INNOVATIVE GAMMA AND NEUTRON RADIATION SHIELDING TECHNOLOGIES FOR MANAGEMENT OF HIGH-LEVEL, TRANSURANIC AND LOW-LEVEL RADIOACTIVE WASTES

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ABSTRACT

This paper presents innovative Gamma and Neutron shielding technologies (patents pending) for safe and efficient management of solid, liquid and sludge radioactive wastes, as well as mixed radioactive, hazardous radioactive wastes. These technologies, along with three formulated grout mixtures (Ca-Al cement, polymer-modified asphaltine complexes and complex polymer foams) offer unparalleled radiation shielding, ease of application and cost-effectiveness. Materials of these technologies have attributes and properties that merit for multifaceted application to different aspects of management of high-level, transuranic and low-level radioactive wastes, as well as to decontamination and decommissioning of radioactively contaminated sites. This paper discusses such attributes/properties, and the scientific and engineering basis for potential applications.

INTRODUCTION

Radioactive wastes, owing to temporal decay of radionuclides and emitting alpha, beta, gamma and neutron radiation, are extremely harmful. They can be solid, sludge and liquid wastes, and are of three types:

a) **High-level radioactive wastes** contain gamma emitting long-half life radionuclides, such as plutonium (Pu-238, Pu-239, Pu-240 and Pu-242) and uranium (U-234, U-235, and U-236). These are made up of solid, liquid and sludge waste forms, and include spent (or used up) nuclear fuel and wastes from commercial and defense related nuclear reactors resulting from reprocessing of spent nuclear fuel. Most spent nuclear fuel in the United States is currently located in pools of water, at nuclear generating plants across the country, to protect workers from radiation, as well as stored in large concrete casks.

b) **Transuranic (TRU) wastes** contain such radionuclides as californium Cf-249 - 252), americium (Am-241, 242 and 243), curium (Cm-242 – 250), neptunium (Np-235 and 236), plutonium (Pu-236-242) and berkelium (Bk-247 and 250). Some of these wastes are admixed with hazardous RCRA chemical constituents and are called TRU mixed wastes. Generally, these include solid, liquid and sludge wastes, and contain radionuclides that have more than 20-year half-lives. TRU wastes are generated by defense nuclear research and development activities, such as development and fabrication of nuclear weapons. TRU waste is usually classified as either "contact-handled" (CH) or "remote-handled" (RH) wastes, which are highly radioactive with high neutron and gamma radiation fluxes. CH-TRU waste emits mostly alpha radiation.

c) **Low-Level radioactive wastes** do not include high-level and transuranic waste materials. Most low-level wastes (classified by the NRC as A, B or C) emit relatively low-levels of radiation from radioactive decay of short half-life radionuclides, such as strontium-90, cesium-137, krypton-85, barium-133 and beryllium-7 and 10. Generally, these wastes have radioactivity that decays to background levels in less than 500 years and about 95 percent of the waste decays to background levels in about 100 years. Low-level radioactive wastes are generated by commercial and university laboratories, pharmaceutical industries and hospitals, as well as nuclear power plants. The low-level wastes include both solid and liquid wastes.

High-level wastes are very radioactive, which emit extremely harmful gamma (like x-rays) and neutron radiation. RH-TRU wastes are primarily gamma and neutron radiation emitters; consequently they require heavy shielding and must be handled robotically. CH-TRU wastes are also very radioactive, which emit harmful alpha, as well as neutron radiation. One of the main radiation hazard posed by this waste is through inhalation or ingestion. Inhalation of certain transuranic materials, such as plutonium, even in very small quantities, could deliver significant internal radiation doses. Among the transuranic wastes, RH-TRU waste presents significantly more radiation hazard than CH-TRU waste. In contrast, radiation emitted by the low-level radioactive waste is relatively less compared to that emitted by high-level and TRU radioactive wastes.

Exposure to gamma and neutron radiation associated with these wastes can induce chronic, carcinogenic and mutagenic health effects that lead to cancer, birth defects and death. However, thousands of tons of both solid and liquid radioactive wastes have been generated in the past and they will be continued to be generated in the future by commercial/private industries and government agencies. Unless they are safely and cost-effectively shielded, managed and disposed, these wastes may pose serious health consequences.

