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Magnox Radioactive Waste Disposal Container

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1 Abstract

As the United Kingdom expands its nuclear power production, it will produce more radioactive waste and so research into its disposal is currently a big area. Though the use of current waste containers and advancement into increasing structural integrity of materials, a theoretical proposed design is produced in which accounts for current disadvantages posed by current container from radioactive waste collection, transport, storage and disposal and what types of waste is produced. Current materials and design features shape the final proposed design where safety and secondary containers influence its design, as to be single use container from the nuclear facilities to storage. The proposed design is designed to be stacked on top of each other to save space but to allow sufficient airflow and also have a replaceable exterior for removable of corrosion covering a honeycomb structure that improves the tensile strength of the design and explore carbon nanotubes which acts as a thin honeycomb layer and improves tensile strength and thermal conductivity. Errors arise due compact heat generation and radiation levels when stacked. Theoretical the proposed design is an acceptable solution to a future problem as the U.K's radioactive waste grows as to store the waste in compact areas.

2 Introduction

The United Kingdom currently operates a series of nuclear reactors generating around 19%-20% of its overall electricity [1] though some of these reactors are coming to the end of their safe operational life the U.K. plans to expands and increase its electricity generated by these reactors. Nuclear reactors although hazardous harness the power of the atom to extract a vast amount electricity over a substantial long period while consuming low quantities of fuel, however nuclear reactors produce highly radioactive waste and disposing of this waste is equally as hazardous. However nuclear reactors are not the only source of radioactive material, organisations and businesses also produce radioactive waste and so the U.K. must transport and dispose of this waste correctly and safely. In transport the waste is placed into special containers that are designed to hold hazardous materials however research into more secure and affordable containers is an ongoing endeavour as outlined in this project's brief;

> "The project is based on the disposability of radioactive waste from Nuclear Power Stations. Specifically the design of a suitably shielded robust waste container for intermediate and higher level active wastes that could be transported by road and rail to the UK Geological Disposal Facility. The project is to propose, design, model and substantiate a novel design for such a container using nuclear physics knowledge. Nuclear power in the United Kingdom generates around 19% of the country's electricity as of 2020, projected to rise to a third by 2035 and the disposability of radioactive waste is a big area of research in the UK currently." [2]

Due to construction restrictions, a theoretical design must be formed off of the handling of current nuclear waste in the U.K, in transport and disposal. Such a design will be new or obtain improvements of current containers currently in use, following the brief where the design is to conform to the standards of carrying intermediate and higher levels of nuclear waste from nuclear power plants. However some nuclear waste from these facilities such as spent fuel rods are deemed to valuable to be classed as waste so they undergo treatment through reprocessing and reusing the fuel [3]. Thus the proposed design should transport all forms of radioactive materials and those deemed as waste can be stored in the same proposed design, which limits the hazard to human life and the environment but also is cost effective. The proposed design is to be based off of current designs, focused heavily on turning the disadvantages of the current containers into advantages where the proposed model shows a solution to a future problem. The proposed design is formed to fit the current regulations and method of radioactive material disposal currently adopted by the United Kingdom.

3 Background of Nuclear Waste

3.1 Nuclear Waste in the United Kingdom

The United Kingdom generates 19%-20% of its electricity from eight nuclear reactors, though more are currently under construction to be operational by 2026-2030, half of its current power generation is set to be retired by 2025. Magnox Ltd which mainly supplies these nuclear reactors utilise AGR (Advanced Gas-cooled Reactors) that use graphite as its neutron moderator to slow down the fast neutrons so that the nuclear fission can take place and the coolant used is an inert gas such as carbon dioxide or helium.

Nuclear waste comes form all sectors across the U.K, however nuclear facilities produce the most waste and when a nuclear reactor is decommissioned due to aging or another hazard that poses serious risk, the materials on site are classed as HAW (Higher Activity Waste) and HLW/ILW (High/ Low Level Waste) as described in section 3.3. When nuclear waste is classified or put into categories the waste is then held at the facilities until transport routes can be determined where the waste will be transported to a recycling or re-processing facility or a storage facility. Nuclear waste that is classified as ILW or HLW must be store for years if not decades until safe to dispose of, this is due to the amount of radioactivity that the materials and objects encounter. HLW is sealed and stored for around 50 years before any further action is taken due to the serious hazard radioactive material presents and what type of nuclear decay the materials undergo [3].

3.2 Types of Nuclear Decay and Radiation

Nuclear reactors generate power from extracting energy that is released by forcing nuclear fission where an atoms nucleus breaks down and releases energy, though these radioactive fuels undergo decay to which are 4 main types: alpha, beta positive, beta negative and gamma decay.

Alpha Decay

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2} X' + ^{4}_{2} \alpha \tag{1}$$

Alpha (α) decay occurs when the element undergoes nuclear disintegration in which an alpha particle is created and emitted. The existing element loses two protons and two neutrons that are transferred to the new alpha particle in which the existing element is converting to another element which is two protons ans neutrons lower than the initial element [4] [5]. Its nuclear decay formula is located above in eq. (1).

Beta Decay

Beta decay is split into positive and negative decay, specified by either a proton or electron being emitted from the elements nucleus. Beta negative (β^-) decay is where an electron is emitted from the nucleus where it becomes a neutron leading to the nucleus have -1 electron and results in a neutron becoming a proton meaning the element has -1 electron and $+1$ proton. shown below in eq. (2) [4] [5].

$$^A_ZX \rightarrow^A_{Z+1} X' +^0_{-1} \beta^- \tag{2}$$

$$^A_ZX \rightarrow^A_{Z-1} X' +^0_{+1} \beta^+ \tag{3}$$

In terms of of beta positive (β^+) decay, a proton is emitted and changed into a neutron causing the element have -1 proton which is shown in eq. (3) [5].

Gamma Decay

$$^A_ZX \rightarrow^A_Z X' +^0_0 \gamma \tag{4}$$

Gamma (γ) decay is one of the most deadliest forms of radiation as it has the shortest wavelength allowing it to pass through virtually anything. When the nucleus enters a state of decay it doesn't actual decay in such that no protons or electrons are emitted from the nucleus, only photons which causes it to ionize other particles that come into contact with it. Its nuclear decay formula is shown in eq. (4)[5].

