EXPOSURE TO WORKERS IN SWEDISH QUARRYING

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1 ABSTRACT

Quarrying is a major industry in Sweden and rock is quarried at more than 1,100 quarries. The Swedish granites, acid gneisses and porphyries are hard rock types with properties making them particularly suitable as material that can withstand weathering and wear. The quarried rock is used as construction materials, tiles, slabs and aggregate, fill for road construction, ornamental stone, tombstones, etc. Some of the best granites have considerably higher uranium, thorium and potassium concentrations than most other rocks. ^{238}U concentrations of 120-400 Bq/kg, ^{232}Th concentrations of 120-360 Bq/kg and ^{40}K concentrations of 1,200-2,000 Bq/kg are not uncommon. In a project at the Swedish Radiation Protection Authority, SSI, aiming at the implementation of Title VII of the European BSS, investigations were made in quarries to study the exposure of the workers to radiation from the rock. The effective dose depends on the time the workers spend in the quarries and the gamma radiation and the radon concentration at their workplaces. At 2,000 working hours per year the received dose is at a maximum 0.4-0.1 mSv/year. When the quarried rock is used in building materials, workers and other people in offices, factories, schools and homes are exposed to gamma radiation and radon gas. The received doses depend on how the rock is used, the amount of rock used and the time spent in the building/room. The European Commission has provided guidance for possible regulatory initiatives concerning natural radioactivity in building materials. Many Swedish types of rock commonly used as or in building materials have uranium, thorium and potassium concentrations that are higher than the criteria for the exemption level, and some exceed the upper level. Adoption of the guidance index proposed by the European Commission would imply problems for the Swedish quarrying and construction industries.

2 INTRODUCTION

A task at the implementation in Sweden of Title VII of the European BSS (1) is to make an inventory of workplaces where enhanced natural radiation can be expected. In the year 2000, as part of the inventory, the Swedish Radiation Protection Authority (SSI) investigated the radiation at a number of hard rock quarries used for the production of construction materials: aggregate, slabs, tiles, fill for road construction and tombstones. A pit in a tailing of burnt alum shale was also investigated. The burnt alum shale is used for the production of hard top dressing for tennis-courts and as surface on racetracks.

The Swedish bedrock is composed to a large extent of acid rock types, e.g. granite, gneiss, porphyries and pegmatite, which often have elevated concentrations of uranium, thorium and potassium, compared to other rock types. The granites, acid gneisses and porphyries are hard rock types whose properties make them particularly suited as materials that can withstand weathering and wear. Some of the best granites have considerably higher concentrations of uranium, thorium and potassium than most other rock types. ^{238}U concentrations of 120-400 Bq/kg, ^{232}Th concentrations of 120-360 Bq/kg and ^{40}K concentrations of 1,200-2,000 Bq/kg are not uncommon. Apart from these rocks with elevated contents, there are also large areas of uranium-rich alum shale (a black shale), with a concentration of uranium of 600 to 5,000 Bq/kg (50-400 ppm U) (2).

Quarrying is a major industry in Sweden and bedrock is quarried at more than 1,100 quarries. The production of aggregate, road fill and blocks is about 50 million tons per year.

In earlier investigations during the 1960s and 1970s, inventories were made of the most radioactive granites in Sweden in order to study their suitability as sources of thermal energy (3). From that study, 12 granite quarries were chosen for studying the weathering effects on the leaching of uranium, thorium and potassium from the granites (4). The aim was to study the correlation between the gamma radiation emitted from bismuth-214, the nuclides in the thorium-232 series and potassium-40 at the surface of the bedrock, with the concentration of these radionuclides at depths of 5-15 meters. Knowledge of this correlation is essential for the evaluation of the results from the gamma ray spectrometric recordings obtained from airborne surveys. In these studies both chemical and spectrometric analyses were performed. Some of the quarries studied are situated in some of the most radioactive granites in Sweden (3). The concentrations at the granite quarries studied varied from 25 to 300 Bq/kg ^{236}Ra (2 to 24 ppm U), 55 to 330 Bq/kg ^{232}Th (14 to 82 ppm Th) and 1300 to 1675 Bq/kg ^{40}K (4.2 to 5.4 % K).

