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AN OVERVIEW OF RADIATION LEGISLATION THAT IMPACTS ON THE PHOSPHATE AND FERTILIZER INDUSTRY (a)

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1. Abstract

Before 1998 the concept of Naturally Occurring Radioactive Materials, or NORM, was not considered to be important and outside of the United States the Phosphate Industry received little consideration the possible radiological threat to workers or members of the public.

However, this changed with the publication of International Atomic Energy Agency Safety Series 115 and subsequent publication of the European Council Directive 96/29/EURATOM after which strong focus was placed on all NORM industries. The industries in the European Union considered to be the most significant, as published in "Radiation Protection 95: Reference levels for workplaces processing materials with enhanced levels of naturally occurring radionuclides", are:

- *Phosphate industry*
- *Processing of metal ores*
- *Zircon sands and refractory materials*
- *Manufacture of rare earths,*
- *Manufacture and use of thorium compounds*
- *Titanium dioxide pigment industry*
- *Oil and gas industry*

With the NORM II (Krefeld) conference in November 1998, the focus was primarily on the oil and gas industry, but since then the regulatory focus moved away from oil and gas and was placed firmly on the phosphate and fertiliser industry. The latest trend was confirmed with papers presented at the NORM III conference in September 2001 in Belgium. During this five-day event, attended predominantly by regulators, more than 70% of all papers presented referred in some way to the industry.

This paper evaluates different regulatory views, proposed and actual legislation and some of the possible impacts on the phosphate and fertiliser industry. It offers some suggestions on how the industry can deal with it and what the fertilizer industry in South Africa, and particularly Foskor, has done.

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2. Introduction

For many the two words “phosphate” and “radiation” never occurred in the same sentence before. It is strange to think of fertilizers as a radioactive material and a source of exposure when radiation risk usually conjures images of nuclear reactors and atom bombs. This inappropriate association is exactly what is not wanted for the industry and efforts should be made to prevent it from happening.

It is recognised that radiation is natural and a permanent feature of the environment with all matter containing naturally occurring radionuclides of the ^{238}U, ^{232}Th and ^{235}U decay chains to a varying degree. For example, about 15 million ^{40}K isotopes, a natural isotope but not part of the decay series mentioned, decay in our bodies every hour. In geological structures the material of sedimentary origin usually has lower levels of these naturally occurring radionuclides, but this generalisation is not true for phosphate rock. Sedimentary material has a higher ^{238}U series and negligible ^{232}Th and decay daughter content. On the other hand, the igneous material of the Phalaborwa Complex has much lower levels of ^{238}U and associated daughters, but with elevated levels of the ^{232}Th series.

The risk associated with radiation can therefore only be restricted or reduced, not eliminated, but of regulatory concern is the incremental dose a person may receive e.g. the additional dose above background as a result of a work activity. Unfortunately the phosphate industry has been identified as an industry that may be a significant contributor to the radiological exposure of workers and public alike and as a result now commands serious regulatory attention.

3. Regulatory Interest

All radiation legislation, no matter what country, has its roots in the International Atomic Energy Agency (IAEA) and its associated publications. The IAEA is a specialised agency within the United Nations system that serves as the world’s central inter-governmental forum for scientific and technical co-operation in the nuclear field. Experts and national representatives develop recommendations that are endorsed and published as Safety Guides, Safety Reports or Safety Recommendations. These documents are then included in national legislation. National legislation may vary significantly from the original document, such as in the United States, or adopted verbatim as it is only recommendations. International bodies, such as the International Maritime Organisation (IMO), tend to follow the latter route, for example the recent acceptance of the IAEA publication ST1: Regulations for the safe transport of radioactive materials [1] by the IMO.

For the past couple of years the European Union has been the most active in the effort to control exposure to Naturally Occurring Radioactive Materials (NORM) with their most significant document produced being the European Union Council Directive 96/29/EURATOM. A Council Directive binds every Member State with regards to the regulatory goals, but leaves the means and procedures to the individual national regulatory bodies. It further requires the regulations to be included in national legislation before a prescribed date. Since 1996 three major international conferences were organised by the EU to bring regulatory bodies, industry and the scientific community together in discussion on the management and control of NORM. It resulted in Europe being the pacesetters when it comes to the control of natural radioactive sources and experience had shown that countries without a formal system or in the process of developing a formal system often refer to decisions made by the EU. Thus, even though this paper frequently refers to European Standards it remains applicable to the international scene, with the major exception being the United States of America.

The following examples illustrate the awareness among regulators.