Generally, alpha radiation can be easily shielded by paper, skin or clothes; whereas, beta radiation can easily passes through paper, skin or clothes but it will be blocked by a thin layer of plastic, aluminum foil or wood. In contrast, gamma and neutron radiation is very penetrating, and neutron radiation is more penetrating than gamma. Gamma radiation can be blocked by heavy shielding materials such as lead, steel and depleted uranium; whereas neutron radiation can penetrate through heavy metal shielding and only engineered, specially formulated concrete blocks can stop penetration of neutron radiation.

Tens of thousands of metric tons of high-level radioactive wastes (Spent-nuclear fuels) are currently stored at nuclear power plants and DOE facilities across the country. Department of Energy’s Office of Civilian Radioactive Waste Management (OCRWM) is charged with identifying and developing a suitable site for deep geologic disposal of these wastes. The OCRWM is currently conducting research and testing to determine the suitability of the Yucca Mountain, Nevada site for permanent safe disposal of these wastes. In addition to these solid wastes, several tens to hundreds of million gallons of liquid and sludge wastes are also currently stored in aging underground/buried tanks at various DOE sites through out the country, which are leaking and causing or threatening to cause serious environmental problems.

Transuranic wastes, which amount to several tens of thousands of metric tons, are destined to be disposed into an already established geologic repository at WIPP site in Carlsbad, New Mexico. These transuranic wastes are made of contact-handled mixed radioactive, hazardous wastes and remote-handled transuranic wastes that are extremely radioactive with neutron emissions. Among the Low-Level radioactive wastes, there are three types of wastes: Class A, Class B and Class C. Class A and B low-level radioactive wastes are currently disposed in isolated shallow burial grounds and/or concrete vaults; where as greater than class C waste low-level waste require deep geologic disposal in specially licensed facilities.

It is essentially important to develop efficient management and disposal approaches/practices to cater to the current problems and minimize or eliminate the future problems. Management practices include handling, interim storage, solidification of liquid and sludge wastes, loading of wastes into storage and transportable containers or casks, and transport of containerized radioactive wastes (waste packages) to disposal sites and finally their long-term safe disposal. Decontamination and decommissioning of sites contaminated with radioactive wastes are also a part of the waste management.

These practices undoubtedly require safe, cost-effective and durable technologies and materials to manage radioactive wastes and to minimize or prevent those associated risks and problems, especially those from exposure to neutron and gamma radiation. Currently, prior to disposal, the radioactive wastes are stored in casks, canisters and other forms of containments with conventional, concrete-based technology. Generally owing to higher energy flux of neutron radiation, significantly thicker and denser concrete aggregate is required than that used for shielding of gamma radiation. Application of thicker and denser concrete grout to radiation shielding is generally costly and unwieldy, and it has limited application to safe handling, storage, transport and disposal of high-flux gamma and neutron radiation generating High-Level Waste (HLW), Transuranic Waste (TRUW) and mixed TRUW. In addition, management of radioactive liquids/sludge, and decontamination and decommissioning with concrete grout is prohibitively costly and very difficult. Similarly, lead-shield liners are being designed for containment of TRUW; however, this approach is neither cost-effective nor efficient and availability of adequate lead reserves for this purpose can be a problem. Furthermore, leaching of lead during post waste disposal period can pose environmental risks. Consequently, there is a real need for more efficient, durable and cost-effective technologies and materials that can enhance safe management and disposal of radioactive wastes.

INNOVATIVE RADIATION SHIELDING TECHNOLOGIES

The innovative technologies include: ***Gamma-Guard ^{TM} Radiation Shielding Technology*** **(patents pending)** and ***Neutron-Guard ^{TM} Radiation Shielding Technology*** **(patent pending).** The Gamma-Guard radiation shielding technology constitutes Gamma-Guard 20; Gamma-Guard 40 and Gamma-Guard 50 products. The Neutron-Guard radiation-shielding technology is made up of specifically formulated composites of various materials, which include Gamma-Guard products and variable amounts of other significant radiation-shielding materials (e.g., oxides/hydroxides of metals and non metals, and complex polymeric compounds) admixed with the abovementioned formulated grouts. Depending on a specific application, these products can be admixed separately with specifically formulated grouts - calcium aluminate cement, polymer-modified asphaltines or complex polymer materials (polymeric foam). Densities of composite Neutron-Gamma Guard bearing grout mixtures vary from 2.8 to 4.5 g/cm^3, depending on the type of admixture grouts. These technologies are developed to cater to the various needs of management of radioactive and mixed radioactive wastes, including solidification or immobilization of liquid and sludge wastes, and decontamination and decommissioning of contaminated sites. In developing such technologies, four main criteria are considered: **effectiveness of radiation shielding, cost-effectiveness, ease of application and long-time durability**. These technology products offer an unparalleled radiation shielding capacity for safe handling, storage and transport of radioactive wastes, as well as a significant potential for consolidation and encapsulation of solid, liquid and sludge wastes. These low-temperature technology materials can be a viable alternative to conventional or currently practiced technologies.

