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Three Dilemmas in Sustainability of Construction Materials and Technologies

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ABSTRACT

The paper deals with three interrelated issues: (a) uses natural vs. artificial stone materials; (b) uses of gypsum vs. portland cement binders; and (c) low-contaminant materials – how pure they should be from the points of view of the customer, producer and of the society. These three topics are of great importance in the development and implementation of sustainable construction materials and technologies for the future. Understanding these dilemmas the society faces in the last years and answering these questions will help scientists and engineers to ensure that the production technology under development would be both environmentally friendly and sufficiently advanced from the technological point of view, and that the materials themselves would be safe and not harmful for the building occupants during all the life cycle of the building. All of these three topics were in the focus of the author's research over the last 30 years.

INTRODUCTION

The high living standards in Western Europe, North America and the rest of the developed world rest on modem industrial economies that consume huge quantities of exhaustible or non-renewable resources. This raises the possibility that the well-being of the current generation, at least those members of the current generation fortunate enough to live in the developed world, is not sustainable, but rather is being purchased, myopically or selfishly, at the expense of future generations [Tilton 1996].

The following numbers can illustrate the accelerated industrial and economical development occurred in the last years. The industrial production in the world has increased for the last century more than by 50 times, while 4/5 of this growth occurred in the second half of XX century. This growth required a huge consumption of natural resources, which doubled the production of raw materials about every 15 years. At the same time, only insignificant part of natural resources (about 5%) turns to end products. The rest goes to a waste, often ecologically harmful and unsafe. Therefore, the future dictates to develop new materials, which have to be produced by means of new resources-saving technologies. The problem of saving natural resources is one of the main environmental problems of the modern industrial manufacture.

Another problem, which is not less important, is a pollution of the environment and its degradation. Non-friendly environment influences to some extent a life of every third inhabitant of the Earth. Construction does not only consume about 40% of materials produced in the world and about 1/3 industrial energy, but also pollutes the environment. Extraction of construction minerals, including sand, gravel, clay, limestone and natural stones, causes noise, vibrations and air pollution, in addition to many other problems related to the extraction of metals. One particular environmental problem, which is related to the consumption of construction minerals, is the transformation of land into built-up area, resulting in significant losses of the basic natural functions of the land.

The paper discusses three controversial issues, which take an important place in sustainability of construction materials: uses of natural vs. artificial stone, uses of gypsum vs. portland cement, and uses of low-contaminant materials in view of cost-benefit analysis. All of these three topics were in the focus of the author's research over the last 30 years.

THE FIRST DILEMMA: NATURAL VS. ARTIFICIAL STONE

The first dilemma is to find an optimum method of production and uses in construction of natural stone (dimension stone products) vs. artificial stone (aggregates and concrete).

The building stone materials and products are usually manufactured in special organized quarries, which produce sand, gravel, crushed stone aggregates and dimension stone. Most of them are highly mechanized and produce numerous valuable construction materials:

- natural stone materials, mainly in the form of fractionated construction materials, such as dense and porous aggregates for concrete, mineral fillers – acid-resistant, temperature resistant, filtering/adsorption fillers, including micro-fillers, geopolymers, mineral pigments, thermal insulation and abrasive materials, quarry stone, raw materials for manufacturing cement, gypsum, lime and other mineral building materials and others;

- natural-artificial materials, such as mineral castings – organosilicates, basalt fibers, foamed and liquid glass, basaltoplastics, expanded products (e.g. perlite), adsorbents, mineral binders, concrete, aerated concrete products including those manufactured in autoclaves, gas-silicate and press-powder products, ceramics, fire-proof products etc.

Let us briefly discuss the technologies, which are popular in the modern stone sector. The construction technological chain usually starts from the extraction of rock. The traditional methods of rock extraction can be divided on *coercive* and *partly coercive* methods.