3.1 IAEA Basic Safety Standard 115 (BSS 115) [2]

The IAEA published the BSS 115, a culmination of efforts, to harmonise the radiation protection and safety standards internationally. It was sponsored jointly by the Food and Agriculture Organisation of the United Nations (FAO), International Labour Organisation (ILO), the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA), the Pan American Health Organisation (PAHO) and the World Health Organisation (WHO).

<u>Principles and Fundamental Objectives (Practices and Interventions)</u>
"The Practices for which the Standards are intended include the following:…and activities, such as the underground mining of coal and of phosphatic and other minerals, that may enhance exposure to naturally occurring radioactive substances."

3.2 European Union Council Directive 96/29/EURATOM [3]

The directive, also known as the EURATOM, was introduced in 1996, with implementation date May 2000. It integrated work activities outside of the nuclear industry in its scope, specifically Title VII.

<u>Title VII Article 40.2b</u> *"…involving operations with and storage of materials, not usually regarded as radioactive but which contains naturally occurring radionuclides, causing a significant increase in the exposure of workers."*

3.3 A survey of potential problems for non-nuclear industries posed by Implementation of new EC standards for natural radioactivity. [4]

The Dutch Ministry of Housing, Physical Planning and Environment commissioned an inquiry into the consequences of fully implementing the EURATOM.

Some comments in the paper are:
"Enrichment can lead to fertilisers having an activity level 1.5 to 2 times as high as that of the ore, so that these too would exceed the limit. Such products might require reporting or certification under the new Council Directive, thus making them unsaleable."

"Phosphate industry: ...if slag and fertilizer could no longer be freely sold, it would mean "the end of the industry", with all the consequences that would have form employment."

3.4 European Commission Radiation Protection 95 [5]

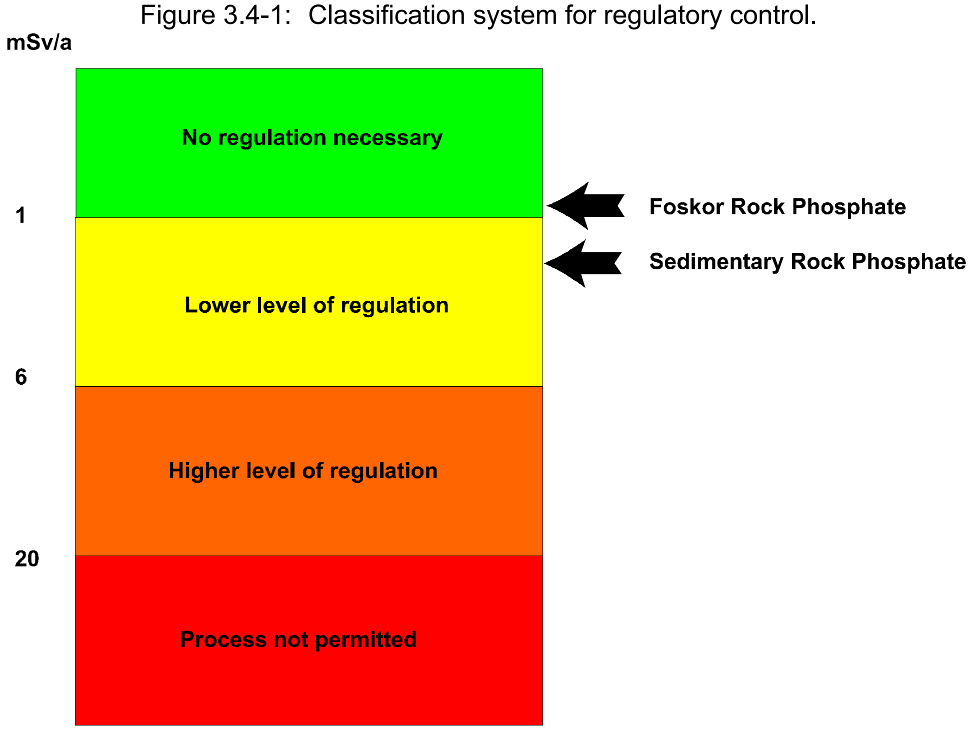
The purpose of the guide was to provide advice on work activities that is subject to the Title VII regime as there is no obvious relationship between activity and the extent of the controls necessary. It firstly identifies industries of concern and secondly proposed a system for the rapid determination of the levels of control necessary.

Section 2 (8): *"The most significant industries within the EU, based on the radiological risk and economic significance, are:*

- *The phosphate industry;*
- *Processing of metal ores;*
- *Zircon sands and refractory materials;*
- *Manufacture of rare earths;*
- *Manufacture and use of thorium compounds;*
- *The titanium dioxide pigment industry; and*
- *Oil and gas extraction.*

The document suggested four bands for increasing levels of regulatory control. Using the proposed decision-making tool in the document, phosphate rock's classifications are presented below.

