gamma surveys.*

Patterson, H. W., A. R. Smith, and L. D. Stephens. Fallout and natural background in the San Francisco Bay area. Berkeley, Univ. of California. USAEC Report UCRL-8401, p. 17, 1958.

Pearson, J. E. Natural environmental radioactivity from Rn-222. U.S. Public Health Service, Center for Radiological Health, Rockville, Maryland. Report PHS-999-RH-26, p. 31, 1966. (NSA 22(1)-171.) *Air and soil environmental influences from radon.*

Penna-Franca, E. and R. T. Drew. Status of investigations in the Brazilian area of high natural radioactivity. Health Phys. 11(8): 699-712, August 1965. *Radium content of soil, teeth, food, urine and background radiation levels reported.*

Penna-Franca, E. and C. C. Ribeiro. Survey of radioactive content of food grown on Brazilian area of high natural radioactivity. Health Phys. 11(12):1471-1485, December 1965. *Radiation surveys; radium and thorium in food, water and soil.*

Penna-Franca, E. and M. Fiszman. Radioactivity in the diet of high background areas of Brazil. Health Phys. 19(5):657-662, November 1970. *Diet survey; alpha activity of foods; radium body burdens.*

Pensko, J., K. Mamont, and T. Wardaszko. Measurements of ionizing radiation doses in dwellings in Poland. Nukleonika. 14:415-424, 1969.

Pensko, J. Variations of the gamma-ray background dose rates and atmospheric radon concentration in Warsaw. Atomopraxis. 13:310-312, 1967.

Pensko, J., M. Biernacka, et.al. Natural gamma background radiation measurements in Poland by means of the scintillation airplane monitor. *In Polish.* CLOR-87/D. *Survey data.*

Pensko, J., J. Jagielak, M. Biernacka, and A. Zak. Ionizing radiation background in the Kowary Basin. Nukleonika. 16(5-6):293-300, 1971. (NSA 26(6)-12319.) *Background gamma; radon levels.*

Pensko, J. and M. Bysiek. The gamma radioactivity of building materials for the construction of low-background laboratories. Polish Report CLOR-20, 1963.

Pensko, J. Sodium iodide scintillation counter for accurate measurements of gamma-ray background. Proceedings of symposium, Solid-State and Chemical Radiation Dosimetry in Medicine and Biology. Vienna. 1966. pp. 421-443. (International Atomic Energy Agency, Vienna, STI/PUB/138, 1967.

Pensko, J., T. Wardaszko, M. Wochna. Influence of some geophysical factors on gamma background and ^{222}Rn concentration in soil and atmosphere. G. Fis. Sanit. Prot. Radiaz. 16(4):157-167, 1972. (NSA 29(12)-29339.) *Radon exhalation studies.*

Perkins, R. W. and J. M. Nielsen. Cosmic-ray produced radionuclides in the environment. Health Phys. 11(12):1297-1304, December 1965. *Radionuclides produced in atmosphere and soil by cosmic ray.*

Peterson, N. J., L. D. Samuels, H. F. Lucas, and S. P. Albrahams. An epidemiological approach to low-level radium-226 exposure. Public Health Report 81:805-814, 1966.

Pinkerton, C., W. Y. Chen, R. G. Hutchins, and R. E. Schrohenloher. Background radioactivity monitoring of a pilot study community in Washington County, Maryland. The Natural Radiation Environment. pp. 919-956, 1964. (NSA 18(20)-35727.)

Plummer, G. L. and F. Helseth. Movement and distribution of radionuclides on granitic outcrops within the Georgia Piedmont. Health Phys. 11(12):1423-1428. *Fallout in soils and vegetation.*

Radiation Protection, Environment, and the Population. First Seminar, Potsdam, October 16-21, 1972. SZS-157, March 1974. (NSA 31(4)-8873. CONF-7210124.