3.3 Types and Classifications of Nuclear Waste

There are three main classifications/ categories for nuclear waste: LLW (Low Level Waste), ILW (Intermediate Level Waste) and HLW (High Level Waste), although there are other types of nuclear waste such as spent fuel rods and household waste that are classified as HAW (High Activity Waste) and VLLW (Very Low Level Waste) respectively [6]. These categories can be separated by the amount of radioactivity an item holds, such measurements use units such as curies (Ci), Becquerel (Bq) and or disintegration per second of the decay of the nucleus, the unit used by the U.K. is in Becquerels where 1 Bq is equal to 2.703x10^{-11} Curie units (27 pCi) as 1 Bq equals that of 1 disintegration per second [7].

Low Level Waste

All of the nuclear waste that the U.K. produces 94% of radioactive waste falls into this categories where low level waste (LLW) specifies items such as: scrap metal, plastics and paper that contain a specific amount of radioactivity: no more than "4 gigabecquerel (GBq) per tonne of alpha (decay) activity, or 12 GBq per tonne of beta/ gamma (decay) activity" [6]. While its important to note that other LLW come from educational and business facilities that contribute to the high percentage of waste, a sub-catergory exist for LLW. Very Low Level Waste (VLLW) is generally for household items and materials from decommissioned nuclear reactors facilities, items include: building materials, contaminated soil, rubber and steel, any misc object/ material that is around but not in direct contact with radioactive material.

To store LLW, the containers used to be placed in concrete boxes/ vaults and then sealed, though nowadays the method involves pouring cement into the containers themselves and then placed into a sealed vault above ground. However some LLW and VLLW objects such as: plastics, paper, textiles and oils are incinerated at high temperatures so that only ash remains [3].

Intermediate Level Waste

Intermediate Level Waste (ILW) contributes to around 6% of the U.K's total annual radioactive waste, it's determined by exceeding the limits of radioactivity for LLW i.e. 4 GBq for alpha decay and 12 GBq for beta/ gamma decay. Objects and materials consider as ILW are: reactor components, graphite from the reactor core and by-products of radioactive treatments. Though ILW has a relatively high amount of radioactivity, ILW doesn't generate enough heat for it too be consider highly dangerous [6].

When ILW is stored it often undergoes treatment, in terms of cutting solids and solidifying liquids so to fill the maximum volume of the storage container. The containers consist of either 500 litre stainless steel drum barrels or $3m^3$ stainless steel boxes for small quantities, for where larger quantities are placed into boxes made of concrete, stainless steel or ductile cast iron. Storage of these containers occur at specific geological disposal sites where the structure of the underground rock geology provides a barrier for the mass of radioactivity that is to be stored, though the containers are placed underground, near the surface the radiation is constantly monitored and the containers stored according their radioactivity [3].

High Level Waste

Due to an objects radioactivity, the temperature can rise to a point where its hazardous and or extremely hazardous, these objects are categorised as Higher Level Waste (HLW). The temperature is a key factor in designing a container to transport HLW, however nearly all HLW consists of a by-product of reprocessing spent fuels rods that are in liquid form and thus the container must be sealed properly. HLW submit to long term disposal and thus only contributes to 1% of the U.K's nuclear waste [6]. When decommissioning a nuclear facility some waste falls under the term, Higher Activity Waste (HAW), these consist of operational parts to a nuclear reactor, reprocessing spent fuel and other objects which can either be recycled or re-purposed and wasted.

When storing HLW or HAW it goes through a process called vitrification where the by-product of re-processing the spent fuel rods is merged with glass to form a molten liquid which is stored in stainless steel container that hold approximately 150 litres of this liquid which when cooled takes a solid form and then can be stored. HLW currently is stored for 50 years before disposal for the radioactive material to enter a state of decay and cool down and then the initial container is place in two larger containers and then disposed of underground much like ILW [3].

3.4 Transport Containers for Nuclear Waste

500 Litre Drum

The 500 litre drum/ barrel is made out of stainless steel that is designed to store ILW. The ILW is stored in the drum and cement is poured in to solidify the radioactive material and the lid is bolted on for storage and disposal. Multiple features in the drum serve to preserve the material for long term storage: tubes are fed into the cement to remove excess water build up, anti-flotation plates forve the material into the cement and a filtered vent to allow built up gases to be extracted without the radioactive particle to escape.

The advantages of using the 500L drum is that water cannot erode the materials making them airborne so that the radioactive material can spread. The use of cement acts as an additionally containment for the radioactivity. Though the disadvantages of the drum is the size and space consumption in storage, the cylindrical shape allows space to be lost though provides sufficient airflow for air cooling and for the excess gases to escape. The position of the filtered vent on top of the cylinder means that drums cannot be stacked on top of one another meaning more space lost unless stored horizontally in which the excess gases may not fully escape out of the vent.

Steel Boxes

The Steel box design can come in any size and be made out of either steel or cast iron both have high melting points which are suitable for radioactive material storage that fit into ILW. The design of these containers for similarly to that of the 500L drums in section 3.4 where material is place inside and cement is poured in to solidify the contents. The circular lid is seals the contents in with multiple vents placed so that the excess gases produced can escape, this design is for materials larger than those that can be placed into the 500L drums.

The advantage for these steel boxes is that the walls can be lined with lead or graphite to increase the resistance of radioactivity particle penetration, the decaying materials wither cannot penetrate the lead or is lowered in intensity. Another benefit is the increased tensile strength of the design as it can be heavily reinforced making it safer for transportation and these boxes are also stack-able due to the raised struts on the corners allowing for compact storage without reducing airflow to the vents. The disadvantages of this design is that of its size and weight, though the physical dimensions can change per specification, storage of these boxes pose a long term disadvantage. The fact that these containers cannot be placed inside other bigger container is a further issue as the steel box can undergo corrosion and will become a safety issue where if one wall yields, the heat from the radioactive material will cause the steel to warp allowing gamma radiation (particles) to escape. To remedy this hazard, the steel boxes must be near to concrete boxes capable of housing each container which is logistically challenging and hazardous.