Figure 3.4-1: Classification system for regulatory control.



3.5 The phosphoric acid production as a source of environmental radioactivity: The Spanish case [6]

The above paper was presented at the NORM II (November 1998) seminar in Krefeld. The following are some of the changes enforced at a plant in Huelva (Spain):

- No direct release of phosphogypsum into Odiel River.
- No new stockpiles of phosphogypsum.
- The phosphogypsum piles must be restored.
- Water used to transport the phosphogypsum to the stockpiles may not enter the river and a closed circuit for the circulation and cleaning must be established.

3.6 IAEA Co-ordinated research program: Development of radiological basis for transport safety requirements for low specific activity materials and surface contaminated objects.

The following is quoted from the IAEA Transport Regulations, ST1 [1]:

> <u>Section 107 (e):</u> *"The Regulations do not apply to: ... natural material and ores containing naturally occurring radionuclides which are not intended to be processed for use of these radionuclides provided the activity concentration of the material does not exceed 10 times the values specified in paras 401 – 406."*

Foskor's specialist on environment and radiation participated in the IAEA Co-operation Research Initiative on Transport workshop during February 2001. The IAEA launched this research program, with contributions from countries such as the United States of America, France, Canada, Germany and the United Kingdom, to ensure a sound radiological background for the next revision cycle of the IAEA Transport recommendations.

During the event, the IAEA transport expert in attendance, Mr G Dicky, verified that the 10 times exemption criteria included in ST 1 is not applicable to the derivatives of phosphate, (fertilisers, phosphoric acid etc) as it falls outside the current definition of natural materials. It is therefore subject to the full transport requirements as presented in recommendations. (The disturbance of the equilibrium in the manufacturing process placed it in the more restrictive category.) Phosphate rock is considered a natural ore.

The 1996 edition of the IAEA Regulations for the safe transport of radioactive materials will no longer be a recommendation, but fully applicable to international transport, including the phosphate industry:

- By air on 1 January 2001 with no transition period. (ICAO Technical Instructions.)
- By sea on 1 January 2001 with 1 year transition period. (IMDG Code)
- By road and rail on 1 July 2001 with 6-month transition period in countries that are contracting parties to RID/ADR.

The general message received at the workshop was that within the next couple of years, countries would be forced to comply with the international requirements, e.g. ST-1.

3.7 Technical committee meeting on the assessment of occupation protection conditions in workplaces with high levels of exposure to natural radiation. 07 - 11 May 2001(Draft Report)

Final Recommendations:
Section 4(3): *The IAEA should create, in priority order, individual sector specific safety reports for:*

- *Metals (including Thorium)*
- *Zircon*
- *Phosphates*
- *Pigments (TiO2)*
- *Coal and coal ash*
- *Fluorspar ?*

3.8 European Union restrictions on building materials

This publication gives guidance on the control of building material within the European Union. In summary, building material is controlled through the calculation of an I-factor. No restrictions will be placed on a material if the I-factor is less than 0.5.

$$I_f = \frac{C_{Ra-226}}{300 Bq/kg} + \frac{C_{Th-232}}{200 Bq/kg} + \frac{C_{K-40}}{3000 Bq/kg}$$

Resolving the above equation using the values reported in Table 3.1 and assuming the same K-40 concentration in sedimentary phosphogypsum as found in the igneous material, an If value of 3.1 for igneous phosphogypsum and 4.5 for sedimentary phosphogypsum is found. Thus, a dose assessment will be necessary before it can be used as a building material.

3.9 Increased International Awareness

The number of papers at any given conference is usually a good indication of what is considered important at that stage. During NORM I conference, held in 1997, 9% of all papers discussed some aspects of the phosphate and fertiliser industry and during NORM II in 1998, only 5%. This increased dramatically to nearly 43% at NORM III in 2001.

Of importance at NORM III was that 10 different regulators as well as the European Union and the International Atomic Energy Agency mentioned that assessments of the phosphate and fertiliser industry are necessary or are already receiving attention. It is interesting to note that the Minister of Internal Affairs for Belgium, Mr A Duquesne, also mentioned the use of phosphogypsum as building material and the need for further investigation during his opening speech.
As seen from the above, the finger is pointing straight to our industry and the approach of "hide till they find me" can no longer be followed.

4. Impact on the Industry

4.1 Regulatory Process

Figure 4.1-1 is a simplified illustration of the regulatory process. It does not represent individual countries' efforts, but rather a generic representation of the decision-making steps that leads to regulatory controls.

Figure 4.1-1: A simplified diagram of a typical regulatory process.