Ramos Rodriquez, E. Control and monitoring of isolated industrial products which contain radioactive nuclides. Energ. Nucl., Madrid, 14: 419-428, October 1970. *In Spanish.*

Redies, M. and I. Vimpany. Determination of total potassium in soils using the gamma-emission of potassium-40. Nature. 210(5040):1078-1079, 1966.

Reitmeier, R. F. Soil potassium and fertility. Soil, Stefferud, A. (ed.). Washington, U.S. Dept. of Agriculture, 1957. pp. 101-106.

Ritchie, J. C. Natural Gamma Radiation in Northeastern and Eastcentral Georgia. Thesis. Athens, Georgia, Univ. of Georgia, 1967. *Thorium, uranium, potassium, beryllium.*

Roehnsch, W. Use of mining refuse with increased radionuclide content. SZS-157, March 1974. *In German.* (NSA 31(4)-8613.) *Use of mining waste for construction purposes.*

Rodier, J., C. Vernhes, and R. Estournel. Exposure of man to natural and artificial sources of ionizing radiations. Maroc. Med. 49:75-91, February 1969. *In French.* (NSA 25(9)-19137.) *Dose equivalent for natural and artificial sources.*

Rodriguez, J. and G. E. Mattingly. Estimation of potassium in soils by determination of K-40 content. J. Sci. Food Agr. 11(12):717-721, 1960.

Rodriguez-Pasques, R. H., H. L. Steinberg, J. E. Harding, et.al. Low-level radioactivity measurements on aluminum, steel and copper. Int. J. Appl. Radiat. Isotopes. 23:445-464, 1972. *Discussion of low activity contamination of metals.*

Roka, O., Z. Vajda, and T. Predmersky. II Symp. Health Phy., Pecs, Hungary, September 26-30, 1966. 2(81), Eotovos L. Phys. Soc, Budapest, 1966.

Rona, E. Natural radioactive elements in marine environment. Final Report, Univ. of Miami. USAEC Report ORO-2411-8, p. 86, 1967.

Roser, F. X., G. Kegel, and T. L. Cullen. Radiogeology of some high background areas of Brazil. The Natural Radiation Environment, pp. 855-872, 1964.

Roser, F. X. and T. L. Cullen. On the intensity levels of natural radioactivity in selected areas of Brazil. UN Document A/AC.82/G/R.34.

Roser, F. X. and T. L. Cullen. External radiation levels in high background regions of Brazil. The Natural Radiation Environment. pp. 825-836, 1964. (NSA 18(20)-35727.)

Russell, R. S. and K. A. Smith. Naturally occurring radioactive substances: the uranium and thorium series. Radioactivity and the Human Diet, Russell, R. S. (ed.). Oxford, Pergamon Press, 1966. Ch. 17, pp. 465-379. (NSA 21(23)-43415.)

Russell, I. J. Radial distribution of fallout nuclides and radium isotopes in a 107 year old oak tree. USAEC Report NYO-3756-7, June 1971. (NSA 25-46808.) *Oak tree sections analyzed for radioactivity.*

Safonov, I. S. Radioactivity of building materials and radiation background of buildings. Energ. Stroit. Rubezhom. No. 4, pp. 17-19, 1972. *In Russian.* (NSA 31(2)-3332.) *Data on radioactivity of Russian building materials.*

Sanderson, J. C. Radioactive content of certain Minnesota soils. Amer. J. Sci. 39:391-397, 1915.

Sax, N. I. and J. J. Gabay. Public health aspects of environmental radiation. New York State Health Dept., Albany, New York, RSG-C1, 1960.

Sax, N. I., M. Beigel, J. C. Daly, and J. J. Gabay. Determination of environmental levels of radium. Proc. 7th Ann. Meeting on Bio-Assay and Analytical Chemistry, October 1961. USAEC Report ANL-6637.