Coercive methods result in rock disintegration in a certain volume, when both the extracted material and the surrounding rock massive are damaged (cracked). Partly coercive methods are based on the disintegration of the rock to be extracted, but keep undamaged the surrounding rock massive (both rock envelope and bulk rock). The example of the coercive methods is the known drill and blast method. The example of partly coercive method is using tunnel boring machines (TBM) equipped with cutter disks.

Another group of the rock extraction methods is represented by cutting/splitting technologies, which do provide a delicate extraction of the rock, when both the extracted rock and the surrounding rock massive are kept undamaged. These methods are *non-coercive* and widely used in modern quarries and factories producing dimension stone.

There are several known methods of excavation of hard rock at construction of buildings and infrastructures in rock massive with complicated topography and in hard rock of complex lithology, significant depth and area:

1) Mechanical method, which is based, mainly, on impact or static loading applied to the rock. Mechanical method of earthworks (the most common representing 85%-90% of all the earth excavation works) is executed by earth-moving machines such as a loader, production trucks, the grader, the bulldozer, the backhoe, the drag line excavator etc. To move an extracted soil from the construction site to a laying place one uses transport method. In that case earth development is fulfilled by earth-moving machine (mainly excavators). After, soil is loaded on track/trackless vehicle or the creeper.

2) Rock blasting, which involves explosive power to move the soil in required direction.

Both mechanical method and blasting are coercive and accompanied by failure or collapse of native rocks in the weakest places, i.e. in cracks, cavities, holes and pores. These methods are considered as main methods for construction in hard rock. The coercive methods are also accompanied by severe environmental damage: noise and vibrations, artificial earthquakes, dust, air and water pollution, visual impact, impact to biodiversity due to land conversion etc.

Intermittent noise is produced by specific operations: mainly blasting, but also the daily starting of engines, the loading of rocks into dumpers, the unloading into the steel entry chutes of primary crushers, etc. When it is not following a periodic cycle, or when the period is long, it could even be qualified as sporadic noise.

The main sources of dust emissions include crushing-grinding, drilling and blasting, which are typical operations of coercive methods.

Toxic and nontoxic gases are normal byproducts generated by blasting activities, regardless of the explosive materials used. NO_2, CO, and NO emissions are generated usually.

Surface water regimes may be altered by blasting operations, because of flow diversions, water intake, and changes to the drainage pattern. However, the most severe and irreversible damage induced by blasting is cracking in the geological layers of sedimentary rock located above the aquifer, which will not be able to serve any longer as a ground water filter. Polluted water can easily penetrate the aquifer through these cracks in the areas with high air pollution (for example, due to the close proximity to chemical plants).

On the contrary, the non-coercive methods, such as those used in the modern dimension stone sector, are free from the deleterious effects on the environment. The dimension stone industry has introduced new anti-noise and anti-resonance circular blades for the cutting of rough blocks and the setting of small pieces [Euro-roc 1998]. The consumption of water in stone cutting operations (for cooling the instrument) can be significantly reduced by using the internal moisture of the rock, and recycling of water in dimension stone factories.

The non-coercive methods are rarely used in construction projects. For example, the mechanical methods of tunneling in hard rock are known, which are based on Full-Face Excavation or Part-Face Excavation [Maidl, Herrenknecht & Anheuser 1995]. In particular, rock excavation works at tunneling by means of high-pressure water and by means of profile saw on guidance frame are described. The authors report that although such non-coercive methods are seldom used, they are of great importance in specific geological conditions.

The same source describes uses of partly coercive methods, such as TBMs equipped with cutter wheels, which work by the following principle. Every natural rock is riddled with cracks and flaws on several scales. When the cutter wheel pushed down on the rock, the compressive force it introduced concentrated around these weaknesses, with most of the compression organized around the worst flaws. Exert enough pressure, and the cracks will extend into the medium. As the wheels roll on, the cracks spring open, splitting the rock still further. Such splitting loading applied locally by the cutter wheels in the plain of the mechanized shield results in effective disintegration of the rock mass, but does not introduce any damage to the surrounding rock massive.