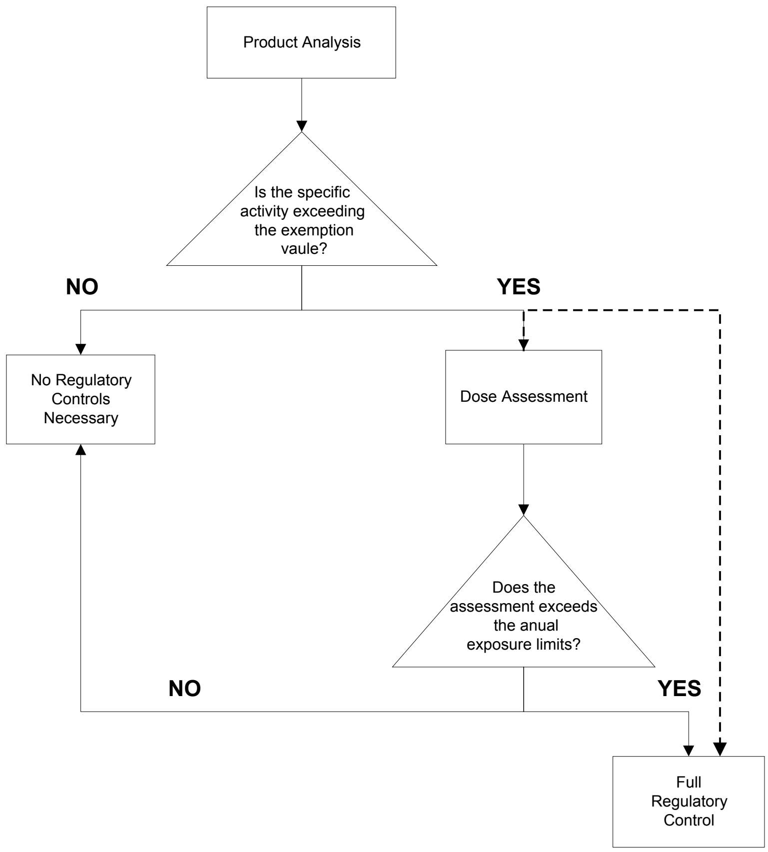
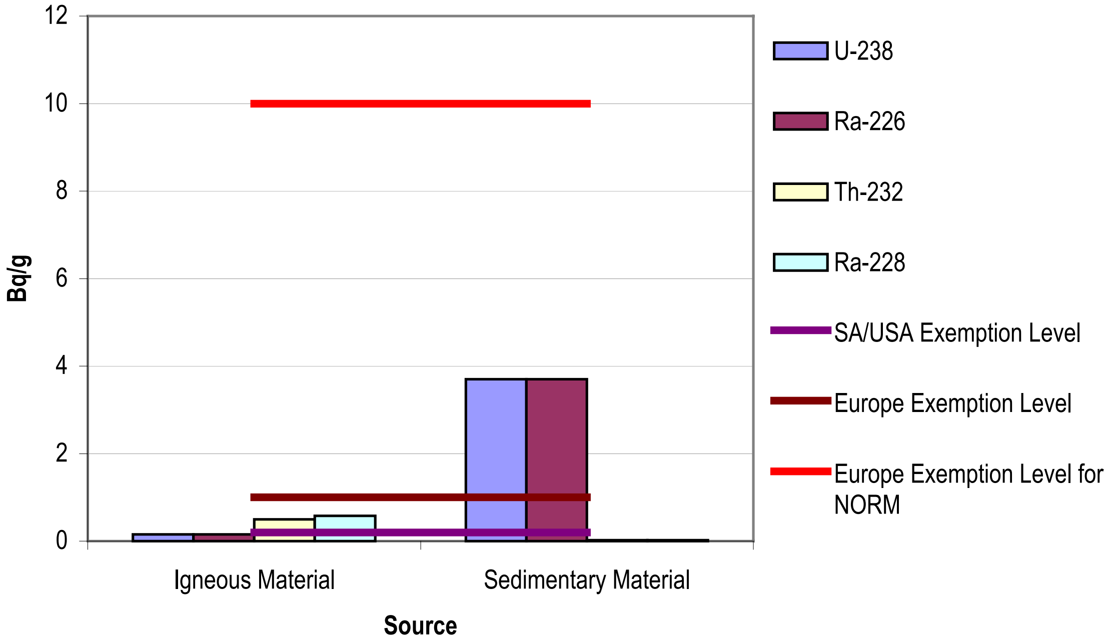


Figure 4.1-2 summarises some of the known nuclide specific activities as average values against some of the regulatory constraints it faces.