Scientific and Engineering Basis of the Radiation Shielding Technologies

In the following, salient scientific and engineering attributes of the Neutron-Gamma Guard radiation shielding technologies and their products are discussed along with some test results.

Attributes of Composite Neutron- Gamma Guard Products: The attributes are outlined in the following:

- These technologies are made up of low temperature products that are proven to be resistant to chemical leaching, non-corrosive, non-biodegradable, non-pyrophoric and environmentally safe. Results of TCLP tests on Gamma-Guard have demonstrated to exceed EPA standards (see Table I).
- The products are environmentally safe: minimizes dust, chemically resistant and durable under variable environmental conditions.
- They are compatible with various grout mixtures, such as specially formulated polymer modified asphaltine materials, polymeric foams and calcium-aluminate cements. These can provide desirable engineering strength and enhanced waste solidification and encapsulation, as well as an unparallel radiation shielding capability for safe handling and managing the radioactive wastes prior to their permanent disposal.
- Because of the elastic and thermal properties of the specifically formulated asphaltines and polymeric foam grout mixtures in the composites, they are self-sealing and impact/shock resistant, as well as thermally resistant, which can sustain radiation heat with out compromising their integrity. Their strong ionic exchange capability allows for binding of radionuclides and hazardous chemicals; thus rendering resistance to leaching and durability to solidified waste forms. Some of these grout mixtures have been subjected to TCLP tests and met or exceed the EPA standards. It has been found that the ionic bonding will not release gaseous contaminants if solute evaporation occurs. Thus, they can provide an effective engineering solution for long-term solidification or encapsulation of radioactive solid waste, as well as mixed radioactive liquid waste. Composite Neutron-Gamma Guard materials admixed with specially formulated calcium aluminate cement grout mixture has the potential to absorb radioactive gases from the

wastes. This is corroborated by the studies on iodine sorption mechanism on to mixed solid alumina and calcium cement by Toyohara et al. (see Reference 8) and on iodine species uptake by cement by Bonhoure et al. (see reference 1).

- Preliminary results of on-going engineering tests have indicated potential for reaching adequate compressive strengths (much greater than 600 psi) and structural integrity, as well as long-term durability. In addition to their capacity and potential for waste solidification and immobilization, these products, owing to composite Neutron-Gamma Guard materials, offer an unparalleled radiation shielding capability for safe handling and managing the radioactive wastes prior to their permanent disposal. Thus, use of these materials can easily facilitate compliance with the minimization of radiation effects as required by the NRC Waste Form Technical Position (see Reference 9).
- The asphaltine grouts with Neutron-Gamma Guard materials have extremely low diffusion coefficients, which can provide a strong barrier for diffusion of volatile radioactive gases, such as radon and iodine. Calculations, based on the worst case diffusion coefficient of radon-222 in asphalt materials ($3x10^{-13}$ m^2/sec) (see Reference 2), suggest that radon in the specially blended composites of formulated asphaltine based Neutron-Gamma Guard materials can migrate only to a linear distance of 0.035 inch in about a month; during which period, little or no radon will be left for migration owing to elapse of its 8 half-lives. In comparison, the diffusion coefficient of radon-222 in cement grout is $3.3x10^{-8}$ m^2/sec (see Reference 6), which translates to its migration to a distance of 11.52 inches/month. This suggests that composite Neutron-Gamma Guard materials blended with asphaltine grout admixtures can offer more radon shielding, as well as containment of volatiles in the radioactive wastes, than the conventional cement grout mixtures.