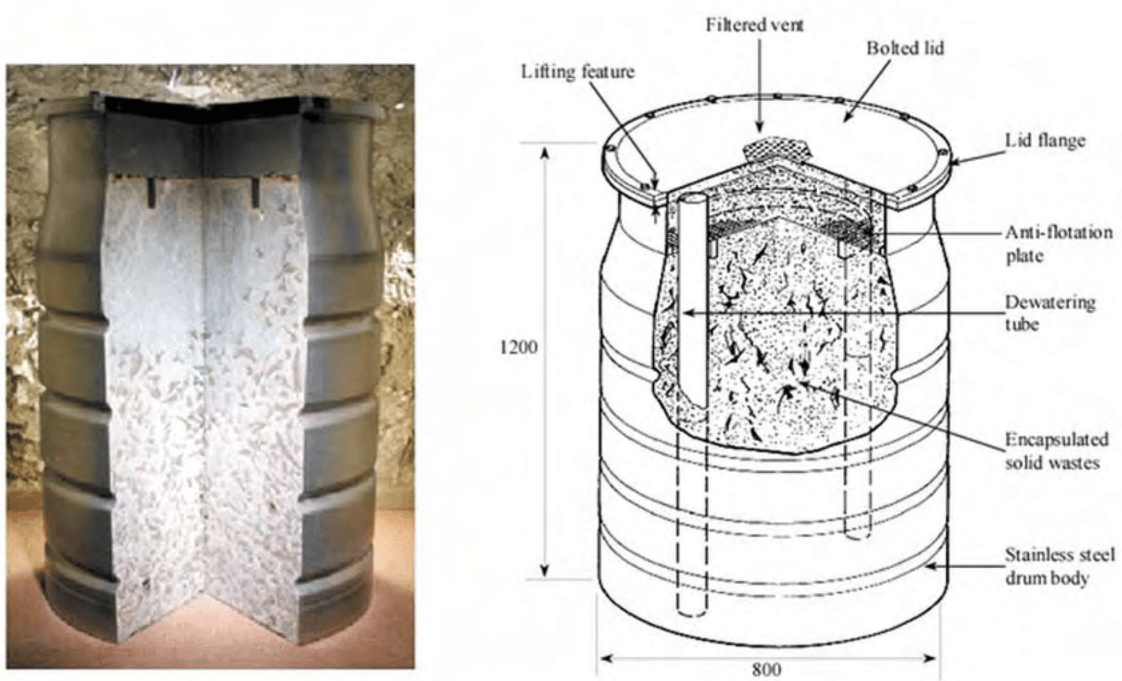

Figure 1: Cross-section of a 500L drum container labeled with materials and features [8].

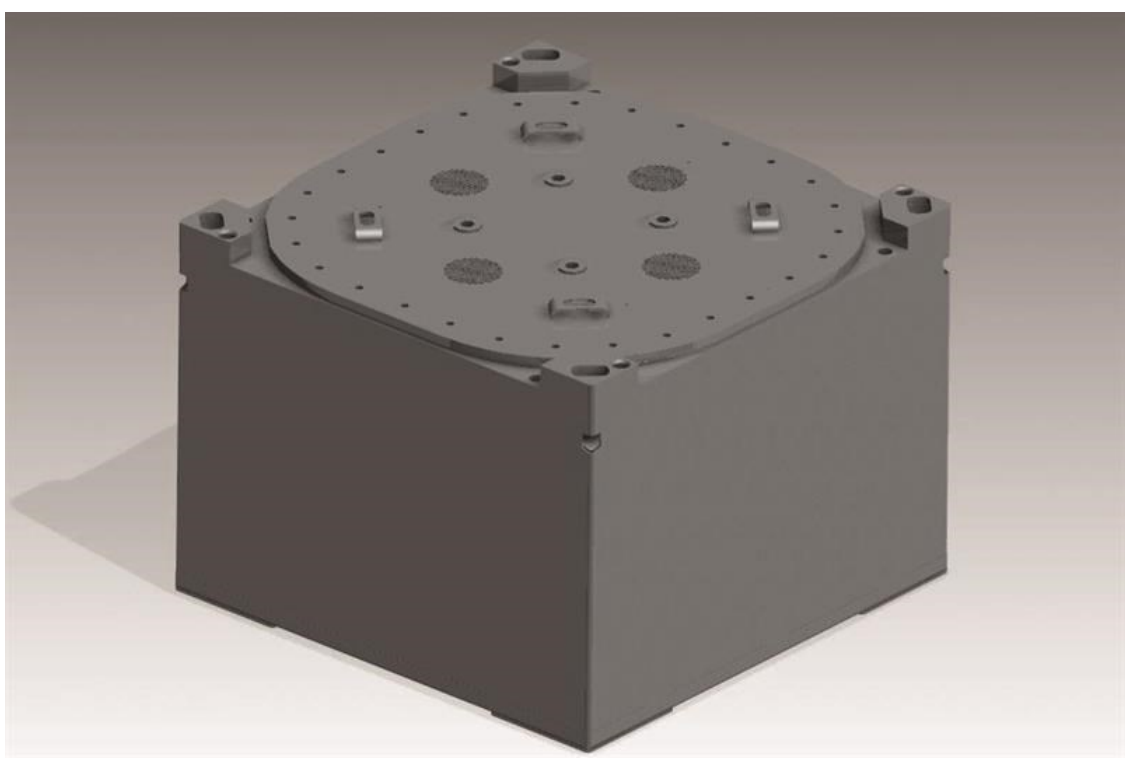

Figure 2: Design of a steel box container [9]