Figure 4.1-2: Nuclide specific activity of phosphogypsum



**Source: http://www.normis.com and measured values from South African material.*

Thus, looking at specific activity only, it appears at first glance that the phosphate and fertilizer industry is subjected to the requirements of a full regulatory regime. It therefore requires control over its work activities, restrictions may prohibit the use of phosphogypsum as building materials, it is subjected to the requirements of the transport regulations and cost will be incurred to maintain a program.

4.2 Control of Work Activities

Being subjected to the full requirements of radiation protection principles has an impact on almost all aspects of an integrated risk management program. A typical radiation protection program demands the following:

- Occupational site-specific risk assessment
- Site-specific public risk assessment
- Radiation protection procedures based on the occupational and public risk assessments.
- Area and personal monitoring programs
- Formal medical surveillance program
- Formal waste management program
- Restrictions on transportation
- Reporting of occurrences e.g. spillages, derailments etc.
- Formal quality management program to control the RP program
- Regular compliance inspections and audits by regulators

- Regular reporting, including dose assessments, to regulators
- Radiation protection function e.g. specialists, technologists, etc.

Once a plant is subjected to a control program it is very difficult to gain exemption and cost has been incurred that perhaps could have been saved if that plant was proactive in its approach towards the possible risk.

4.3 Radiation Protection Staff

Such a program may only run under specially trained and competent personnel. Using South Africa as an example, a radiation protection specialist will only receive consent from the National Nuclear Regulator to assume responsibility of a program after complying with the following:

- Minimum a National Higher Diploma or Honours Degree.
- Admission to a Masters Degree in Science.
- Approximately 5 years relevant experience verified by a panel.
- Registered as a professional scientist under the auspices of the Natural Scientific Professions Act, No 106 of 1993
- Accreditation by the South African Radiation Protection Accreditation Board.

4.4 Building Materials

With reference to Section 3.8, phosphogypsum exceeds the I-factor that would have exempted the material from regulatory controls. Its use as a building material is therefore prohibited. However, some Dutch companies were very successful in obtaining permission to use contaminated material in construction, following the risk assessment route.

4.5 Transportation

The specific activity of phosphate rock of both sedimentary and igneous origin is below the exemption level of 10 Bq/g specified by the Transport Regulations for natural ores and can thus be transported without constraints. However, of concern is the transportation of both phosphoric acid and phosphate fertilisers of sedimentary origin where some of the isotopes exceed the 1 Bq/g exemption level. It is thus subjected to the full requirements of the relevant regulations and can either be transport as an “Excepted Package” or a “Low Specific Activity Material (LSA 1)”, depending on interpretation of ST1. Some of the requirements are the following:

Parameter	Excepted Package Requirements	LSA 1 Requirements.
UN Number	2910	2912
Packaging	Keep integrity under normal transport conditions.	Tank containers must conform to the United Nations Recommendations on Multimodal Tank Transport of Dangerous Goods.
Radiation levels on surface	5 μSv.h^{-1}	0.1-10 mSv.h-1 at 1 meter from external surface depending on conditions.
Contamination	Determined on external surfaces only.	Determine on both internal and external surfaces.
	Not exceeding 4 Bq.cm-2 for beta, gamma and tow toxicity alpha emitters and 0.4 Bq.cm-2 all other alpha emitters.	Not exceeding 4 Bq.cm-2 for beta, gamma and tow toxicity alpha emitters and 0.4 Bq.cm-2 all other alpha emitters.
Labelling and Marking	Shall bear the marking "RADIOACTIVE" on an internal surface.	At least four placards with the radiation warning sign, with labels identifying the radioactive content.
Radiation Protection Provisions	Risk assessment to determine if any stage of the transport requires further controls in terms of common protection practices.	Formal radiation protection program established, that include dose assessment, training of personnel and periodic assessment by a regulatory authority.
Accidents or Incidents	Provisions to be made to protect members of the public in terms of radiation content e.g. treated as a nuclear incident.	Provisions to be made to protect members of the public in terms of radiation content e.g. treated as a nuclear incident.
Quality Assurance	Formal quality assurance program may be required.	Formal quality assurance program may be required.
Damaged Packaging	May be stored for the interim, but not forwarded.	Assessment of the risk by qualified person and appropriate response on the level of risk.
		May be stored for the interim, but not forwarded

As seen from the above, both options will have a significant cost implication to the relevant company. Not quantified is the physiological and political impact of presenting a material for use in agriculture that is clearly marked with a radioactive sign.