It has to be emphasized that the native hard rocks are usually characterized by high strength (e.g. unconfined compressive strength) and other mechanical properties, which are valuable for construction purposes. The overall goal of the earth excavation at construction is to remove the top layer of the native rocks and to build structures these rocks support. About 75% of the area of the Earth crust is covered by sedimentary rocks. In other words, most of the construction is executed in these rocks.

At the same time, hard sedimentary and other rocks are widely used at manufacturing of building stone materials and products, ~ 95% of which are produced by another industrial sector – in numerous stone quarries and mines extremely, which are limited in space. The goal of the extraction and processing of natural building stone is utilizing its unique native physical and mechanical properties, and also acquired finished properties, which are requested by consumers.

Part of the organized quarries uses coercive methods of rock extraction and processing, but some others use semi-coercive methods or non-coercive methods.

The main problem is thus in the contradicting goals of the two sectors, which consume natural stone resources: construction of engineering structures and construction materials industry. This problem leads to the paradoxical situation, when 95%-99% of the excavated rock (mainly, of sedimentary origin) in construction earthworks is removed to disposal or simply wasted. As a result, the low efficiency of stone extraction creates irreparable economical losses, and in addition leads to environmental loads and damage.

Let us compare technological platforms available for production of concrete vs. dimension stone products, their environmental impact (including CO_2 emissions), demand of raw materials, labor, energy and water, productivity and suitability for industrialization. Unfortunately, we have to admit that the main technologies available in the stone production sector of many countries are outdated, wasteful and not environmentally friendly (Table 1) [Kovler, Rozenfeld & Zingerman 1999]. The question is how to improve the situation.

The serious changes are needed in economical and legislative spheres regarding the status and protection of the natural stone resources as *national priority*, while everybody involved in their use is going to have a benefit: the state gets significant royalties for providing license on using natural resources; the producers are stimulated to use advanced (economical and environmentally friendly) methods of rock extraction combined with getting more value (for instance, producing underground spaces for different purposes); and the consumers get valuable building products by prices lower than they pay today for imported products.

Application of the modern stone cutting and splitting technologies seems to be especially effective in underground construction. Here two available products can be obtained simultaneously: an underground space meeting all the requirements of the design (geometry, climate, acoustics, fire protection, etc., and the extracted building products (dimension stone). The shortage of available open land in many countries and defense considerations dictate development of new alternatives based on underground construction. Many underground installations, for both civil and military purposes, consist of tunnels excavated in solid rock, which is relatively fault-free and is not prone to flooding during construction. Often, the rock is so strong, that the tunnel walls do not have to be lined. Such underground facilities can be used as storehouses, airdromes, plants, parking places, theaters and many other purposes.

Table 1. Two Groups of Technologies in the Building Stone Sector

Field	Parameter	Technologies	
		Resources-consuming and low-tech	Resources-saving and high-tech
General	Main product	Aggregates for artificial materials (mortar and concrete)	Finished products (dimension stone)
	By-product	Finished products (dimension stone)	Aggregates for artificial materials (mortar and concrete)
	Raw material (rock) cost	Low	High
	Production cost of dimension stone	High	Low
	Production cost of artificial materials	Low	Low
Technological	Main product to by-product ratio	Low	High (>60%)
	Re-use and recycling of by-products; control of product properties	Limited	Wide
	Power consumption	High (hundreds horse powers per m^3)	Low (dozens horse powers per m^3)
Environmental	Consumption of quartz sand in concrete production	Very high (hundreds of kg/m^3)	Very low, if at all (sand from carbonate rock can be used)
	Possible environmental damage	Irreversible and sometimes catastrophic damage	Environmentally friendly
Technological-economical-environmental	Consumption of water, energy and resources	High	Low
	Durability of the main product	Low (dozens of years)	High (hundreds of years)
	Environmental comfort in living spaces	Satisfactory	Good (dimension stone products "breath" and are self-adapting to the environment)
Social	Consumption of labor	High	Low
	Work motivation	High	Low