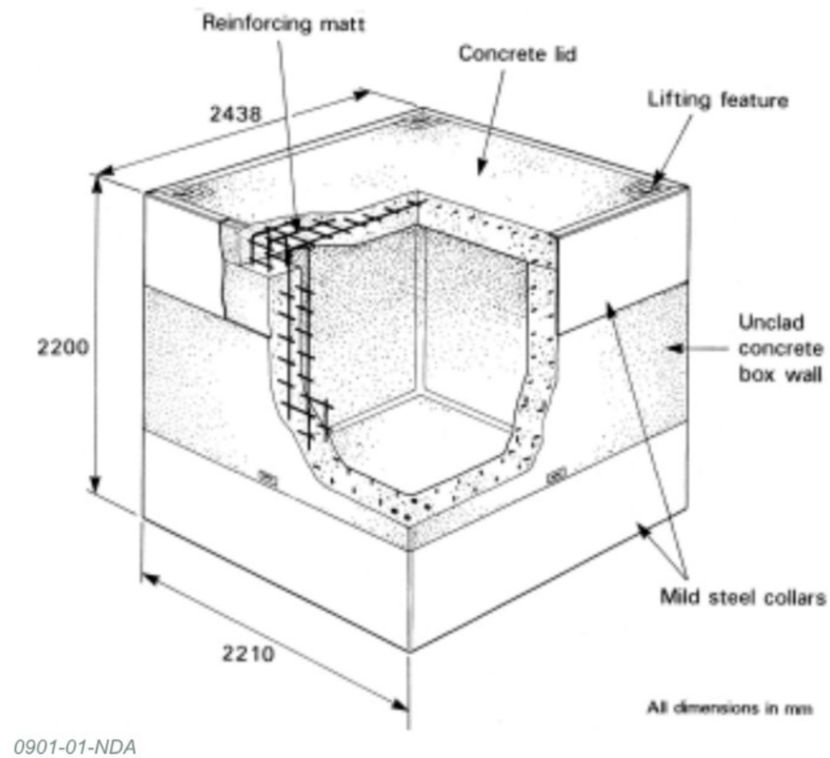

Figure 3: Cross-section of a concrete box container with its features labelled [10]

Figure 4: Cross-section of a Tru-Shield cylinder [11]

Concrete Boxes

Concrete boxes are designed for long term storage for HLW or ILW. These boxes are made from a steel frame in which concrete or high density concrete is moulded around it with steel collars to reinforce the corners, a benefit to this design is it can be lined with lead to reduce radiation penetration. The design in fig. 3 implies that the concrete box houses already shielded materials, containers and due to zero ventilation, inside the concrete box must be a vacuum to provide no moisture for erosion. In reference to space saving techniques, as the boxes do not require airflow for ventilation the boxes are stack-able [10].

Advantages of this concrete box is that it can change physical dimension per specification and isn't time-consuming to build and serves as a permanent above ground home for ILW and HLW. Disadvantages for this container is concrete is fragile to high impacts and is soluble so water penetration can cause corrosion to the containers stored inside the concrete box so its must stay above ground in a dry and sheltered environment. Furthermore concrete can crack allowing radiation to pass more freely through if the original containers inside are compromised [10].

Tru-Shield Cylinder

The Tru-Shield container serves as an additional shield for the 500L drums which is design to hold ILW. The design shown in fig. 4 shows a thick lead lining inside the stainless steel container and in addition further ventilation systems to further prevent radiation leaks, promoting safety in storage and transportation. These are not commonly used in the U.K, but exists to serve as a secondary container should the primary container fails i.e. a 500L drum [11].

The advantages of using the Tru-Shield is that is acts as a secondary barrier for a compromised container, it also acts as an extra safety net for if dealing with HLW. The disadvantages of this type of container is that due to the concrete box in which multiple 500L drum can be place if necessary this on contains one. This type of container serves as a temporary container for HLW due to its thick lead wall and added protection mechanics when added to the primary container.

4 Product Design

Initial designs fitting to the project brief in section 2 are formed based off of the current container models currently in use in section 3.4. The current containers describe the importance of how the radioactive material in stored though the containers consume space and therefore are impractical in the long term where space consumption poses a serious problem as the United Kingdom plans to expand its nuclear power source.

4.1 Design Ideas

The proposal is a container similar to that of the existing containers with space consumption in mind without sacrificing practicality, safety and effectiveness. The first problem to contend with is space consumption, many of the existing containers when stored or sent for disposal, waste space that could be used. The second problem is structural integrity during transportation and in storage, while a third concern is radiation exposure during the stages from extracting the radioactive materials from the nuclear power plants/ facilities to transport to unloading and processing to finally storage.

A hexagonal shape for the proposed container will allows for space saving either when the proposed design stand vertically or lies horizontally, geometry will allow the design to interlock. Though the design's size can be increased and decreased per specification of the radioactive waste load it will carry, two hexagonal barriers at either end to undergo the stress of the weight when the proposed design is stacked on top of each other. The two barriers will be larger than the interior hexagon in which the radioactive waste will be stored to allow for airflow for the built-up gases are able to leave the container.

Honeycomb Structure

A honeycomb structure consists of a material laid out in combined hexagonal or octagonal pattern that is placed perpendicular to that of the surface area of another material shown in fig. 5, the benefit is the improved tensile strength to weight ratio of the material. A weak plastic formed into a honeycomb structure has the same strength to weight ratio as that of a sheet of weak metal, the aim is to use a light and weak material and improve its strength by not altering the material by making it into a composite or an alloy but by changing how the material handles a weight/ impact that is now dispersed of a wide area instead of a localised impact causing the material to weaken and ultimately fail.

The advantages of the honeycomb structure is that a design can be given the tensile strength of a solid block of metal with only a fraction of the weight. The use of a honeycomb structure in this theoretical design is useful as to pair it to lead, steel, aluminium and iron, some of which are heavy materials that can replace the effect of strength and lower the weight of the container, improving handling of the container.

Carbon Nanotubes

Carbon nanotube utilise the same hexagonal shape that the honeycomb structure does however the diameter of each individual strand is in nanometers. Carbon nanotube are woven onto a material where the much like the honeycomb structure improves the tensile strength of the original material, they have high thermal and electrical conductivity and hold a low thermal expansion co-efficient. However the carbon nanotubing is highly expensive to produce as a continuous laser cuts away at a graphite sheet to from the structure when cooled. Another way is where two carbon rods are place end to end as an electtode where a direct under is placed upon the two rods and the soot that is expelled contains the carbon nanotubes [12]. The carbon nanotube is beneficial not only to the proposed design but as an improvement to current containers as multiple carbon nanotube sheets can be placed on the surface of a material and increase its thermal conductivity and tensile strength. A disadvantage though is that its expensive to produce and therefore counter intuitive as future container must be affordable as increase in radioactive waste creates high demand for such containers.