It is obvious that the regulations were not written with NORM industries in mind, as some of the requirements are clearly not practical or not proportional with the level of risk. It remains possible to obtain full exemption or having to comply with reduced controls by subjecting processes to radiological risk assessments. This is achieved if the exposure (or risk) is acceptable, usually below 250 - 300 μSv/a to members of the public. It is therefore recommended that a joint, detailed study be completed for submission to an authority such as the IAEA. Such assessments have commenced, for example for the transportation of igneous phosphate from the Phalaborwa Region. Cost and recognised expertise however, remain major stumbling blocks when attempting to cover the whole industry.

5. The Way Forward

5.1 Responsible Stewardship

At the end of 1998 Foskor realised the need for a cradle-to-grave approach when dealing with radiation. The company has always been a world leader in safety management, but safety is but part of radiation protection and it was found that the concepts of Product Stewardship and Sustainable Development better describes the scope of what is needed.

5.1.1 Product Stewardship

Some examples of the international interpretation of the concept.

Product Stewardship is the safe use and handling of products at all stages of their life cycles.

Health, safety and environmental protection must be an integral part of designing, producing, manufacturing, marketing, distributing, using, recycling and disposing of the products.

An American Company, Ashland Chemicals, states in their corporate mission that:

We will not make or sell any product or use any raw material that cannot be developed, handled, stored, transported, used and disposed of safely.

5.1.2 Sustainable Development

President Clinton, in an executive order, provided the following definition:

"Sustainable development is broadly defined as economic growth that will benefit present and future generations without detrimentally affecting the resources or biological systems of the planet."

The Oxford Dictionary defines Sustainable Development as: -

"…to meet the needs of the present without compromising the ability of future generations to meet their own needs."

Soon after a decision was made to start with a Product Stewardship Program it became apparent that regulators in general were reluctant to deal with individual companies. However, when the same individual companies jointly approached them, communication tends to improve and it was experienced that regulators are themselves more predisposed to assist rather enforce, to the benefit of both parties.

It was under these conditions that Foskor approached the Fertilizer Society of South Africa (FSSA) to promote a South African Fertiliser Industry Assessment under the auspices of the FSSA that includes co-operation with the national regulatory body.

5.2 Industry Assessment Process

The first step of the joint approach was to map out a cradle–to-grave route for the phosphate rock, supplemented by discussions with other affected parties. As a result the Industry was grouped into five levels, depending on the degree of beneficiation involved. The Project Plan can thus be summarised in the following figure

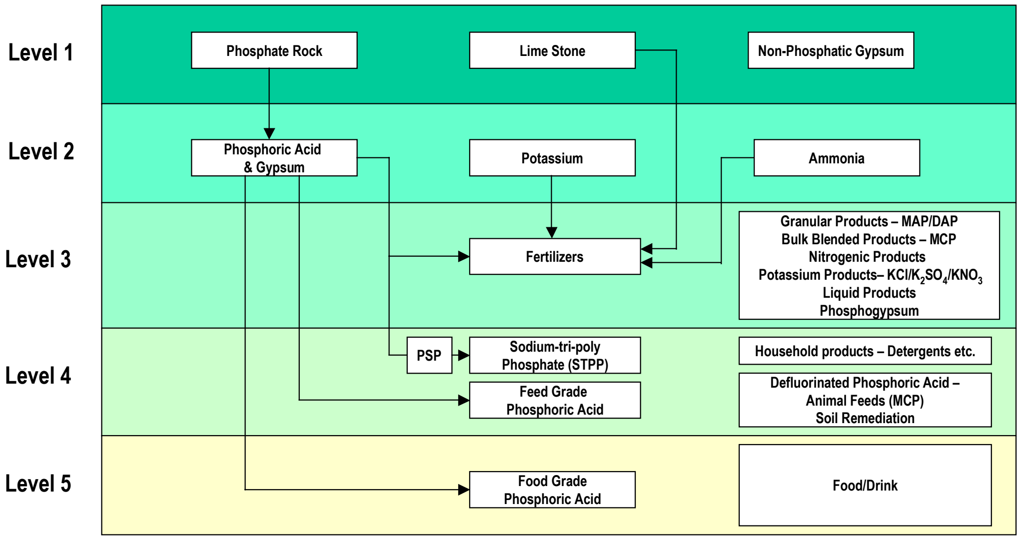


Figure 6.2-1: Flow diagram of the Phosphate Industry.