We assume that in areas rich by valuable mineral rock resources, the excavation operations for production of dimension stone can be effectively combined with the organization and further uses of the produced underground spaces for civil and military purposes. For example, limestone is widely distributed in eastern and north central Kansas. Six underground mines exist in northeastern Kansas that produce crushed limestone for the local building and road construction industries. However, producing crushed stone usually requires blasting, which results in (a) damage of the excavated rock, which cannot be used as a valuable dimension stone product and (b) cracking of the rock in the vicinity of the underground space, which cannot be used for setting up civil and military facilities without further investment.

The advanced technological systems include different types of environmentally friendly techniques, which are not based on blasting. Such technological systems can be based on either mechanical or non-mechanical (chemical, for example) principles. The mechanical systems include a combination of (a) tunnel boring machines, or TBM, (mainly for forming the approach zone of the future underground space), (b) advanced splitting and saw/diamond wire cutting machines (mainly for organization of the secondary quarrying routes and producing different types of dimension stone: large blocks, slabs, tiles, paving stones etc.). Such machines are available in Italy, Germany, USA and some other countries; they are highly effective and damage neither the surface landscape, nor the envelope of the underground quarry, which is designated to be used as future facility for civil or military purposes. In cases, where blasting is prohibited, because of proximity to residential or industrial neighborhoods or other reasons, the proposed environmentally friendly methods may be the only solution to the needs of underground construction.

The algorithm of the design of underground space and development of the optimum construction technology with simultaneous manufacture of dimension stone should include the analysis of (a) properties and future market of the dimension stone products; and (b) availability of the technologies, their technical characteristics and possible environmental impact. In the development of the project concept we propose to follow a simple principle, namely: "The sales of the dimension stone products should cover a prescribed percentage (preferably 100%) of the expenses for the underground construction".

THE SECOND DILEMMA: GYPSUM VS. PORTLAND CEMENT

Gypsum and portland cement are viable cementitious materials widely used for the production of components. Gypsum has the advantages of early hardening and a fine finish, but is limited to internal use because of its sensitivity in a water environment. Portland cement in the hardened state is strong and durable in moist conditions, but unlike gypsum it does not possess early hardening or the fine finish needed for precast components.

The second dilemma discussed in the paper is related to a possible replacement of portland cement by gypsum in various construction applications, where these materials are competing.

To develop an accurate understanding of the building’s overall sustainability, it is important to determine the environmental impact of its individual components and systems. Embodied energy (the total amount of energy used to manufacture a given material and then to transport it to its point-of-use stage) is a critical measure of a product’s sustainability. By this measure, gypsum materials and products are considered as one of the best and have a priority before similar materials and products made of portland cement. However, gypsum materials and products are used at present, as a rule, only indoors, when air relative humidity does not exceed 60%, because of their low durability and high creep in humid environment. The works performed by the author since 1986 promote the uses of water-proof gypsum materials and products can successfully replace energy-consuming portland cement in many building products and structures, raise their efficiency due to fast hardening, economy of metal and energy at their manufacture, lower the environmental loads caused by the CO_2 emissions, decrease of transportation expenses and finally acceleration of construction speed.

