CONTAINERS FOR LONG-TERM STORAGE OF LOW AND INTERMEDIATE-LEVEL NUCLEAR WASTE

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ABSTRACT

This paper describes containers made of engineerd stone as developed by COMING Plus, j.s.c., for the Ministry of Industry and Trade of the Czech Republic. It was developed as coherent The serie of structural units compoundable mutually one inside each other were moved. This arrangement enables very broad field of radiation shielding. Using advance knowledge and technology (nanomaterials, C-fibres, vibrorheology etc.). simultaneously provided excellent mechanical and dynamic properties of developed material, with the resistance to different chemical media and/or atmospheric surroundings The production is currently in preparation.

Between 2004 and 2006, through a combination of significant financial support from the Ministry of Industry and Trade of the Czech Republic and the R&D division of COMING Plus, j.s.c., a container system for short-term and long-term storage and transport of low-level and intermediate-level nuclear waste was developed, composed of a modern composite material –special engineered stone.

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The task was evidently motivated by the need to address growing demands, for environmental protection in the broadest sense of the term, for safety during the handling of radioactive waste, and to finally achieve lower overall costs for the handling and long-term storage of this waste. The need to replace existing decades old and from a global perspective obsolete technology with arguable safety potential doubtlessly also played a role.

Thanks to excellent cooperation with experts and institutions here and abroad, and much excellent work of employees working with this or related subject matter their entire lives, we succeeded in achieving results with a wide scope of application.

We came up with an inorganic/organic material – engineered stone, which to an extensive degree meets safety characteristics required of it for use in containers, not only from the perspective of long-term stability, but also from the perspective of cost and reproducible production.

This material's mechanical properties (for example tensile bending strength of 48 MPa, compressive 75 MPa) exceeds by more than an order of magnitude the mechanical/physical properties of traditional materials like concrete, but possesses equal shielding properties against variegated sources of ionizing radiation.

During development, the formulated material was exposed to long-term effects of various types, including a changing atmospheric environment (from – 20 °C to 60 °C, from 30 to 99% RH), ultraviolet radiation and penetrating ionizing radiation, as well as mechanical stress, with results showing its exceptional resistance without any observable change in its properties.

Aside from these influences, the formulated material is also resistant to an entire number of chemicals, from aliphatic hydrocarbons to non-oxidizing acids or alkalis, enabling containers to be used not only for the storage of radioactive substances, but also various chemicals, including difficult or impossible to break down toxic waste.

Fig. 1 Three sizes of engineered stone containers

Containers made of engineered stone were designed (as opposed to the round barrels used up to now) as a rectangular box dimensioned so that two containers can be placed on one Europallet, i.e. with plan dimensions of 800 x 600 mm, and a height of 800 mm (Fig 1). The main "large" container with usable internal volume of 265 dm^3 has a wall thickness of 30 mm and ribbing that is also 30 mm thick. A "medium" container was also developed for cases when the volume of radioactive waste is relatively small and when only manual handling tools are available, with dimensions of 310 x 420 and 320 mm, a usable internal volume of 33.5 dm^3, and a wall thickness of only 12 mm. Four of these medium containers fit into a large container. Finally, for very small amounts, for example in hospitals and similar facilities, a "small" container was developed, easily carried even by a woman, with dimensions of 210 x 165 x 280 mm, with a useful internal volume of 6 dm3 and a wall thickness also of 12 mm (Fig. 3).


Fig. 3 Easy-to-carry small container


Fig. 4 Container transport with a forklift

The bottom of the container has monolithic feet that are 50 mm high, allowing easy insertion of forklift forks for transport (Fig. 4), and storage stability and accuracy when stacked by the insertion of the feet into corresponding depressions in the lid (Fig. 5). For vertical transport using a harness (Fig. 6), the container bottom has stabilization protrusions to prevent harness slippage.

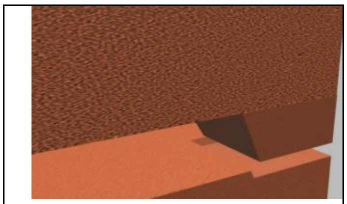
Fig. 5 Container feet allow for easy handling with pallet trucks or forklifts

Containers are equipped with a sliding lid that is glued to slot in the walls prior to storage using glue based on the same material as the product. The seal is as solid as the container material and just as impermeable.


Fig. 6 Container transport on straps

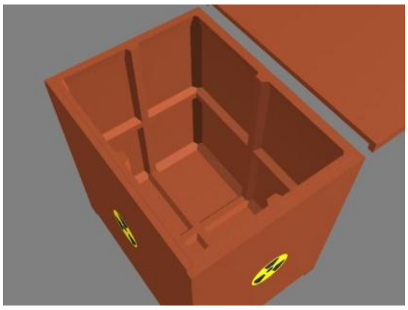

Fig. 7 View of container interior with reinforcing ribbing

The sophisticated manufacturing process, which involves production in a vacuum using an internal form using leave-in-place laminate forms (with cross-ribbing) (Fig. 7), reinforced by a combination of carbon and aramid fibres, increases the container's stiffness and its overall resistance to dynamic and impact stress, while creating a completely smooth and washable internal surface. This laminate layer also provides a second impermeable barrier (aside from the wall) to the escape of liquid waste from the container.