3 METHODS

During the visits to the quarries the gamma radiation was measured by hand-held scintillometers (Exploranium 210 and Scintrex BGS-3). These instruments also register the cosmic radiation. The effect of this is included in the readings and it is about 0.02 µSv/h. The instruments were calibrated at the National Laboratory for Ionising Radiation at SSI.

A portable gamma ray spectrometer of type Exploranium 210 was used for in situ determination of the concentrations of ^{226}Ra, ^{232}Th and ^{40}K. This spectrometer instrument is equipped with a 3x3” NaI(Tl) detector. It is calibrated against the known sources of ^{226}Ra, ^{232}Th and ^{40}K of the calibration pads at the Borlänge airport (5). These pads are designed for the calibration of the gamma ray spectrometers used at in airborne surveys. In Sweden, where the inland ice during the last ice age (which ended 10,000 years ago) scraped away the weathered rock, there exist little no or no disequilibrium within the uranium and thorium series in the bedrock (4).

Outdoor radon measurements were made at a quarry (Latorp) where alum shale is quarried for the production of surface material for tennis courts. In these measurements, a radon monitor of type Genitron Alpha-Guard was used. This instrument was calibrated in the radon room at SSI (6).

4 INVESTIGATIONS OF QUARRIES

Among the quarries visited (all in the in southern Sweden) one is quarrying Vånga Granite and one quarrying Halen Granite, both these granites are among the most radioactive in Sweden. Investigations were also made at one quarry in Blekinge Coast Gneiss and one quarry in dolerite. These quarries were chosen as reference objects for other quarries in Sweden. Investigations were also made at a quarry in an old tailing of burnt alum shale (Latorp).

At the quarry in the **Vånga Granite** area (*Figure 1)* a beautiful red medium-grained granite is quarried. The main minerals are microcline and albite feld-spars, quartz and to lesser amounts biotite. Huge blocks of granite, 5-20 tons, are “cut out” from the rock *(Figure 2).* These blocks are then sold to companies that cut the blocks into slabs and tiles to be used as wall covering or flooring in buildings. The blocks are also used as a material for tombstones. The quarry is more than 20 meters deep. In the quarrying, most of the quarried rock breaks and forms waste rock which is temporally stored in huge tailings. This waste rock is crushed to be used as aggregates.

Figure 1. Granite in the Vånga quarry.

The measured ^{226}Ra concentration in the Vånga Granite in the quarry is rather uniformly approximately 280 Bq/kg (23 ppm U); the ^{232}Th concentration is 170 Bq/kg (42 ppm Th) and the ^{40}K 1,200 Bq/kg (3.9 % K).

The gamma radiation level within the quarry is 0.7 - 0.9 µSv/h and over the tail-ings 0.5 µSv/h. The variation of the gamma radiation depends on how close to the granite walls the measurements are made. When the gamma radiation is emitted from two large nearby surfaces the radiation increases by 30 % compared to the gamma radiation emitted from one surface.

The quarry in the **Halen Granite** area (*Figure 3*) is used now and then for the production of blocks. This granite is light grey and medium-grained. The main minerals are quartz and microcline feldspar with lesser amounts of biotite and hornblende. This granite is one of the most radioactive granites in Sweden. The ^{226}Ra concentration at the quarry is uniformly approximately. 380 Bq/kg (30 ppm U), the ^{232}Th concentration 300 Bq/kg (75 ppm Th) and the ^{40} K concentration 1,500 Bq/kg (5.0 % K). The gamma radiation level within the quarry is 0.7-0.9 µSv/h.

Figure 2. Extraction of granite blocks in the Vånga quarry.