Table I. Results of TCLP tests on Gamma-Guard samples using 100 g of 0.1 N and 25% HNO_3 with 2 hour digestion at 80^o C

Sample	Barium (ppm)	Arsenic (ppm)	Selenium (ppm)	Lead (ppm)	Cadmium (ppm)	Mercury (ppm)
Tests with 100g of 0.1N HNO_3						
Gamma-Guard # 1	0.055	< 0.002	<0.001	0.173	<0.002	0.124
Gamma-Guard # 2	<0.004	<0.002	<<0.001	0.148	<0.002	0.050
Tests with 100g of 25% HNO_3						
Gamma-Guard # 1	0.013	<0.009	<0.004	0.217	<0.003	0.028
Gamma-Guard # 2	<0.011	<0.005	<0.004	0.165	<0.002	0.018

Note: Sample # 1 and # 2 are derived from 3- hour and 6- hour extraction- processing respectively.

The radiation shielding performance of the composite Neutron and Gamma Guard technology products: The radiation shielding performance of the composite Neutron-Gamma Guard technology products is based on analytical assessments by Duratek, Oak Ridge National Labs and by U.S. DOE Fernald Operations. Results of these assessments are explained in the following:

- According to Duratek, Gamma-Guard product aggregate alone have been proven to provide up to 25% more shielding (see Table II) in uniform mixed cement grouting applications for low, medium and high radioactive waste forms than the conventionally used grout products. As a result, the thickness of Gamma-Guard product aggregate required for shielding of a given gamma radiation flux from high-level wastes can be up to 25% less than that of the conventional concrete.

Table II. A summary of radiation shielding results of Tri-E Technology Gamma-Guard products admixed with concrete and fly ash, using MicroShield^{TM} Version 5.05) Shielding Code (Analysis by Duratech) (see Reference 4)

Energy Levels in Mega Electronic Volts (MeV)	% Decrease of gamma radiation with 19.5% Pb Gamma-Guard and 3.438g/cc (214.627lbs/ft^3) admixture density	% Decrease of gamma radiation with 40.0% Pb Gamma-Guard and 4.037g/cc (252.022lbs/ft^3) admixture density
0.5	16.3	24.8
1.0	13.1	25.1
1.2	12.9	25.2
1.4	12.8	25.4
1.6	12.8	25.4
1.8	12.8	25.5
2.0	12.9	25.5

Input Parameters: Initial exposure dose of 100 curies total activity source; concrete dimensions of 77 inches high and 74 inches diameter, 1 inch thick stainless steel container, and exposure rate evaluation at 36 inches from midpoint of the cylinder

According to Oak Ridge National Labs, the composite Neutron-Guard technology products have proven to provide up to 74 times more neutron radiation shielding and up to 35 times more gamma radiation shielding than any other tested shielding products (see Table III). As a result, the thickness of composite Neutron-Guard product aggregate required for shielding of a given neutron radiation flux can be up to 74 times less than that of the conventional concrete aggregate. Similarly, the thickness of composite Neutron-Guard product aggregate required for shielding of a given gamma radiation flux can be up to 35 times less than that of the conventional concrete aggregate.

Table III. A summary of neutron-gamma shielding results of Tri-E Technology composite Neutron-Guard admixtures as compared with other admixtures, using MCNP4C model (Analysis by Oak Ridge National Labs)(see Reference 7)

Tri-E Technology Composite Admixtures	**Neutron dose after exposure** (mrem/hr)	**Capture gamma dose after exposure** (mrem/hr)	**Direct Gamma dose after exposure** (mrem/hr)
Composite admixture A	26.2	0.3	2.8
Composite admixture B	23.5	0.3	2.4
Composite admixture C	2.8	0.2	3.2
Other Admixtures			

Hudson admixture	85.0	3.3	2.0
Mix #1	206.0	7.0	2.7
Mix #2	207.0	6.6	2.7
SNS admixture	118.0	2.5	1.4

Input Parameters: Initial exposure dose of 100 micrograms Cf-252 source (~ 800 mrem/hr). Cylindrical waste cask with inner length of 73 inches, inner diameter of 42 inches, wall thickness of 6 inches, bottom thickness of 6 inches and top thickness of 4 inches. Dose rates measured at the outer surface cylinder.

Fernald's virtual testing of specifically formulated complex polymer foam (Polyfoam) Gamma-Guard product has equally demonstrated not only the foam and Gamma-Guard compatibility but also the efficacy of admixture for shielding of gamma radiation. The results of the testing are given in Table IV.