Up to 18 of these small containers can fit into a large container, and two into a medium one (Fig. 8). This type of shape and arrangement has many advantages. First and foremost, the container's usable volume (372 litres) is not much smaller than its outside volume (384 litres), and is several times greater than the usable volume of a drum in existing configurations (about 57 to 100 litres depending on thickness of concrete liner) with an outside drum volume of 226 litres. Further, due to their shape, the containers take up 25% less space in storage areas and transport vehicles than round drums do. Containers may be stored without stability problems in stacks of five (depending on circumstances, even more). Container weight remains within acceptable limits for easy horizontal and vertical transport (in most cases around 600 kg including contents). The containers are entirely and permanently impermeable, so they can also be used for storage of liquids, if required by the storage facility, thickened with suitable sorbents. When smaller containers or irregular metal and similar items have been put inside, the remaining free space is filled with dry fine-grained barite. This provides further significant shielding without excessively reducing the container's usable internal volume.

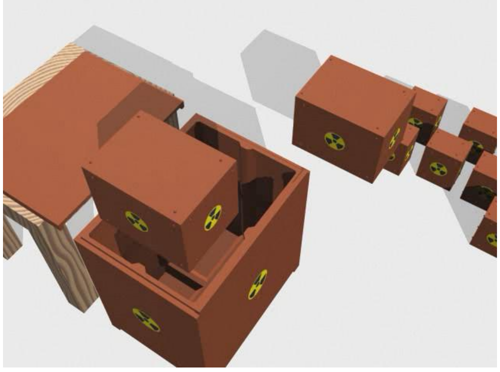

Fig. 8 A large, medium and small container nestle into each other like a "matryoshka doll" in 14 possible combinations

Container shape and dimensions made it possible to double or triple shielding through container arrangement (like in Russian "matryoshka dolls"), to achieve otherwise unachievable shielding effects, but also huge storage space savings. For example, a Co source of radiation with total activity of up to 60 GBq can be placed into a small container, and if this small container is placed into a medium one and this one into the centre of a large one with barite fill, radiation limits at the container's outer surface will not be exceeded. Storage of radiation sources in the traditional manner, i.e. in a metal container (e.g. a pipe), placed into the centre of a concrete-lined metal drum, allows for insertion of a radiation source with maximum activity of 3 GBq. In the first instance, storage of Co 60 radiation sources with a total activity of 60 GBq will thus occupy an area of 0.6 x 0.8 = 0.48 m^2, while the traditional method will occupy an area of 20 x 0.6 x 0.6 = 7.2 m^2, thus 15 times as large, not taking into account the fact that individual sources of radiation with an activity exceeding 3 GBq cannot be stored using the second method at all.

Two versions of shielding performance (depending on material composition) for the large and medium container and three shielding versions for the small container allow one to choose lighter or heavier (more effective) shielding depending on the activity and type of radioactive waste being stored/transported and the penetration level of stored radioactive waste, and thus optimize the cost of the containers themselves.

A not insignificant advantage of the main engineered stone container is its large internal storage area, which allows for the storage of long pieces of radioactive waste (the container's diagonal measures 110 cm) as well as large pieces without the need to split them.

As can be seen, an engineered stone (ES) container or set of containers of various dimensions and material composition for storage of low and medium-level radioactive waste, as developed and described, allows heretofore impossible combinations of shielding effectiveness, storage area and price.

The utilization coefficient of **space** occupied by an ES container measuring 600 x 800 x 800 mm with an internal volume of 372 dm^3 is 0.969. For a barrel 600 mm in diameter and 800 mm high, with an internal waste storage volume of 57 dm^3, if you include the lost storage space between barrels, the utilization coefficient of occupied storage space is 0.198; this means an ES container uses storage space about 5x more efficiently than a barrel.

If we recalculate stored low-level waste per **1 m^2** of floor space in barrels and containers, it is easy to ascertain that for example three layers of containers can store 2325 dm^3/m^2, while three layers of drums (storage height approx. 240 cm) only 475 dm^3/m^2; containers can thus store 5x as much radioactive waste per square metre.

If storage charges for a standard container unit (drum) were 100, the price per container (according to occupied volume) would be 133. This means that the existing storage cost of 1.75/dm^3 of treated radioactive waste would be reduced to 0.357/dm^3, thus to about 1/5. In other words, storage of 1m^3 of treated radioactive waste in barrels would cost 1754, while storage in containers only 357, resulting in savings of 1397/m^3. Yet another way of putting it is that under these conditions, storage of 1 m^3 in barrels requires 6.32 m^2 of floor space, while for containers only 1.29 m2 is required, i.e. one fifth. This also means transport costs of only one fifth as well.