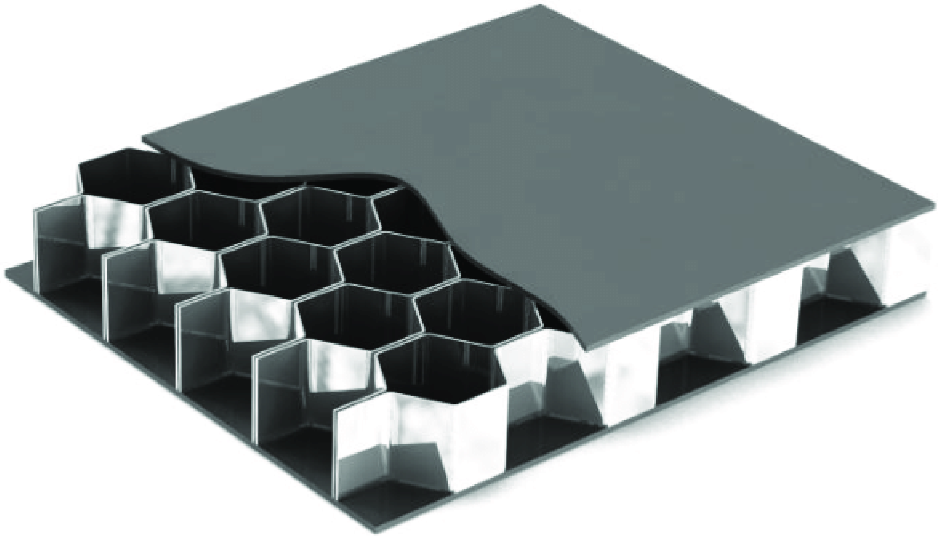

Figure 5: Visual aid of the implementation of a honeycomb structure [13].

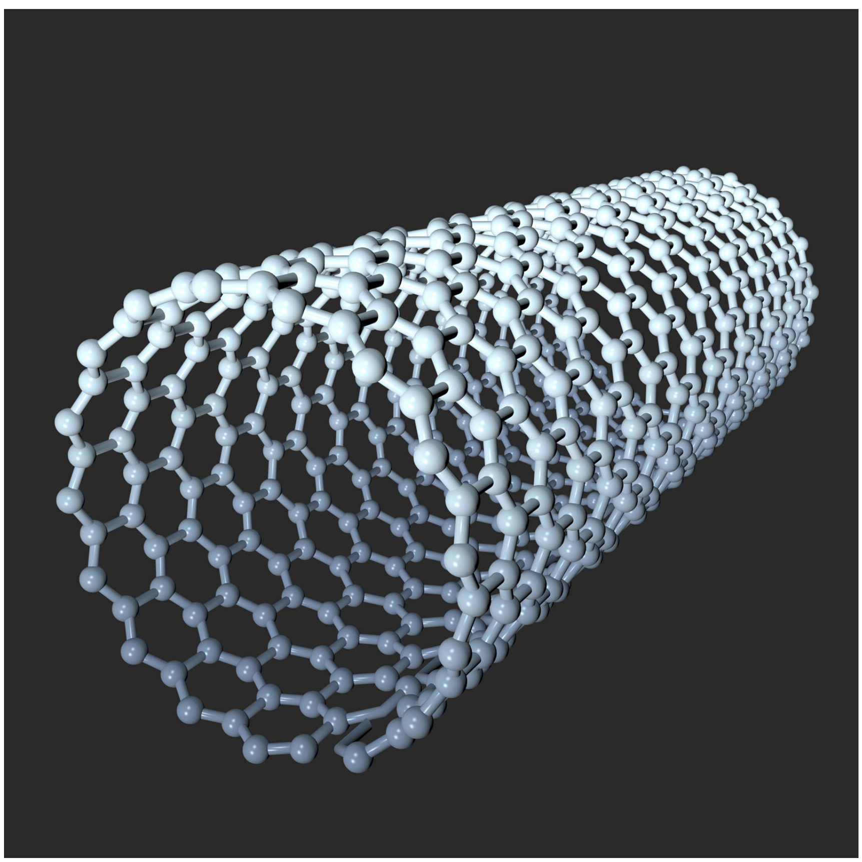

Figure 6: Illustration of a sheet of carbon nanotube [12].

4.2 Proposed Design

The proposed design is addition to that of current containers for radioactive materials that is formed off the basis of the 500L drum in section 3.4 and the Tru-Shield container in section 3.4. The use for the proposed design is that of instance storage where instead of the radioactive material being collected from the nuclear reactor facilities it's placed directly into the proposed design and then transported via rail or road to is treatment, storage and or disposal facility. The design for this type of transport limits the human interaction with the material as when the proposed design reaches the site its either filled with cement much like the 500L drum or put straight into storage. The proposed design can have the ability to be adapted to adopted lead plating to improve its radiation penetration resistance as proved in section 5 where it shows as lead is such a dense material it blocks most of the gamma radiation that tries to pass through it.

The proposed design shown in fig. 9 can have multiple openings whether it be vertical from the top where the lid can be screwed on and bolted in place much like the 500L drum or Tru-Shield. Another opening is horizontally where each side plate can be taken of similar to that of the lids and seals on concrete and steel boxes, where they are sealed on for long term storage. The orientation of the proposed design is how its to be stored and as each side plate can be taken off, the honeycomb structure as seen in fig. 7 can be filled with cement to further enforce the radioactivity resistance. Each side plate is connected to a steel strut running along the length of the proposed design as seen in fig. 8 to improve the tensile strength, its further allows for the honeycomb structure to be 100% effective. Sheet steel or aluminum is used as the external coat of the design as its malleable properties absorb the impact vibrations so not to damage to honeycomb structure that protects the integrity of the inner chamber that holds the radioactive material.

When ready for storage the proposed design can be stacked on top of one another whether it be horizontally or vertically shown in fig. 10. The current 500L drum are of circular design that can only be placed vertically due to the lid and vent placement on top of the container whereas the proposed design can can the opening placed at multiple points depending on specifications meaning it can be stacked vertically or horizontally. The inner hexagon in smaller than the two outer barriers promotes airflow no matter how the proposed design's are stacked on top on one another or side by side, this allows for more containers to be stored and less space to be wasted.