Table IV. Results of testing by U.S. DOE Fernald Operations (see the Reference 3)

Gamma Energy KeV	Relative Attenuation (Count Ratios)		Mass Attenuation Coefficients		Flux Reduction (percent)	
	Control / Blank	Polyfoam Gamma Guard / Blank	Control Sample	Polyfoam Gamma Guard	Control Sample	Polyfoam Gamma Guard
123	0.77835	0.10620	0.28673	0.97749	22.2	89.4
238	0.81445	0.56081	0.23485	0.25212	18.6	43.9
583	0.83419	0.77026	0.20744	0.11379	16.6	23.0
911	0.87271	0.79014	0.15580	0.10268	12.7	21.0
1274	0.85996	0.84430	0.17264	0.07378	14.0	15.6
2615	0.89866	0.82124	0.12226	0.08585	10.1	17.9

Note: Tested materials: Control material with density of 0.032 g/cm^3 and Polyfoam Gamma-Guard with density of 0.084 g/cm^3. Test container diameter of 27.31 cm.

POTENTIAL APPLICATION OF COMPOSITE NEUTRON-GAMMA GUARD TECHNOLOGY ADMIXTURES

The composite Neutron-Gamma Guard admixtures, owing to their flexibility and compatibility to formulate and design with other materials, can provide a multifaceted application to different aspects of management of **high-level, transuranic and low-level solid, liquid and sludge radioactive wastes**, as well as **uranium-thorium mine and mill tailings.** Some examples of potential applicability of these admixtures to different radioactive wastes are outlined below.

Application to High-Level, Transuranic and Low-Level Radioactive Waste Management

- As an over-pack material/outer shell material, as well as inner-pack/liner material for waste bearing casks and containers replacing the high density concrete or lead for shielding the radiation from radioactive wastes in canisters/casks used for storage, transport and disposal. Thus reduces high-risk radiation area footprint (ALARA)
- For solidification, stabilization and immobilization of radioactive or mixed radioactive, hazardous liquid and sludge wastes and their constituents

- As thin film material for coating the surface of **high-level waste canisters, waste package containers and drip shields at Yucca Mountain Repository,** which can provide long-term prevention of metal corrosion and release of radionuclides to accessible environment.
- For grouting and coating of radioactive beryllium blocks for eliminating water infiltration and corrosion of the blocks
- For long-term encapsulation or entombment and containment of leaking radioactive waste storage tanks
- For construction of radiation shielding storage casks and surface/subsurface storage vaults of high-level and low-level radioactive wastes respectively.
- For mitigation of radon, iodine and other hazardous radioactive volatiles
- As material for radioactive decontamination and site decommissioning
- For grouting and coating of underground storage metal tanks and containers for eliminating water infiltration and metal corrosion
- For construction of radiation shielding vaults for storage of low-level-radioactive wastes
- For construction of bottom liners for waste container storage areas, as well as for low-level radioactive waste landfills

Application to Uranium-Thorium Mine and Mill Tailings and Sludge Management

- For long-term solidification and stabilization of waste sludge
- For encapsulation of mine and mill tailings and contaminated soils
- For construction of liners for mill and mine waste **landfills**
- For construction of liners for container storage areas, as well as for **low-level radioactive waste landfills**
- Application for mitigation of radon and other radioactive gases/volatiles
- Application for construction of radiation shielding vaults for storage of mine and mill tailings

COMPARATIVE ADVANTAGES OF THE INNOVATIVE RADIATION SHIELDING TECHNOLOGIES OVER CONVENTIONAL CEMENT GROUT TECHNOLOGIES OR OTHER EMERGING TECHNOLOGIES

The innovative radiation shielding technologies offer technological, economic and implementation/application advantages/benefits over other technologies, such as conventional cement grouting, vitrification and calcinations technologies. Examples of these comparative advantages/benefits are outlined below.

Technological Advantages

- The Neutron-Gamma Guard technologies are low-temperature technologies unlike high temperature vitrification, thermal plasma process, Synroc or calcination technologies.
- Conventionally, Portland cement-based grouts have been used for solidification/encapsulation of hazardous and low level radioactive wastes. However, this technology has shown to be effective only in case of situations where the salt loading is

relatively low (i.e. < 10%). In case of wastes such as the sodium-bearing radioactive waste streams (SBRW), where the concentration of salt loading is high, use of the composite Neutron and Gamma Guard admixture technology materials has advantage over Portland cement grout technology.