From the above, each or industry in a level is broken down into the relevant assessment segments. The figure below, using the mining and beneficiation of phosphate rock of Level 1 as an example, then represents the detailed of that specific industry

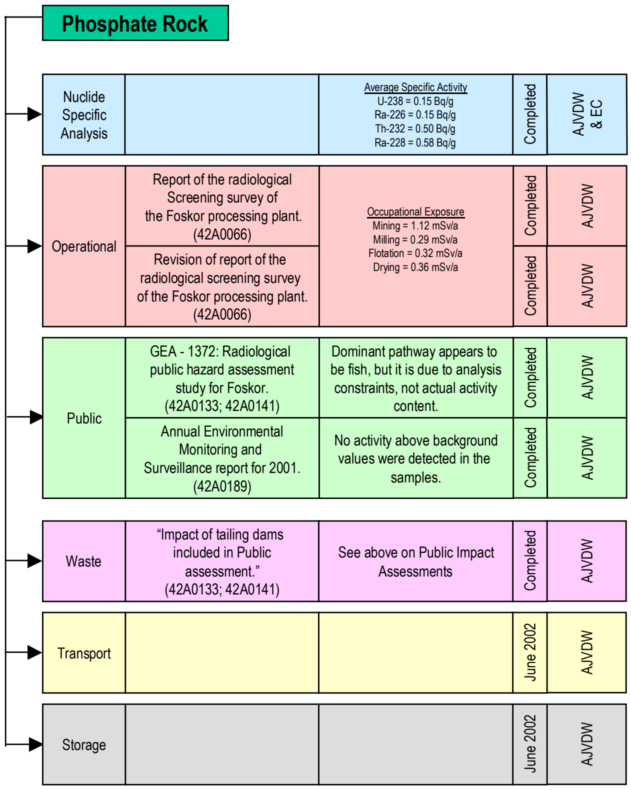


Figure 6.2-2: Detail for the Mining and Beneficiation of Igneous Phosphate Rock

The methodology followed serves several purposes.

- It is a quick reference for available detail of that industry.
- It serves as reference of documents submitted to and approved by a Regulatory Authority.
- Knowledge gaps are quickly identified.
- Responsibilities delegated.
- Completion dates for assessments accessible.

The number of studies necessary to ensure a comprehensive cover of each segment depends on the segment and materials under consideration. An example is the sub segment "Public" in the figure above. It will include the public exposure from a site, various uses of its products in the public domain etc. The more information available, the more comprehensive the picture of our industry is, ensuring a sound knowledge base when approaching a Regulator for possible relaxation of restrictions.

6. Assessment Case Study

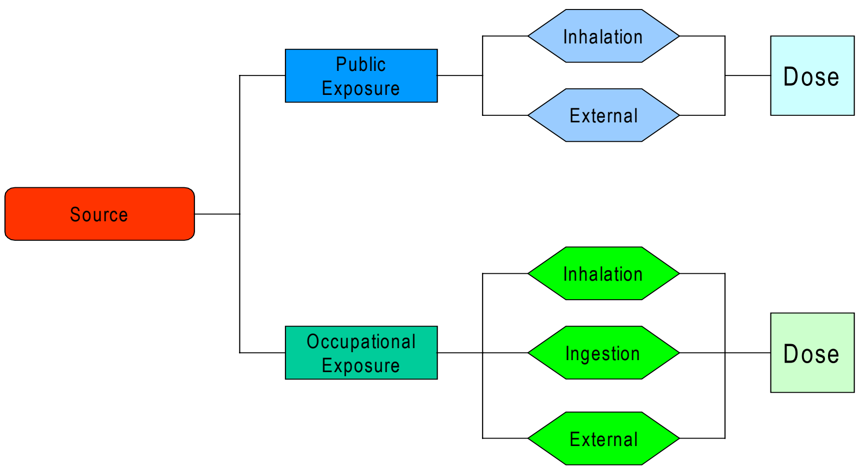
6.1 Problem Statement

Phosphogypsum places a significant burden on any phosphoric acid production facility, (See Section 4.5), and the re-use is usually encouraged. As seen from Section 3.8 however, the radiological content of the phosphogypsum is a prohibiting factor when using simplified classification tools and a detailed assessment is therefore necessary.

Inhalation and gamma doses from phosphogypsum plasterboards have been done in Australia [7,8] Again the assessments only covered sedimentary phosphate with little or no reference to igneous material. In addition, these two reports were very specific and had limited reference to occupational exposure.

6.2 Pathways for Consideration

A theoretical assessment was conducted, using both sources of phosphate rock, of the effect of phosphogypsum when using plasterboard in the building industry [9]. The effect of cover, paper or paint, was considered to reflect actual practice. The following figure illustrates the pathways considered in the assessment process.