During the visits to the **granite quarries in the 1970s,** no record were made of the gamma radiation in the quarries However, the gamma radiation can be calculated by applying the conversion coefficients given for the ambient dose equivalent rate from the uranium-238 and thorium-232 series and potassium-40 in equilibrium and homogenously distributed in the ground (4). These are for the uranium-238 series 0.531 nSv/h, the thorium-232 series 0.718 nSv/h and for potassium-40 0.049 nSv/h per Bq/kg. These coefficients are valid for the gamma radiation 1 metre above a large flat surface. Taking into account the fact that in the quarries the radiation originates from the floor and the walls, the exposure may increase by 10 to 30 % depending on the local situation. The gamma radiation levels at the quarries visited are thus calculated to be 0.15 µSv/h to 0.55 µSv/h.

Figure 3. Crushing plant at the Blekinge Coast Gneiss quarry.

The quarry that uses the **Blekinge Coast Gneiss** (Figure 3) produces aggregate for concrete and road-construction. The Coast Gneiss is a grey medium-grained gneiss with a granitic composition. The main minerals are feldspar, quartz and to a lesser amount biotite. The ^{226}Ra concentration in the quarry is uniformly approximately 90 Bq/kg (7 ppm U), the ^{232}Th

Figure 4. Gamma spectrometric measurement in the dolerite quarry.

concentration 68 Bq/kg (17 ppm Th) and the ^{40}K concentration 1,250 Bq/kg (4.0 % K). The gamma radiation level in the quarry is approximately 0.22 µSv/h.

Close to the quarry in the Blekinge Coast Gneiss is a huge **quarry in dolerite** (diabase) (Figure 4). This is a black rock of basaltic composition that has intruded as a large dyke into the Coast Gneiss. The main minerals are dark plagioclase and pyroxene. This rock is used as aggregate in concrete, for road construction and for the production of mineral wool. Being a basaltic rock it has very low concentrations of radioactive elements. The ^{226}Ra concentration in the quarry is uniformly approximately 10 Bq/kg (1 ppm U), the ^{232}Th concentration 8 Bq/kg (2 ppm Th) and the ^{40}K concentration 400 Bq/kg (1.3 % K). The gamma radiation level in the quarry is 0.05 µSv/h.

In the year 2000, investigations were also made at a pit (Figure 5) in a huge tailing of burnt **alum shale at Latorp** in Närke in the southern part of central Sweden. During the 19th century this alum shale was quarried for the production of alum, K, $Al(SO_4)_2$. In this production the alum shale was burnt, using the high kerogen concentration in the shale. The burnt shale has an orange-red colour. It is used as a hard top dressing on tennis-courts and as a surface material on racetracks. In the production the alum shale is excavated from the tailings and moved to a crusher where it is crushed fragments with the size 1-6 mm.

Determinations of the concentrations of radium and potassium in the shale were made using in situ measurements in which the gamma spectrometer was placed in dug pits The ^{226}Ra concentration in this burnt shale is approximately 5,000

Figure 5. The alum, shale pit at Latorp.

Bq/kg (400 ppm U), the ^{232}Th concentration 80 Bq/kg (20 ppm Th) and the ^{40}K concentration 1,200 Bq/kg (3.8 % K). The gamma radiation level measured at the excavation wall is 1.7 µSv/h and in the open area around the crusher 0.6-0.8 µSv/h.

The radon gas concentration in the outdoor air on the day of investigation, a fairly calm day, was 50 Bq/m^3 at the crusher and 500 Bq/m^3 in a calm area close to the excavation wall.

5 EXPOSURE AT WORK IN THE QUARRIES

The radiation doses received by workers in the quarries depend on the exposure to external gamma radiation, inhalation of radon gas and radon progeny and on the inhalation of dust.