The price of containers manufactured from high-grade materials is, of course, significantly higher than the price of existing barrel containers, made of the most common of materials. However, it would be a mistake to assess price only according to initial material costs. A comprehensive calculation requires one to consider all other circumstances related to the collection, transport and storage of radioactive waste, as well as the "performance" of both container types and their safety over the expected next several hundred years.

ES containers have a number of other secondary but not insignificant advantages, which are worth taking into account in a comprehensive evaluation.

Advantages in healthcare:

Large containers allow for the temporary storage of laundry, including bed linen, of patients who have undergone radionuclide therapy and whose laundry cannot be washed with other laundry due to its radioactivity. The container's easily washable surface permits its deactivation and if needed eventual disinfection. In palliative care facilities, containers can be used for temporary storage of volume waste, which can then be disposed of in conventional ways once they have ceased to be radioactive.

Medicine predominantly uses radiation sources with relatively low energy and thus low radiation penetrability, and short half life (several hours to several days) such as I-131, I-123, Ga-67, In-111 and TC99m, which can be kept in polymer concrete containers until their radioactivity has declined to a level where they can be released into the environment.

A large container makes it possible, in combination with smaller containers, to store radioactive waste on the spot in hospitals, without the need for "decay rooms" (as has been the case up to now), and thus makes it possible to better utilize building space.

Well-shielded small and medium containers make it possible to replace existing, often needlessly heavy and expensive, lead boxes (costing 30 to 40 thousand CZK) in facilities where radiopharmaceuticals are used. Their easy-to-clean surface makes them suitable for these applications. Aside from their lower price, their lower weight is also an advantage, making handling easier. Their building-block arrangement also allows one to better utilize storage space and if needed to achieve more effective shielding.

Its absolute impermeability, when combined with the use of a suitable sorbent, makes the large container usable for storage of significantly active liquid waste from radiotherapy facilities.

Advantages in industry:

A number of radioactive wastes in industry exhibit quite high activity and penetrating radiation. A combination of shielding provided by the combination of a large and small and/or medium container plus eventual shielding backfill allows for the storage of very high activities, for example up to approximately 100 GBq of Co 60.

For sources with less penetrating radiation or lower activity, a less expensive container with lower shielding capacity can be chosen. Up to 18 less penetrating sources, such as the often-used Am-241 radionuclide (with a gamma radiation of only 59.6 keV and alpha radiation energy of around 5.5 MeV) can be safely stored in one large container (in small containers) as opposed to current practice, where only one source can be placed in one barrel. In this schema, radiation sources are stored separately, with each one being protected by the impermeability of a small and large container. If local destruction occurs, the container's entire contents are not released into the environment, and all that happens is that activity is released from the affected small container. Even so, a double container provides better protection – it is in effect a double-engineered barrier. Unleachability is then guaranteed both by the properties of the small as well as the large container. For this use, existing storage regulations must be changed; this requires that a safety analysis be performed.

In nuclear power plants, ES containers primarily allow for more efficient use of storage space. Due to their large internal volume, they can for example be used to store, without any further handling, large parts of piping from the reactor's primary circuit and other pieces of waste whose dimensions exceed the internal dimensions of concrete drums used up to now. Optional combinations of shielding levels allow for economic optimization here as well. If sorbents are used, after required analyses are performed, liquid waste can also be stored, such as sludge or ion exchanger resin.

It is doubtlessly possible to find many other uses for engineered stone in various sectors radiation shielding. This material's advantage is that it can be used to manufacture elements of practically any shape, size or weight according to specific needs.

Below is a point-form summary of the objective advantages and benefits of the newly developed ES container or system of containers:

- provides incomparably greater shielding efficiency than existing concrete barrels;

- is easier and safer to handle thanks to container feet for forklifts and anchors for harness lifting equipment;
- allows for safe container stacking thanks to "locks" on their top and bottom;
- allows shielding to be optimized for the given application while minimizing radioactive waste storage and transport costs;
- allows for cost-efficient use of structures and storage areas;
- by lowering nuclear waste storage costs, particularly medical facilities can use radionuclides in a problem-free manner;
- enables use (temporary radioactive waste storage) inside buildings and directly within site facilities (in rooms) containing radionuclides;
- provides water impermeability and chemical resistance;
- provides a wide range of shielding levels by changing material composition while maintaining similar mechanical properties;
- provides a wide range of shielding levels using a combination of small, medium and large containers;
- eliminates wet processes (i.e. concrete work) during storage of radioactive waste in containers – any remaining space in containers is filled with a fine powdery mixture of shielding material;
- even despite high material costs, can result in extensive cost savings when evaluated in a comprehensive manner;
- the formulated material has excellent physical/mechanical characteristics and has long-term stability (measured in centuries) in terms of decomposition or destructive processes.

It can also be expected that the formulated material may become the basis for protection from ionizing radiation in areas other than the manufacture of containers and long-term storage of radioactive waste. Thanks to their high chemical resistance and absolute and permanent impermeability, these containers will doubtlessly also find applications for the permanent storage of various types of chemical, otherwise difficult to dispose of (including toxic) waste.