The idea to overcome the disadvantages of gypsum by adding portland cement with active mineral additives belongs to Volzhensky, which studied these blends with his coworkers in Russia [Volzhensky 1944; Volzhensky, Stambulko & Ferronskaya 1971; Volzhensky & Ferronskaya 1974]. This idea looked an absurd in the beginning, because mixing gypsum and portland cement is usually unfeasible since it can result in the formation of calcium sulfo-aluminate hydrates, which causes expansion and leads to deterioration. These and other studies have shown that the problem of combining gypsum with portland cement could be reduced to prevention of ettringite formation in the mix. The further studies shed more light on the reasons of deterioration of gypsum-cement system in water [Kovler 2006]. For example, it was shown that the mix made of 50% portland cement and 50% gypsum can be strong and durable in water, when the thaumasite formation (caused by carbonation) is avoided. In this case ettringite is formed as a result of interaction between cement and gypsum and successfully contributes to the strength, together with C-S-H. However, carbonation of cement- gypsum materials in humid conditions results in complete disintegration of the system caused by the thaumasite formation, while ettringite serves as a precursor for thaumasite. Finally, monocarbonate formation (calcite and monocarbonate accompany thaumasite formation at later stages of carbonation) seems to be related to the ettringite disintegration, when portlandite is consumed completely.

[Bentur, Kovler & Goldman 1994] described a study intended to develop a blend of gypsum and portland cement that would possess the advantages of gypsum and portland cement, but would be free of the deleterious effect of ettringite and thaumasite, which are formed when gypsum and portland cement interact. This was achieved by preparing a blend of 75% gypsum with a 25% mixture of portland cement and silica fume. The improved mechanical performance of such a gypsum-cement-silica fume (GCSF) blend was explained by the reduction in ettringite formation and the development of a microstructure in which gypsum crystals were engulfed by C-S-H. This work proved the conclusions obtained earlier in the former Soviet Union about successful "coexistence" of gypsum and portland cement in blends with even less reactive pozzolanic materials such as natural pozzolans.

For higher contents of portland cement in the blends, about 60±70%, as was shown by [Alksnis 1988], the early strength of the binder decreased considerably, although the properties of early hardening were kept, as for the gypsum binder. For binders with a very high cement content, more than 75% by mass, the property of early hardening disappeared. Optimum compositions of GCSF blends with different gypsum to cement and silica fume to cement ratios were identified in the work [Kovler 1998c], while the high water absorption for some compositions, together with the low strength in the wet state, were explained by the extra content of silica fume, which was not needed for pozzolanic reaction and could be freely removed from the structure by washing. Water resistance of the optimum GCSF compositions were comparable with that of cement-silica fume systems [Kovler 2001], and the properties of fresh GCSF compositions (excellent workability and fast setting) were not worse than those of the pure gypsum [Kovler 1998a,b].

Water resistance is considered as the most important property of building materials, which contact with water. The ratio between short-term compressive strengths determined in wet (water-saturated) and dry conditions, is usually accepted as a characteristic of water resistance. The wet/dry strength ratio of the material can vary from 0 for soaking clays up to 1 for metals. As a rule, natural and artificial stone materials are not used in building structures in contact with water, if their wet/dry strength ratio is less than 0.8.

Wet/dry strength ratio, however, has some limitations. Any parameter determined by short-term testing cannot adequately estimate long-term behavior, including water resistance. Similarly, wet/dry strength ratio determined via short-term tests cannot be used to ascertain long-term behavior. This limitation is typical for all known methods of engineering prognosis of long-term material behavior. It must be emphasized that the wet/dry strength ratio may significantly change in time producing both favorable and adverse effects. This may result from structure-forming or rehabilitation in the material (caused by hydration) on one hand and as from structure deterioration, caused by dissolution of solid phase or by secondary reactions resulting in the volume expansion. Therefore, the same materials can have different values of wet/dry strength ratio dependent on time. In other words, the kinetics of wet/dry strength ratio in time is of great importance. For example, the material having initially the wet/dry strength ratio less than 0.8, but increasing with time, cannot be excluded from the group of water resistant materials. This happens, for example, in gypsum-cement blends with 5% silica fume, which show pronounced improvement of the wet/dry strength ratio in time.