Inside the inner hexagon will fit a stainless steel cylinder than can be externally lined with lead where to improve radioactivity resistance, the steel cylinder will hold the radioactive material where with a lead coating, no or little cement is needed to lower the radioactivity of the waste, if no lead exterior the cylinder can be access either from the top or a side panel to which then it's ready for storage. Upon regular checks on container health and radiation checks, the side panels protect the container from surface contact: scratches, corrosion and water where the honeycomb structure and carbon nanotubes project the container from high strength external contact: rocks falling, other container hitting it and being dropped by a crane. What ever hazard the container faces, the externally skin can be removed and reprocessed and the physically dimension of the proposed design does not change where with current models, they are placed into larger containers with pose a future physical space issue.

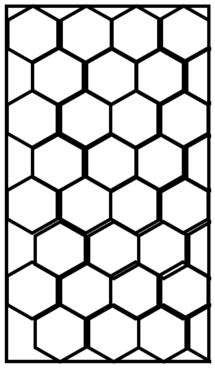

Figure 7: Layout of the side panel on the proposed design using a honeycomb structure.

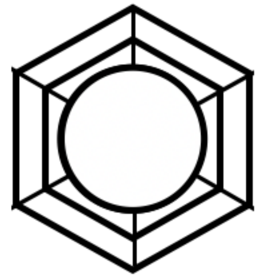

Figure 8: A birds eye view of the proposed idea when placed vertically, showing all 6 side plates and the 6 support bars connecting each side plate.

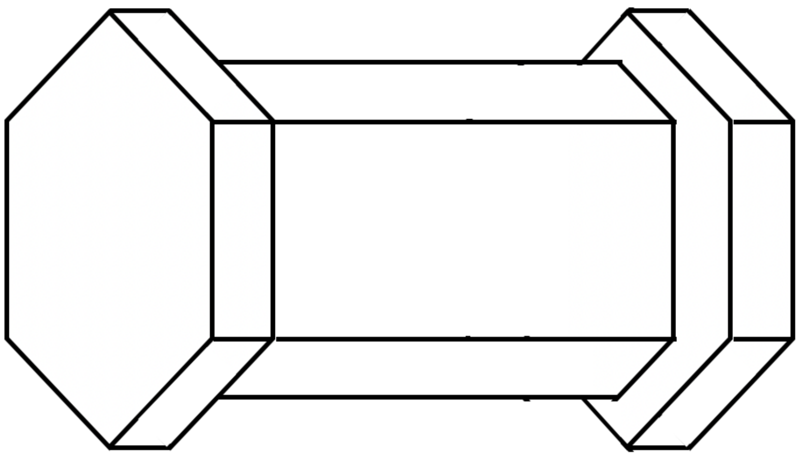

Figure 9: Proposed design shape and outline, can either be placed horizontally or vertically.

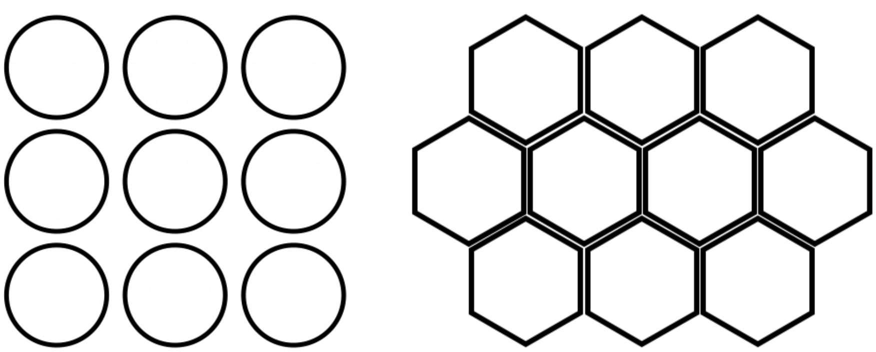

Figure 10: View of the current circular storage containers (Left) and of the storage of the proposed design (right) in either vertical or horizontal storage.

4.3 Relative Merits of the Proposed Design

Proposed Design Advantages

The proposed design can be stacked on top of one another or alongside each other as depicting in fig. 10, this saves space without restricting airflow due to the smaller hexagonal shape in the middle of the proposed design shown is fig. 9.

The radioactive materials can be place directly into the container at the nuclear reactor facility eliminating risk to human life. The proposed design isn't one fixed design, its customize straight from the factory in prediction for its plan in the future.

Furthermore the proposed design doesn't have to be placed in larger container to preserve the radioactive materials integrity whereas in the proposed design, new layers of sheet steel and aluminium can be applied thus maintaining the same sized container through tout its lifetime and only the exterior is affected.

As each side panel and the external metal surface is replaceable, it has the ability to use recycled materials and reused and re purpose old materials, thus this container has some sustainability.

Proposed Design Disadvantages

The proposed design is more complex than current containers that are centred around one single shape with minimal layers, making current designs easier to produce.Due to the ability to stack them, if corrosion in detect on a container at the bottom, all containers above need to be removed creating risk to human life.

If the proposed design is single use where the radioactive materials go into the design at the nuclear power facilites, the large proposed design much undergo transportation to the storage and disposal facility but 500L drum dues to the small size can be transported in greater quanitity.

5 Data Analysis

5.1 Lead vs Aluminium

Lead is a dense metal, which is why certain types of radiation cannot penetrate fully through, its also why lead makes for a good material to use for radiation shielding. An experiment [14] to measure gamma ray particle counts through lead and aluminium over time was conducted, where a decaying radioactive isotope Cesium 137 is suspended above various thicknesses or lead and aluminium to measure the particle count able to penetrate through the two materials. In **??** and fig. 12 shows the count for lead and aluminium respectfully where the experiment proved that the gamma ray particle count when the thickness of the lead material is increased lowers due to the highly dense material blocking/ absorbing the particles. Whereas with the material aluminium in fig. 12 shows minimal change of the particle count as the material thickness increases do to aluminium being less dense. The density of both materials is seen through their independent physical properties; lead is heavy and less malleable whereas aluminium is light and highly malleable.