<u>Gamma radiation</u>

Exposure to gamma radiation occurs both at work within the quarry and during the transport and handling of the blocks and the waste material. For calculation of the effective dose the following formula has been used (8, 9):

E =H(10) · 0.6 (1 MeV, ISO geometry)*

where:

E *is the effective dose*
H(10)* *is the ambient dose equivalent*

Assuming that the number of working hours in the quarry is 2,000 hours per year the maximum effective dose from gamma radiation received by a worker in the quarry in the Vånga granite would be:

0.8 (µSv/h) · 0.6 · 2,000 (hours) = 0.96 mSv/year

However, the maximum number of working hours in Sweden is 1,600 hours per year and no worker spends all his working-hours in the quarry. The actual effective dose will therefore be considerably lower, probably about 0.4–0.6 mSv/year. This dose may be compared with the dose the workers in the dolerite quarry receive, which is less than 0.06 mSv/year.

At 2,000 working-hours per year the workers at the alum shale quarry at Latorp could receive a dose of 20 mSv/year. But the workers work only part time in the quarry and on the average 200 hours per year. Table 1 shows the calculated doses at the quarries visited.

<u>Exposure to radon</u>

No radon measurements were made in the granite quarries, but the average radon levels can be expected to be less than 20 Bq/m^3. Thus the dose due to radon would be less than 0.1 mSv/year. The workers at the alum shale quarry are exposed to a radon concentration that may be about 50-100 Bq/m^3. If they work 2,000 hours per year the average received dose could be 0.3–0.6 mSv assuming a dose coefficient of 0.0063 mSv per Bq/m^3 over 2,000 work hours (10). However since the time spent at the quarry is about 200 hours the dose is actually in the order of less than 0.05 mSv per year.

Table 1: Doses to workers in Swedish quarries due to exposure to gamma radiation and radon.

Quarry type	Gamma radiation, ambient dose equivalent, μSv/h	Gamma radiation, effective dose with 2,000 working-hours per year, mSv	Radon, conc., Bq/m^3	Radon, dose with 2,000 working-hours per year, mSv	Total dose assuming 1,600 working-hours per year, mSv
Vånga Granite	0.5 – 0.9	< 0.6 – 1.1	< 20	< 0.13	< 0.7 – 1.2
Halen Granite	0.7 – 0.9	< 0.8 – 1.1	< 20	< 0.13	< 0.9 – 1.2
Blekinge Coast Gneiss	~ 0.22	< 0.25	< 20	< 0.13	< 0.35
Granites in southern Sweden (Mellander 1983)	0.15 – 0.55	0.18 – 0.7	< 20	< 0.13	< 0.3 – 0.8
Dolerite	0.05	0.06	< 10	< 0.06	< 0.11
Latorp alum shale	0.6 – 1.7	0.7 – 2.0	~ 50	~ 0.3	< 0.9 – 2.2

Exposure to dust

No measurements were made of the dust load in the quarries. However, according the Regulations issued by the Swedish Work Environment Authority the maximum per permitted inhalation of quartz containing dust is restricted to less than 600 mg/year. Therefore at dusty work in the quarries, protection masks have to be used to prevent silicosis. In work in the granite quarries that have the highest concentrations of radium, thorium and potassium the inhalation of dust can give a maximum dose of less than 0.03 mSv/year.

6 INDOOR EXPOSURE WHEN THE QUARRIED ROCK IS USED IN BUILDING MATERIALS

A large part of the quarried rock material is used for constructional purposes, mainly as aggregate in concrete. This is usually made of 1 part cement, 2 parts fine material (usually sand) and 3 parts crushed stone (aggregate). When the concrete is used as a building material in walls, floors or ceilings it becomes a source of gamma radiation and radon emission in workplaces and dwellings.

In a room with the dimensions 5 m x 4 m x 2.8 m with walls 20 cm thick, and the floor and ceiling made of concrete the ambient equivalent dose rate can be calculated using the factors in Table 2 (11).

Table 2. Ambient dose equivalent rate for the decay series uranium-238, thorium-232 and potassium-40 for a room with the dimensions 5 m x 4 m x 2.8 m. Walls, floors and ceiling are assumed to be 20 cm thick and made of concrete with a density of 2.320 kg per m^3 (11).