THE THIRD DILEMMA: USES OF LOW-CONTAMINANT MATERIALS IN VIEW OF COST-BENEFIT ANALYSIS

The third dilemma, which will be discussed hereafter, is how pure construction materials should be, in order to meet the requirements of sustainability. In the last years international society became aware of the problem of the increasing production of industrial waste. Indeed, the construction industry uses large amounts of by-products from other industries. The advantages of utilization of coal fly ash, slag and some other industrial by-products in construction are well-known, as well as numerous technological and environmental problems caused by an elevated content of chemical and radioactive contaminants and the need to purify the materials or products before their final uses in construction.

Let us consider, as an example, the situation around production and use of construction materials with enhanced levels of radioactive contaminants. In recent years there is a growing tendency in European and other countries to use new recycled materials with technologically enhanced levels of radioactivity [RP-112 1999; Kovler 2009].

Before starting the analysis, we have to remind the reader that radiation exposure due to construction materials can be divided into external and internal exposures. The external exposure is caused by direct gamma radiation. The internal exposure is caused mainly by the inhalation of radon (^{222}Rn) and its short lived decay products. Radon is part of the radioactive decay series of uranium, which is present in construction materials. Because radon is an inert gas, it can move rather freely through porous media such as construction materials, although usually only a fraction of that produced in the material reaches the surface and enters the indoor air. This fraction is determined by so called emanation ratio (or emanation coefficient) of the building product. The extent of radon released by building materials is characterized by its exhalation rate, which can be expressed in $Bq \cdot kg^{-1}s^{-1}$ or $Bq \cdot m^{-2}s^{-1}$. The knowledge of the radon release is important for accurately assessing radiation exposure in buildings.

Coal fly ash is one of the most known examples of industrial by-products with enhanced radioactivity levels [Dinelli et al. 1996; Smith et al. 2001; Kovler, Perevalov, Steiner et al. 2005]. The use of coal fly ash in concrete is a well-recognized source of gamma exposure that is due to the presence of activity concentrations of ^{226}Ra, ^{232}Th and, to a lesser extent, ^{40}K, while its effect via radon exhalation is controversial, due to the low emanation coefficient from the ash [Kovler, Perevalov, Steiner et al. 2005]. Large quantities of coal fly ash are expelled from coal-fired thermal power plants and these may contain enhanced levels of radionuclides along with other toxic elements. More than 280 Mt of coal ash (fly ash and bottom ash combined) are produced annually. About 40 Mt of these are used in the production of bricks and cement [IAEA 2003]. Since most of the process residues further processed into building materials do not meet the required technical specifications, they are typically mixed with pristine raw materials. The net effect is a dilution of the NORM (Naturally Occurring Radioactive Material) content relative to the process residues.

Let us analyze the radiological aspects and legislation issues related to the use of building materials incorporated coal ash and other industrial products with enhanced levels of radioactivity. Because there is no threshold value for stochastic effects, the aim of radiological protection of the members of public is not to just keep within the dose limit, but to ensure that protection is optimized and the exposures are all kept *as low as reasonably achievable* (ALARA principle), economic and social factors being taken into account.

The tendency to develop stricter environmental norms is observed in the last years in both national and international scale. However, the trials to introduce too strict regulations fail without conducting an appropriate cost-benefit analysis. The author personally supports with enthusiasm the concept of ALARA, which serves as a fundamental principle in radiological protection. ALARA concept provides that no level of radiation exposure is acceptable without justification. The question is how to make the justification. Restricting the use of certain building materials might have significant economical, environmental or social consequences, which should be assessed and considered when establishing binding regulations [RP-112 1999]. The stricter are the restrictions, the more expensive would be their implementation.

Unfortunately, cost-benefit analysis ignores the question of *who* suffers as a result of environmental problems and, therefore, threatens to reinforce existing patterns of economic and social inequality [Heinzerling & Ackerman 2002]. Let us discuss briefly how this issue can influence the decisions of environmental authorities.

The environmental protection in general, and the radiological protection of population exposed to ionizing radiation in particular, are under financial and juridical responsibility of governmental authorities. In many cases, the expenses are shared between governments, private sector (a local construction industry, mainly) and public. However, the budget resources in some countries are very limited, and their national authorities would unlikely imply strict regulations. The Gross National Product (GNP) per capita, which is a measure of national income per person, should influence the decision how expensive (i.e. how strict) should be the regulations.