6.3 Conclusions

The major conclusions from this assessment were:

Description	Comment
Effect of origin	The source of the radiation and its associated characteristics determine the exposure. There is no linear correlation between the doses obtained from igneous and sedimentary material and as a result the calculations should be done for both types of material.
Radon	Thoron has a much more significant effect than anticipated. Nevertheless, a layer of paint inhibits the exhalation of thoron, thus removing it as a possible source of dose. The inappropriateness of the "Instantaneous Mixing Model" for thoron is illustrated. Thoron and radon may require some additional measurements.
	Radon dose to workers requires a second iteration, as the assumptions used, such as ventilation rate, are inappropriate.
Gamma dose to Public	The theoretical gamma doses were found to be a significant contributor to the total dose for members of the public.
Conclusions	Occupational exposure does not pose a significant risk in terms of dose.
	Painting the plasterboard greatly reduces the radon dose and should remove the contribution of thoron completely
	Future work should focus on the measurement of gamma dose, radon and thoron in the public environment.
Advantages of study	The assessment was based on a sample analysis and, using generic models, the major areas of concern was immediately identified.
	The industry now only has to focus on one or two areas for future work instead of a whole range of tests.
	Remedial action for one of the possible risks was identified and available for implementation by the producing company.
	A detailed formal radiation protection program for builders and labourers in the building industry is not necessary.
	It will serve, as a positive argument on the issue of company liability or responsibilities as it will receive peer review.

6.4 Conflicting Results

A quick comparison between the Australian and South African assessments thus reveals the following:

Parameter	Australian Assessment	South African Assessment
Radon Exhalation	1.00E-03 Bq.$m^{-2}s^{-1}$ (Does not specify if the effect of cover was considered.)	Blank Plasterboard: 5.54E-03 Bq.m-2s-1 Painted Plasterboard: 3.11E-03 Bq.m-2s-1 Papered Plasterboard: 5.02E-03 Bq.m-2s-1
Radon Exposure for room of plasterboard	160 μSv.a-1 (Does not specify if the effect of cover was considered.)	Blank Plasterboard: 564.77 μSv.a-1 Painted Plasterboard: 317.12 μSv.a-1 Papered Plasterboard: 512.10 μSv.a-1
Worker Dose Inhalation	500 μSv.a-1 – 1500 μSv.a-1	1.42 μSv.a-1
Calculated Gamma Dose for Public	155μSv.a-1	2590 μSv.a-1
Radon exposure to workers	Not determined	Blank Plasterboard: 52.44μSv.a-1 Painted Plasterboard: 29.45 μSv.a-1 Papered Plasterboard: 47.55 μSv.a-1

At first glance there appears to be significant differences between the two assessments. To add to the confusion is that both used sound scientific principles and accepted models in determining the impact of the phosphogypsum plasterboard. Fortunately the differences can be explained if the methodologies and parameters are compared.

Some reasons for the differences are:

- Different specific activities are used. (Sedimentary phosphate range between 1.5 Bq/g to 4.5 Bq.g)
- The Australian paper assumed equilibrium for the phosphogypsum isotopes and the South African paper did not.
- Whether the contribution from thorium and its decay isotopes is included or not.
- Inclusion of radon progeny in the assessment or estimate radon concentration with dose conversion factors.

The apparently conflicting studies may cause harm to the phosphate and fertiliser industry, especially in countries where there is a less than sophisticated regulatory regime. A cooperative approach would identify possible areas for concern, resolve apparent differences and could determine parameter values for best practices, thus aiding not only the regulator in his functions, but also ensuring the industry is making informed decisions.

7. Conclusions

The phosphate industry has been identified as an industry that requires attention in terms of new legislation.
The regulatory bodies in Europe and countries such as South Africa are considering or already subject the phosphate and fertiliser industries to regulatory controls.
Certain areas, such as the transportation of sedimentary phosphoric acid and –fertilisers and the use of phosphogypsum as building material require immediate attention or will prove costly to the industry.
Co-operation between various sectors of the industry are necessary, especially where specialist studies are considered.

The immediate benefits of co-operation for the Phosphate- and Fertiliser Industry are:

- There will be no duplication of studies.
- The industry presents a uniform front to the Regulatory Authority, thus more bargaining power.
- Eliminating or pro-actively dealing with conflicting studies.
- Shared resources, such as studies, Radiation Protection Specialists etc.
- Wider and increased database.
- Cost saving.

8. References

[1] International Atomic Energy Agency Safety Series No. TS-R-1 (ST1): Regulations for the safe transport of radioactive materials. (1996)

[2] International Atomic Energy Agency Safety Series No 115: International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. (1996)

[3] European Union Council Directive 96/29/EURATOM: Laying down basic safety standards for the protection of the health of workers and the general public against the dangers arizing from ionizing radiation. European Union. (13 May 1996)

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[8] Gamma doses from phosphogypsum plasterboard. RS O'Brien (January 1997)

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