Ambient dose equivalent rate, nSv/h per Bq/kg	Nuclides
1.06	Uranium-238 series
1.24	Thorium-232 series
0.09	Potassium-40

As an example, if Vånga Granite is used as the aggregate in concrete, the excess indoor gamma radiation could be approximately 0.4 µSv/h as a maximum. This is assuming that the concentrations in the sand are ^{238}U 20 Bq/kg, ^{232}Th 40 Bq/kg and ^{40}K 1,000 Bq/kg; and in the cement are ^{238}U 20 Bq/kg, ^{232}Th 40 Bq/kg and ^{40}K 200 Bq/kg.

In the worst case, when all walls, the floor and the ceiling all are made of that concrete and the room has no windows or doors, the maximum effective dose to a worker in that room with 1,600 working-hours be 0.4 mSv/year, or to a resident in a dwelling living 80 % of his time in the room 1.4 mSv/year. This exposure may be compared with the exposure in the same room if the aggregate in the concrete was Blekinge Coast Gneiss, which has a normal concentration of uranium, thorium and potassium for crystalline rocks. The workers dose would then be 0.2 mSv/year and the resident's 0.8 mSv/year.

During the last few years, fine fractions and rock flour produced in the aggregate crushing have often been used instead of sand. This results in a concrete with greater strength. However, the uses of rock flour increases the radioactivity of the concrete and in the example above it would result in a 40 % increase in the gamma radiation in the room.

7 EU RECOMMENDATIONS FOR NATURAL RADIOACTIVITY IN BUILDING MATERIALS

A working party of the Group of Experts established under the terms of Article 31 of the Euratom Treaty has for the European Commission 1999 provided guidance when considering possible regulatory initiatives concerning natural radioactivity in building materials at a Community level (12). The Group of Experts advices the use of an activity index (*I*) for identifying whether a dose criterion is met:

$$I = C_{Ra}/300\ Bq\ kg^{-1} + C_{Th}/200\ Bq\ kg^{-1} + C_K/3{,}000\ kg^{-1}$$

Where C_{Ra}, C_{Th}, C_K are the radium, thorium and potassium activity concentrations (Bq kg^{-1}) in the building materials. According to this guidance *I* for materials used in bulk amounts, e.g. concrete should not exceed 1 corresponding to a dose of ≤1 mSv/year and the exemption level shall be *I* <0.5 corresponding to a dose of ≤0.3 mSv/year. In the case of permanent stay indoors (8,760 hours per year) exposure to a gamma radiation of 0.2 µSv/h corresponds to an effective dose of 1 mSv per year (8).

If this index is applied, the Vånga Granite has an index of 2.8 and the Blekinge Coast Gneiss 1.2. Of the quarries visited only the one quarrying dolerite, index 0.2, meets the criterion of the indices.

8 CONCLUSIONS

Although the concentrations of natural radionuclides in the quarried granites are more than twice as high as those for normal acid crystalline rocks, the annual effective doses to the workers at the quarries are below the recommended level of 1 mSv even if the dose received from inhalation of radon is included. However, there are other groups of workers that are exposed at their work to enhanced gamma radiation due to their workplaces being situated in granites with high concentrations of natural radionuclides, e.g. workers in underground facilities and in tunnel construction. These workers may receive effective doses exceeding 1 mSv/year due to the gamma radiation at these workplaces being emitted from all surfaces around them, which increases the exposure by 60 % compared with the situation when the radiation is only emitted from one flat surface.

As have been shown above, many of the quarried rocks in Sweden have uranium, thorium and potassium concentrations that are higher than the proposed criteria for the exemption level and some do not pass the upper level for contents of natural radioactive nuclides in building materials. Adoption of the guidance index proposed by the European Commission would imply problems for the Swedish quarrying and construction industries, since granite is the most commonly rock material available for construction purpose. Granites are also necessary for making concrete that must withstand weathering, wearing and high levels of stresses and strains and stress as they are hard have high wearing qualities and good adhesiveness properties.

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