- Unlike any other technologies, including Portland cement grout technology, the Neutron-Gamma Guard technology products provide far superior gamma and neutron radiation shielding capacity. By virtue of the fact they provide up to 74 times more neutron radiation shielding and up to 35 times more gamma radiation shielding, the volume and thickness of the composite Neutron-Gamma Guard technology materials needed for radioactive shielding can be significantly lower than that of the cement grout; thus the technology offers a volume reduction capability.
- Vitrification technology being a high temperature technology has limited applications in the waste management, and has certain limitations. Some disadvantages of application of vitrification technology for the Hanford Tank Farm type of radioactive wastes are that they generate gases when vitrified, and their containment may require treatment in the off-gas system, which is costly. Certain metals such as mercury and cadmium in the mixed radioactive wastes can be difficult to incorporate into the glass-melt; as such, the technology reduces the product quality. In vitrification, incorporation of volatile constituents like iodine and assimilation of waste at variable pH are uncertain. In contrast, those problems are not expected with the composite Neutron-Gamma Guard technology because, the technology materials facilitate homogeneous ionic bonding of waste constituents, including gases, and because, the extremely low gas-diffusivity of asphaltine based composite Neutron-Gamma Guard admixtures.
- The innovative technology materials, with special additives, have the potential to accommodate immobilization of solid and mixed liquid wastes with variable forms, composition and pH conditions. In contrast, Portland cement grout at < 5 pH may weaken its mechanical properties owing to appreciable alkaline silica reaction (ASR). Additionally, minor waste components can significantly compromise the setting, strength and other engineering properties of cement grout products.
- The specifically formulated polycarboxylate polymer complexes (polymeric foam) are non-biodegradable and they can solidify significantly more liquid radioactive waste per pound of polymer than cement grouts and vitrification glass. Similarly, the composite Neutron-Gamma Guard with admixtures of specially formulated calcium aluminate cement grout mixtures can promote not only waste stabilization and encapsulation at variable conditions but also reduction in volume of waste forms. In addition, they can provide unparalleled radiation protection and maintain the required durable engineering properties.
- Composite Neutron-Gamma Guard bearing grout admixtures, by virtue of their significant radiation shielding capacity, can accommodate for enhanced physical and radiation protection with less wall/liner thicknesses and low volumes, without potentially compromising the structural strength compared to Portland cement grouts. Thus, they permit for more thermal loadings of storage casks and transportation containers with more transuranic waste and spent-nuclear fuel wastes at lower maximum temperatures within the current regulatory volumes and weight limits. For example, in the Sierra System, a 29-inch concrete wall/liner shielding for a storage cask is required, which translates to a wall volume of 977.5 ft^3 and a mass of 169, 684 lbs (see Reference 5).

With the composite Neutron-Guard admixtures, the shielding wall thickness can be potentially reduced at least by 40 percent and yet provide a better radiation shielding than the Sierra System concrete because, these admixtures have the capability to provide up to 74 times more neutron radiation shielding and up to 35 times more gamma radiation shielding than the concrete shielding products (see Table II). Consequently, the cask mass (170, 000 lbs) and volume (977.5 ft^3) can be potentially reduced by at least 40 percent (102, 000 lbs and 586.5 ft^3 respectively), which would facilitate more thermal loading or construction of smaller and more manageable casks.

- Unlike vitrification and conventional cement grout materials, the proposed technology materials have the potential for high impact shock-resistance with self sealing properties, which prevents the release of radioactive and chemical constituents, including, iodine, radon and other volatiles to the environment.