Schiager, K. The evaluation of radon progeny exposures in buildings. A report on equipment and techniques. Colorado State Univ. Report, March 1971. *Radon study in buildings where uranium tailings have been used in construction.*

Schiager, K. J. Reduction of natural radiation intensity in a large storage area. Health Phys. 27(5):433-445, November 1974. *Discusses construction of low-background room with exposure rate less than 11 μR/h.*

Schiager, K. J. Analysis of radiation exposure on or near uranium mill tailings piles. Radiat. Data Rep. 15(7):411-425, July 1974. (NSA 30 (10)-26776.) *External gamma exposure rate and radon emanation from tailings.*

Schmier, H., W. Sielentag, and B. Waldeskog. Radiation environment of human beings. IAEA, STI/DOC-10/123. (NSA 25(19)-44949.) *Cosmic and terrestrial sources; human exposure.*

Schraub, A. Natural radiation exposure. Atomkernenergie, 23(2):127-136, 1974. *In German.* AED-CONF-72-385-032. (NSA 30(8)-21369.) *Discusses sources of exposure.*

Schultz, R. U. Soil chemistry of radionuclides. Proc. Hanford Symposium, Radiation and the Terrestrial Environment. Held in Richland, Washington, May 3-5, 1965. Hungate, F. P. (ed.). Pergamon Press, Health Phys. 11(12):1317-1324, 1965.

Segall, A. Radiogeology and population exposure to background radiation in northern New England. Science. 140:1337-1339, 1963.

Segall, A. and R. Reed. Human exposure to external background radiation. A population survey in northern New England. AMA Arch. Environ. Health. 9(4):492-499, 1964. *External gamma exposure rates and uranium content of soil.*

Shalak, N. I., E. M. Krisyuka, and S. I. Tarasov. Determination of specific release of radon by protective enclosures in premises. Gig. Sanit. 2:72-74, February 1970. *In Russian.* (NSA 25(12)-26356.) *Method for measuring radon emissions.*

Shamos, M. H. and A. R. Liboff. A new measurement of the intensity of cosmic-ray ionization at sea level. J. Geophys. Res. 71(19):4651-4659, 1966.

Shamos, M. H. and A. R. Liboff. New ionization chamber technique for the measurement of environmental radiation. Rev. Sci. Instrum. 39(2): 223-229, February 1968.

Shapiro, J. Report UR-298, 1954. Univ. of Rochester.

Shem'i-zade, A. E. Atmospheric radioactivity in Tashkent buildings. Gig. Sanit. 5:111-113, April 1970. (JPRS-53671) *Radon and other airborne radioactivity inside buildings correlated to ventilation rates.*

Sievert, R. M. and B. Hulqvist. Variations in natural gamma radiation in Sweden. Acta Radiol. 37:388-398, 1952.

Sievert, R. M. Measurements of low-level radioactivity, particularly the radiation from living subjects. Proc. Int. Conf., Peaceful Uses of Atomic Energy, Geneva. 13:187-195, 1965. v.e. United Nations Document A/AC.82/G/L.15 Part 7. *Data on radon measurements in Swedish homes.*

Sievert, R. M., G. A. Swedjemark, and J. C. Wilson. Exposure of man to ionizing radiation from natural and artificial sources. Handbook Medscher. Radiol. 2(2):334-371, 1966. Zuppinger, A. (ed.). Springer, Berlin.

Smith, A. R. and H. A. Wollenberg. Geology and natural terrestrial dose rates. USAEC Report HASL-269, pp. 8-11, August 1972. (NSA 27-19825.) *Uranium, thorium, potassium distribution, abundances and dose rates.*

Snihs, J. O. The significance of radon and its progeny as natural radiation sources in Sweden. Proceedings of the Noble Gas Symposium. Las Vegas. September 24-28, 1973. In Press.

Soldat, J. K. Models for calculation of environmental radiation doses. Trans. Amer. Nucl. Soc. 17:536-537, November 1973. (NSA 29(3)-5111.) CONF-731101.

Solon, L. R., W. M. Lowder, A. V. Zila, H. D. LeVine, H. Blatz, and M. Eisenbud. Measurements of external environmental radiation in the United States. Science. 127:1183-1184, 1958.