In view of this, the cost-benefit analysis based on the cost of 1 mSv/year depending on GNP/capita seems to be a reasonable tool to be used by national legislating authorities dealing with radiological protection of buildings occupants. Different approaches for executing such cost-benefit analysis are illustrated in the work [Kovler 2009]. According to one of the approaches, in countries with GNP/capita of $3,000 only the cost equivalent of the reduction of mortality risk by 5.6·10-5 - 7.3·10-5 due to preventing the radiation exposure by 1 mSv/year would be equal to $30 approximately; or about 1% of GNP/capita. In countries with higher GNP/capita, with GNP/capita of $16,000, the cost equivalent of 1 mSv/year would be $700, which is about 4% of their Gross National Product per capita. This approach clearly shows than in the countries with higher GNP per capita the expenses for radiation mitigation are higher.

On the other hand, cost-benefit analysis treats questions about equity as, at best, side issues, contradicting the widely shared view that equity should count in public policy. Poor countries, communities, and individuals are likely to express less “willingness to pay” to avoid environmental harms simply because they have fewer resources, and this is in spite of the fact that they are going to pay less GNP per capita, as shown in the previous example. Therefore, cost-benefit analysis would justify imposing greater environmental burdens on them than on their wealthier counterparts [Heinzerling & Ackerman 2002]. That is why the results of cost-benefit analysis seem to be valid, when obtained for similar conditions, i.e. for the countries with a similar GNP/capita ratio.

Another problem of cost-benefit analysis is that it fails to produce the greater objectivity and transparency promised by its proponents. Cost-benefit analysis rests on assumptions that cannot be described as objective. Moreover, the highly complex, resource-intensive, and expert-driven nature of this method makes it extremely difficult for the public to understand and participate in the process [Heinzerling & Ackerman 2002]. This is especially relevant for discussing radioactivity allowed in construction materials, which is extremely sensitive public issue. It is theoretically possible that cost-benefit analysis could be used to choose the overall limit on the allowable maximum level of radioactivity in construction materials. However, better public policy decisions can be made even without cost-benefit analysis, by combining the successes of traditional regulation with the best of the innovative and flexible approaches that have gained ground in recent years [Heinzerling & Ackerman 2002].

One of the approaches is informational regulation, which requires disclosures to the public and/or to consumers about risks they face from enhanced radioactive exposure in dwellings. These “right-to-know” regimes allow citizens and consumers not only to know about the risks they face, but also empower them to do something about those risks. For example, one of the types of exposure is internal exposure from breathing radon exhaling from the construction materials with elevated content of radium ^{226}Ra, which is a precursor of ^{222}Rn in the ^{238}U disintegration chain. There are different methods of radon mitigation, which can be successfully applied by the producers or occupants, which are aware about the possible problem of radon exhalation, such as introducing special additives into concrete mixes to reduce radon exhalation [Lau, Balendran & Yu 2003] or using special sealers or coatings preventing radon release from the surface of building elements into the room space.

The product warning labels or the labels of low-contaminant product seem to be an additional useful step towards the successful "information-based" regulation. The example of the second type of the labels can be the Swan label, which is the official Nordic ecolabel, introduced by the Nordic Council of Ministers. The Swan label demonstrates that a product is a sound environmental choice.

For the implementation in construction of the suggested approach, which does not necessarily require a thorough cost-benefit analysis, there is a need to develop standards, methods for testing and certification schemes. All these are especially effective in combination with the "information-based" regulation described before. In order to guarantee independent testing and judgment, laboratories have to meet quality standards put forward in an accreditation scheme. Although this legislation does not cover all environmental aspects, it has proved to be an important element in judging the environmental quality of construction materials in a direct or indirect way, and a contribution to the management of waste materials.

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