Application Advantages

- Use of composite Neutron-Gamma Guard materials in combination with formulated grout mixtures provide best management solutions for long-term safe management of **High-level, Transuranic** and **Low- level** radioactive solid, liquid and sludge wastes
- Use of composite Neutron-Gamma Guard technology materials for storage casks and as canister over-pack or inner pack or liners can provide a significantly more radiation shielding protection than any other conventional/currently used technologies (see Tables II, III and IV)
- They offer greater radiation shielding protection with significantly lesser density and thickness than the concrete products; consequently allowing for more thermal loading or construction of smaller and more manageable casks and canisters for storage, loading and transportation; all of which can be with in the regulatory limits of volumes and weights.
- They facilitate meeting the criteria of improved protection by reducing high risk radiation area footprint (ALARA)
- Facilitate excellent implementability: Provides flexibility and ease of application with formulation of tailored composite technology materials to cater to the specific needs of not only the management of solid, liquid and sludge radioactive wastes but also of decontamination and decommissioning of sites contaminated with radioactive materials
- The technology products can meet the requirements of structural strength, integrity and durability. Polymer modified asphaltine and complex polymer foam based grout admixtures, owing to their elastic properties, can be potentially high impact/shock resistant and self-fracture sealing.
- Use of composite Neutron-Gamma Guard technology admixtures can minimize the use of extensive matrix of metal-rebar or lead liners used in the current container/cask designs
- Application of Neutron-Gamma Guard technology admixtures for construction of storage cells or vaults for interim storage of thousands of existing and future waste canisters. They can potentially provide durable structures with appreciable greater radiation protection.
- Application, by spraying, of a thin layer of Neutron-Gamma Guard admixed with either polymer modified asphaltines or complex polymeric foam grouts onto the waste containers/packages and drip shields will have the advantage of an extra barrier that could lower the potential for long-term nuclear criticality in the repository by containing

the thermal perturbations of the waste-bearing containers and lower the potential for corrosion and leaching of waste constituents by seepage water during post-closure period of the repository. Furthermore, use of the technology materials as backfill could also augment the barrier potential to limit the infiltration of seepage waters into the waste packages. Thus, the barrier system can potentially reduce the release of radionuclides from the waste to the accessible environment. Similarly, application of these specially formulated composite Neutron-Gamma Guard grout materials as liners in the waste emplacement tunnels could potentially create barrier to incoming seepage waters.

- Application of Neutron-Gamma Guard technology admixtures to encapsulating or entombing and containment of leaking radioactive waste storage tanks can prevent environmental leakage of radioactive waste liquids/fluids and radiation exposure.
- As an over-pack material/outer shell material, as well as inner-pack material for storage casks and containers can not only provide significant radiation shielding but also enhance their long-term durability by minimizing their deterioration due to environmental factors.
- Using the technology products for grouting and coating of radioactive beryllium blocks could eliminate water infiltration and corrosion of the blocks
- When used for grouting and coating of underground storage metal tanks and containers, the technology products can provide not only protection against radiation but also eliminate water infiltration and metal corrosion.

In general, composite Neutron-Gamma Guard technology admixtures can facilitate environmentally safe management of radioactive and mixed solid, liquid or sludge wastes with desirable attributes; these include simplicity of application, non-corrosive to containers, physical stability and ruggedness, good compressive strength, thermal stability, good packaging efficiency, significant radiation shielding, physical protection, resistance to chemical leaching and long shelf-life. Thus, the Neutron-Gamma Guard technology products have potential for meeting the waste form requirements of 10 CFR Part 61.

Economic Advantages

Usage of composite Neutron-Gamma Guard admixture technologies have very compelling cost savings for DOE, DOD and commercial radioactive waste processors, handlers, packagers and storage providers, while providing significantly more protection from deleterious radiation. Depending on the type of application, it is estimated that the total cost savings can be as much as 61 percent when compared with the costs of conventional concrete or currently used technologies. Some examples of cost savings areas are given in the following:

- Significant economic benefits can be realized by replacing bulk volumes/thicknesses of conventional concrete with considerably lower volumes/thicknesses of composite Neutron-Gamma Guard technology admixtures in the storage casks and containers, transportation containers. According to IAEA criteria for storage and transportation of spent fuel, the casks have to be lined with heavy concrete (4.1 gm/cc density) with a wall thickness of 35 cm. For approximately the same shielding effectiveness, the composite Neutron-Gamma Guard technology admixtures with a density of less than 5.00 gm/cc would have a thickness of less than 20 cm. This difference will translate to reduction in dimensions and weight of casks, and consequent storage and transportation cost savings