Solon, L. R., W. M. Lowder, A. Shambon, and H. Blatz. Further investigations of natural environmental radiation. USAEC Report HASL-73, 1959.

Solon, L. R., W. M. Lowder, A. Shambon, and H. Blatz. Investigation of natural environmental radiation. Science. 131:903-906, 1960. *Cosmic radiation vs. altitude; background radiation in some U. S. cities; exposure rates inside dwellings.*

Solon, L. R. Dosimetry of Natural Ionizing Radiation, Ph.D. thesis. New York University, New York, 1960.

Sources of ionizing radiation and population exposure. Effects on populations of exposure to low-levels of ionizing radiations. U.S. Sources and Exposure Calculations, NP-19638, pp. 11-19, November 1972.

Spiers, F. W. and H. D. Griffith. Measurements of local gamma-ray background in Leeds and Aberdeen. Brit. J. Radiol. 29:175-176, 1956.

Spiers, F. W. Radioactivity in man and his environment. Brit. J. Radiol. 29:409-417, 1956.

Spiers, F. W., M. J. McHugh, and D. B. Appleby. Environmental gamma-ray dose to populations. The Natural Radiation Environment, 1964.

Spiers, F. W. Dose rates from background gamma radiation to populations in four districts of Scotland. Proc. Roy. Soc. Med. 53:763-764, 1960.

Spiers, F. W. Gamma-ray dose rates to human tissues from natural external sources in Great Britain. The Hazards to Man of Nuclear and Allied Radiations. London, H.M. Stationery Office. pp. 66-72, 1960.

Stephens, L. D. and H. W. Patterson. Fallout and natural background in the San Francisco Bay area. Health Phys. 4(4):267-274, April 1961. *Data on background levels, and distinguishing fallout levels from background.*

Storruste, A. and A. Reistad. Measurement of environmental gamma radiation in Norwegian houses. Health Phys. 11(4):261-269, April 1965. *Radiation surveys of dwellings and comparison to other countries' results.*

Stradling, G. N., N. Green, and M. A. Fletcher. Effects of foodstuffs and related compounds on durability of glazes containing natural thorium and natural or depleted uranium. Trans. J. Brit. Ceram. Soc. 71(6): 171-175, September 1972. (NSA 26(24)-58816.) *Toxicity and radiological aspects of use.*

Stretta, E. J. P. and R. del Arenal. Geochemistry and radioactivity of waters in Lourdes, San Luis Potosi, Mexico. An. Inst. Geofis. UNAM (Mex.). 9:69-84, 1963. *In Spanish.* (NSA 19(21)-40835.) *Building surveys and bathing waters.*

Sunta, C. M., K. S. Nambi, S. P. Kathuria, et.al. Radiation dosimetry of population in monazite bearing areas using thermoluminescent dosimetry. BARC-519, 1971. (NSA 26(24)-59042.) *TLD for human exposure and for radiation exposure rates inside homes.*

Talibudeen, O. Natural radioactivity in soils. Soils Fert. 27:347-359, 1964. (NSA 21(3)-3182.)

Talibudeen, O. and Y. Yamada. Total potassium in soils by radioactivity measurements. J. Soil Sci. 17:107-120, 1966. (NSA 20(19)-35651.) *Nineteen British soils; carbon-14, potassium-40, rubidium-87, thorium-232 and daughters, uranium-238 and daughters.*

Telfair, D., R. Garrison and C. Smith. Natural radioactivity of Miami soils. Science. 131(3402):727-728, 1960.

Thie, J. A. Low-level environmental monitoring by fluctuations analysis. CONF-720607. Trans. Amer. Nucl. Soc. 15(1):84, June 1972. (NSA 26(18)-42954.) *Data analysis.*

Thomas, J. W. Modification of the Tsivoglou method for radon daughters in air. Health Phys. 19(5):691, November 1970. *Equations for calculating radium-A, radium-B, radium-C concentrations.*

Throckmorten, C. R. Environmental Gamma-Ray Analysis. Thesis. Colorado State University Microfilms, Order No. 74, 17, 551. (NSA 30(9)-23987, 1973.) *Detector and Monte Carlo methods used to evaluate environmental radiation sources.*

Toth, A. Meteorological problems of determining the concentration of radon-daughter products in the air of living rooms. Symposium on Health Physics, Pecs, Hungary. 2:75-79, 1968. (CONF-660948.)