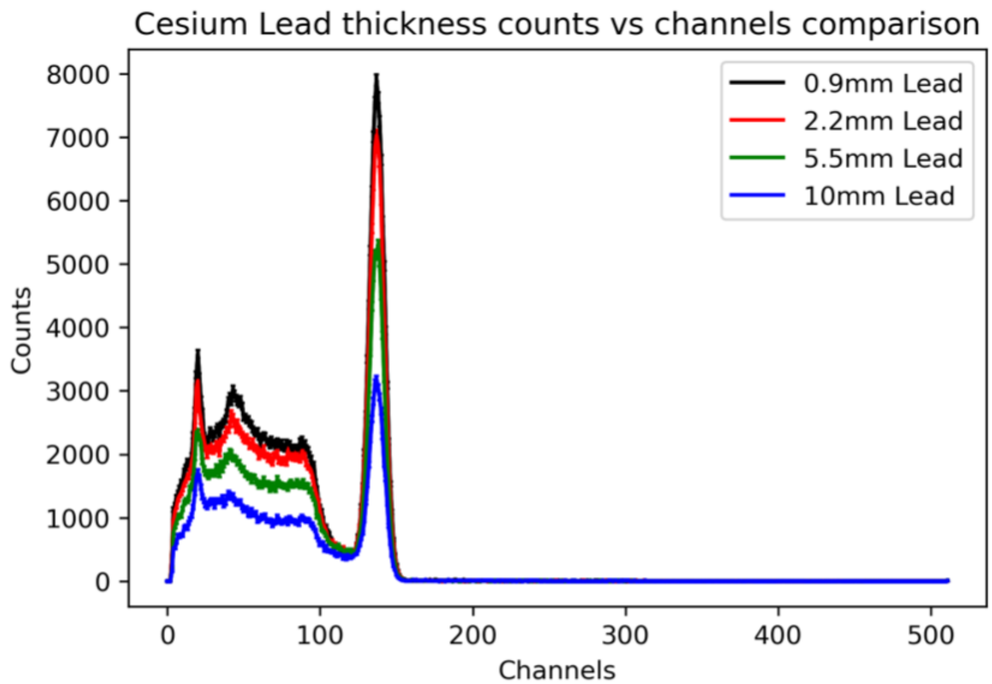

Figure 11: Graphical representation of energy counts vs time from Cesium 137 through various Lead thicknesses [14]

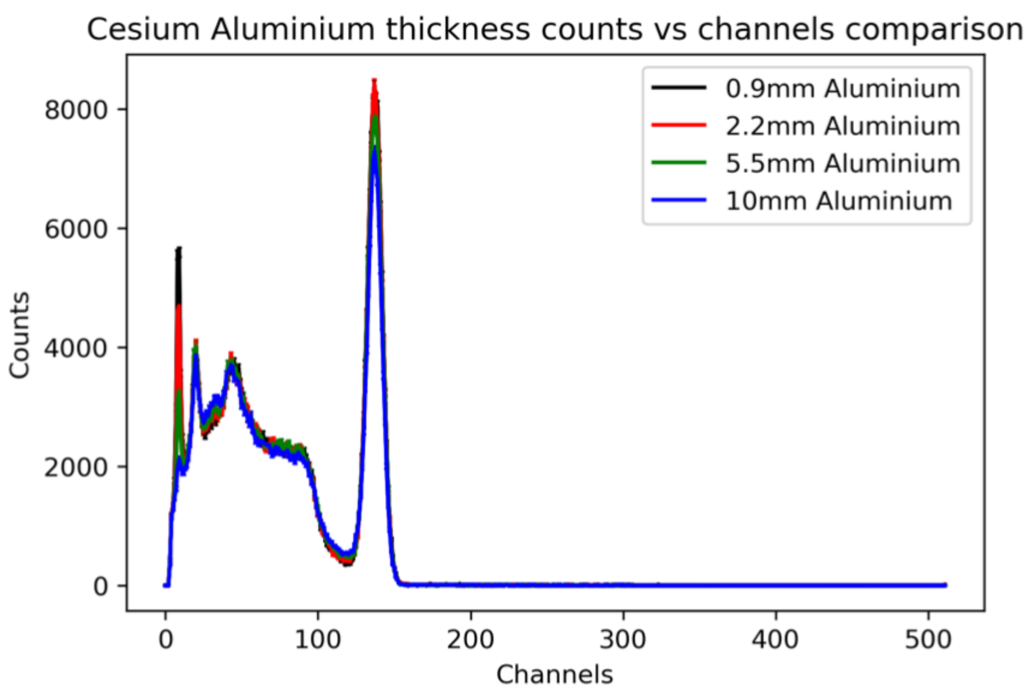

Figure 12: Graphical representation of energy counts vs time from Cesium 137 through various Aluminium thicknesses [14]

6 Error Analysis

As outlined in section 2, the proposal of a new design for a storage container for high and low level radioactive waste is that of theoretical design. This project relied heavily on research and design though error calculations could've been constructed through a random size model of the proposed design internal volume but due to the ability to have varied specification the error analysis does not support any evidence found.

Further analysis would focus highly on penetration levels for different materials and how the honeycomb structure stand against potential common hazard currently faced in the life cycle of nuclear waste. The size and measurement of the side plates and honeycomb structure will have to be cutting to strict tolerances as to provide a airtight seal in each joint so to avoid water infiltration.

7 Discussion

Though this project is 100% theoretical due to the restrictions upon testing the design in a real world situation, small laboratory experiments specific to the proposed design would have proven insightful and given clarity on the success or failure of the design and or shown areas of improvements needed. The design is based off of turning disadvantages of current containers into advantages where by highlighting design improvements or developing solutions to long term issues such as storage space. The United Kingdom has pledged a growth in nuclear power that will result in more radioactive waste as outlined in the project brief in section 2, where all radioactive waste will take years to be at safe levels until ready for regular disposal.

The issues raised in section 3.1 show that that nuclear waste must be kept away from the public due to its hazardous nature. Another problem arises where the United Kingdom doesn't have much land space especially if a container breaks or a storage facility collapses causing the landscape to become radioactive. This forces the design of these containers to consider space saving methods such as stacking containers on top of one another. The proposed design highlights this issue and bring a simple geometry solution much like the concrete boxes supply in section 3.4.