- Potentially reduce the capital costs of high integrity storage casks /containers) and eliminate costly storage, surveillance and maintenance associated with on-site storage of high surface dose rate waste.
- Some cost estimates of application of composite Gamma-Guard technology admixture grouts in lieu of conventional cement grout mixtures in low-level radioactive waste storage and transport scenario indicated that the proposed technology composite admixtures can potentially reduce the total costs up to 61 percent (see Table V).
- Considerably reduce the costs of waste treatment, preparation, packaging and transportation
- Can significantly reduce the overall costs of decontamination and decommissioning activities
- Cost savings can be realized by using the technology products, in lieu of conventional concrete, for long-term solidification and stabilization of radioactive liquid and sludge wastes
- Using the technology products for a long-term encapsulation/entombing and containment of leaking radioactive waste storage tanks can minimize the environmental pollution; thus avoid prohibitively costly tasks of mitigation or remediation of contaminated soils, surface waters and ground waters.
- When used for construction of radiation shielding surface/subsurface storage cells/vaults for radioactive wastes, in lieu of conventional concrete, the technology products can be more economical.
- Can substantially contribute to reduction of overall costs of operating and management of radioactive wastes of different physical and chemical types, as well as of different levels of radiation.

Table V. Estimated cost savings of using Gamma-Neutron Guard technology materials in lieu of conventional concrete mixtures for management of LLW radioactive wastes in terms of containment, storage and transportation (Note: Cost data are obtained from DOE sites)

Containers	**Quantity**	**Price**	**Total Price**				**Total Per Cost Category**		**Totals Utilizing Gamma-Neutron Guard**
High Integrity Containers	8800	$6,600	$58,080,000				$58,080,000		$33,105,000 (43% Additional waste can be added per container by using Gamma-Neutron Guard Shielding Mixture = $ 24,975,000 Savings)
Container Parameters	180 Cubic Feet Per Container								
	100 lbs of concrete per cubic foot								
	18,000 lbs per container (180 x 100 = 18,000)								
Storage Costs	**Charge Per Cubic Foot**	**Cubic Feet Per Container**	**Storage Charge Per Container**	**Number Of Containers for Project**	**Total Storage Costs**				
LLW Base Disposal Rate	$22								
Cement Grouting Stabilization Charge	$100								
Mixed LLW Storage Rate	$220								
Total Storage Per Cubic Foot	$342 ($22+$100+$220)	180 cubic feet	$61,560 ($342 x 180)	8800 containers	$541,728,000		$541,728,000		$308,784,000* (43% less storage costs due to additional 43% waste loading per container. = $232,944,000 Savings)
Transportation									
Cost Per Truck Mile	$1.80								
Loaded Truck Weight	36,000 lbs.								
Trip Distance	2000								
Containers Per Truck	2 per truck								
Number of Shipments	4400 (8800 units / 2 per truck)								
Total Shipping Costs	$15,840,000						$15,840,000		$9,028,000 (43% less transportation costs, due to additional 43% waste loading per container. = $6,812,000 Savings)
							Project Total *Without* Gamma-Neutron Guard		**Project Total *With* Gamma-Neutron Guard**
							$ 615,648,000 (Containers + Storage + Transportation)		$ 350,917,000 (Containers + Storage + Transportation)
									$28,215,000 (Gamma-Neutron Guard Product Purchases, Add to Project Total Above)
Note: This Project Costing Model does not include any other standard operational cost savings, examples: labor, facilities, processing time resources, etc.									$379,132,000 (Project Total: Including Gamma-Neutron Guard Purchases)
							Total Project Savings =		**$236,516,000**

CONCLUSIONS

Neutron-Gamma Guard technology materials offer an unique potential and benefits for safe management of high-level, transuranic and low-level radioactive solid, liquid and sludge wastes, as well as for safe decontamination and decommissioning of contaminated sites. These materials have demonstrated unparalleled capacity for shielding of deleterious gamma and neutron radiation. The composite Gamma-Neutron Guard technology offers four performance advantages: high capacity for radiation- shielding, ease of application, durability and cost-effectiveness. The technology radiation shielding properties allow for more thermal loading and/or reduction in size and weight of storage, transport and disposal casks/containers or canisters. The technology materials can be easily modified or tailored to meet the requirements of a specific management application. While the technology materials warrant as a viable alternative to the existing cement grout technology materials, modification of their formulations may be required and further engineering tests may have to be conducted to demonstrate their compliance with the requirements of a given specific application. Preliminary calculations have shown that use of composite Neutron-Gamma Guard technology can save as much as 61% of the total costs of applying conventional cement grout technology for management of low-level radioactive waste, and these cost-savings can vary depending on the type of radioactive waste and application.

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