Toth, A. Determining the respiratory dosage from Ra-A, Ra-B and Ra-C inhaled by the population in Hungary. Health Phys. 23(3):281-290, September 1972. *Radon daughter products inside houses and calculated dose to the bronchial epithelium.*

Toyer, M. Application of radioelements and radiations in building and public works. EURISOTOP-55, 2:1151-1186, 1972. *In French.* (NSA 27-27803.) *Radioactive materials used as tracers and for radiography.*

Truelle, M. A. Increased Rn-222 concentrations in the atmosphere of water treatment plants. Cesk. Hyg. 16(2-3):98-102, April 1971. *In Czechoslovakian.* (NSA 26(6)-12072.) *Radon indoors; equilibrium 52-78%.*

Tsivoglou, E. C., H. E. Ayer, and D. A. Holaday. Occurrence of non-equilibrium atmospheric mixtures of radon and its daughters. Nucleonics. 11:40-45, 1953.

United Kingdom Research Council. Existing and foreseeable levels of exposure to radiation, Ch. 5. The Hazards to Man of Nuclear and Allied Radiations. 2nd Report, Cmd. 1225, London. pp. 20-23, 1960.

USAEC. Summaries of USAEC environmental research and development. TID-4065, September 1970. (NSA 24(22)-46593.)

USAEC. Study of natural radioactivity in Brazil. NYO-2577-12, November 1970. (NSA 25(7)-13393.) *TLD's used inside residences; 630 mR/yr dose rate.*

USAEC. Radium. A Bibliography. USAEC-TID-3345. (NSA 30(3)-6105.) May 1974.

UNSCEAR. Radiation from natural sources. Report of the United Nations Scientific Committee on the effects of atomic radiation. Thirteenth Session. Suppl. 17 (A/3838). UN, New York. pp. 49-59, 1958.

UNSCEAR. Radiation from natural sources. Report of the United Nations Scientific Committee on the effects of atomic radiation. Seventeenth Session. Suppl. 16 (A/5216). UN, New York. pp. 207-230, 1966.

UNSCEAR. Report of the United Nations Scientific Committee on the effects of atomic radiation. Nineteenth Session. Suppl. 14 (A/5814). UN, New York. 1964.

UNSCEAR. Radiation from natural sources. Report of the United Nations Scientific Committee on the effects of atomic radiation. Twenty-first Session. Suppl. 14 (A/6314). UN, New York. pp. 13-43, 1966.

Vassilaki, M., L. Salmon, and J. A. B. Gibson. Measurement of radioactivity in soil. Geochim. Cosmochim. Acta. 30:601-606, 1966. (Also United Kingdom Atomic Energy Research Establishment, Harwell, Report AERE-R-4996.) (NSA 20(18)-33519.) *Radium-226, thorium-232, potassium-40 results.*

Velletri, J. and R. Spring. Effects of finite source fields on radiation doses in a structure. Contract DAHC-20-70-C-0227 (AD-713019). July 1970. (NSA 26-19555.)

Vennart, J. Measurement of local gamma-ray background at Sutton, Surrey and in London. Brit. J. Radiol. 30:55-56, 1957.

Vilenskii, V. D. Radium-226 in atmospheric precipitation, and the possibilities for lead-210, bismuth-210, and polonium-210 to penetrate the atmosphere from the earth's surface. 1969. (TT-74-50011, pp. 220-223, translated from Russian.) (NSA 30(6)-15412.) *Data on concentrations in Moscow precipitation.*

Welford, G. A. Stable strontium and radium survey at five pasture sites in the United States. Health and Safety Laboratory, USAEC Report NYO-4648, p. 11, 1955.

Weng, P., C. Tsai, et.al. Background activity of Taiwan. Hoken Butsuri. 6(3):131-136, September 1971. (NSA 26(20)-48041.) *Gamma radiation surveys; soil sampling; average background = 11.8 μR/h.*

Weng, P. S., T. C. Chu, and C. M. Tsai. Environmental radioactivity in North Taiwan. Health Phys. 25(2):123-128, August 1973.

Willey, E. J. B. Natural levels of radioactivity in Cornwall. Brit. J. Radiol. 31:31-56, 1958.

Wollenberg, H. A. and A. R. Smith. A concrete low-background counting enclosure. Health Phys. 12(1):53-60, 1960.

Wollenberg, H. A. and A. R. Smith. Earth materials for low-background radiation shielding. Lawrence Radiation Laboratory, Univ. of California. USAEC Report UCRL-9970, 1962.

Wollenberg, H. A. and A. R. Smith. Radioactivity of cement raw materials. 2nd Annual Midwest Forum, Geology of Industrial Minerals. Bloomington, Indiana, March 31-April 1, 1966. (CONF-660329-1) Univ. of California, USAEC Report UCRL-16878, p. 31, 1966. (NSA 20(23)-43514.)

Wollenberg, H. A. and H. W. Patterson. Natural and fallout radioactivity in the San Francisco Bay area. Health Phys. 17(2):313-321, August 1969. *Radiation from terrestrial and fallout sources.*

Yamagata, N. and K. Iwashima. Terrestrial background radiation in Japan. (Note). Health Phys. 13(10):1145-1148, 1967. (NSA 21(24)-45244.) *Uranium, thorium, potassium; soils; 22 districts of Japan.*

Yamashita, M., S. M. Oguchi, and H. Watanabe. Measurement of natural gamma radiations inside residential structures. National Institute of Radiological Sciences, Annual Report. USAEC Report NIRS-5, p. 65, 1966. National Institute of Radiological Sciences, Chiba, Japan.

Yeates, D. B., A. S. Goldin, and D. W. Moeller. Radiation from natural sources in the urban environment. Dept. of Environmental Health Services, Harvard School of Public Health. Report HSPH/EHS-70-2, 1970. (NSA 26(23)-56165.) *Gamma surveys inside buildings; radon measurements.*

Yeates, D. B., A. S. Goldin, and D. W. Moeller. Natural radiation in the urban environment. Nuclear Safety. 13(4):275-286, 1972. *Gamma exposures and radon levels inside buildings; effects of building type, construction and ventilation rate.*

Yeates, D. B. and B. E. King. Estimation of the gamma-ray natural background radiation dose to an urban population in western Australia. Health Phys. 25(4):373-380, October 1973. *Gamma background inside and outside dwellings and estimated dose.*

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. ORP/LV 75-1	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Technical Note: Radioactivity in Construction Materials--A Literature Review and Bibliography		5. REPORT DATE April 1975-Issuing Date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Gregory G. Eadie		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Radiation Programs-- Las Vegas Facility, P.O. Box 15027 Las Vegas, Nevada 89114		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency National Environmental Research Center Las Vegas, Nevada 89114		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Surveys to determine the radioactive content of specific building materials used in the United States have not been reported in the literature. The external dose to the U.S. population from exposure to natural radioactive materials (exclusive of uranium mill tailings) contained in U.S. building materials has not been evaluated, and the possibly significant external exposure from the use of by-product gypsum and fly-ash materials should be evaluated. The effects of various construction materials on the attenuation of cosmic and terrestrial radiations have been evaluated in a limited number of surveys in the urban areas of Boston, New York, and Livermore, California. The measurement of radon and radon daughter product concentrations has only been reported for a few dwellings and several multi-story office buildings in Boston and in several State-owned buildings in North Carolina. This literature search has found a lack of meaningful data for use in evaluating the U.S. population exposure from building materials.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
natural radioactivity, building materials, radiation surveys, population exposures, background radiation, radium		

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 45
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)