Further analysis of the proposed design could have been worked through a series of laboratory experiments measuring different levels of radiation penetration through different materials such as lead, aluminium, titanium and steel where these materials are placed in a honeycomb structure. Outline in section 5, a decaying isotope of Cesium 137 was used to measure such particle penetration and proved valuable in supplying evidence that lead is a good material for radioactive shielding. These measurements though inconsistent with the project outline due to the safety issues of radiation levels could have proven useful in determining how the honeycomb structure works with radiation penetration. Other experiments such to measure the tensile strength of a steel, aluminium and potentially titanium honeycomb structure to show which worked better while keeping weigh low and what's the ideal thicknesses of the walls of the honeycomb structure.

In summary, research specific into what exactly the U.K. does and the designs of specific containers were vague and so logical physical reasoning from other similar containers were sourced. The total sum of the project went highly well as outline in section 8 where current problems were isolated and addressed, future problems were derived through the statement that the U.K. is planning on expanding its nuclear power presence which will ultimately produce more radioactive waste where when dealing with radioactivity is still new and due to the hazard of radiation the waste must be stored for years if not generations. The brief was too design a container that could transport ILW and HLW materials however the question arises on how the U.K. can reduce it's radioactive waste as it expands its nuclear power stance. This can be done through limiting material exposure and further research into radiation retardant materials and clothing, though radiation truly limits what the mankind can do to limit, reduce and dispose of its radioactive waste.

8 Conclusion

In conclusion to the project brief outlined in section 2, current containers were analysed and the types of radioactive wastes that are handled through collection at nuclear facilities to transport to storage/ disposal and recycling/ reprocessing. Advantages and disadvantages were drafted per container that's currently in use with respect to the life cycle of the containers and an initial design was drafted to combat some disadvantages currently impacting radioactive waste disposal. Future issues such as space consumption for a projected increase in radioactive waste were also taken into account in the proposed designs.

The proposed design fixes space consumption issues while allowing for sufficient airflow allowing for the built up gases to escape the container and also allow for the containers to be air cooled, which matches the current 500L drum in section 3.4 but takes up much less space. The design has the ability to be customised in physical size and also the option for cement, lead lined walls and side wall plate replacements while not changing the physical size of the container. The ability to replace the side panels without exposing the radioactive materials allow for corrosion and materials weaknesses to be removed and replaced without having to put the container into a larger container much like the 500L drum being placed into a concrete box or a tru-shield container thus saving more space.

The use of a honeycomb structure to increase the tensile strength of a weak material such as aluminium where is can absorb external damage and easily replaced.The improvement of filling the holes in the honeycomb structure with cement improves it strength even further, the concrete box has a steel bar frame and concrete walls where it can become brittle or break where as an aluminium honeycomb structure will improve the tensile strength of the wall. The possibly use of the carbon nanotube to on the multiple surfaces would improve the tensile strength much like a honeycomb structure whereas carbon nanotubes and smaller allowing for space saving containers to gain further strength.

The proposed design theoretically works though requires further testing and analysis, the idea of a space saving container which can have parts replaced will continue saving space and saving money as placing small containers into larger one will no longer be required.

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10 Appendix

10.1 Magnox Mini Project Plan

Project Outline:

With nuclear waste within the UK on the rise, more nuclear waste is being made as the projection of power that is made by nuclear power plants is likely to increase in the next decade. The goal of this mini project in relation to Magnox nuclear waste is to design a cheap, strong, reliable and feasible container that will hold and transport nuclear waste. I will begin researching the type of nuclear waste the UK disposes of and how its currently transported and disposed of, then I will look at specific materials used to transport nuclear waste, why they are used and highlight positives and negatives of these methods. From this research I will begin designing and constructing the ideal container factoring in variables such as the intensity of radioactive waste against the type and size of the materials used in the container and what happens to the containers after transporting radioactive waste. By researching what radioactive waste is being disposed of and how it will get to the specified facility, I can specify what hazards the container may face without cracking, leaking or breaking the inner core that holds the radioactive waste.

As I cannot physically build and test such a container, I will gather data from scientific journals to show the penetration of gamma rays, x-rays, alpha and beta particles through lead. Through these values and my understanding of nuclear and particle physics I shall calculate numerous values for the tensile strength, weight, ray penetration (leakage), material degradation and other key factors. Ultimately, I shall have to prove mathematically that the container works.

My current theoretical proposal is a hexagonal container lined with lead core surrounded by a perpendicular titanium honeycomb inner wall, covered by aluminium or another composite material. Its proven that the thickness and quality of the lead wall greatly determines the penetration of gamma rays, which ultimately will affect the design of the container. The container should be as light weight as possible without prompting any hazards, the proposed titanium honeycomb wall shall improve the strength of the container and prevent deformation of the lead core and the aluminium / composite material will act protect the honeycomb structure from wear and tear, rust and other environmental hazards allowing the container to be built to last.

Magnox Nuclear Waste Project Timeline:

<u>Week 10:</u>

Initial mini project option selected. The construction of this project plan will act as a guide for this project and give weekly goals to achieve.

<u>Week 11:</u>

Basic research completed, construct multiple ideas for a container to work off of. The submission and finalisation of the project plan. The project report to be started and the project report introduction to be wrote.

Week 12:

Start research relating to the restrictions of the container such as materials, shapes, general design and thus a series of crude ideas and possible designs to be constructed. Thus, start the research in section the project report.

Week 13:

Finish all research and start looking at a series of ideal materials for the construction of the container, calculations of the containment of radioactive material through gamma ray, x-ray, alpha and beta particles penetration of the material will be used to prove the most ideal material.

Week 14:

Finish all research. Start finalising 2/3 designs and proving all positives and negatives and compare them. Proving through mathematical calculations of radioactive penetration and strength will be used to primarily judge which design is the best to pursue.

Week 15:

Complete all current sections in the project report (Introduction, research, designs). Continues with calculation proving that the chosen design work and is suitable for the task its design to do and hazards it will face. Investigate errors and develop a report of these errors and ensure these errors are within suitable parameters (previously researched).

Week 16:

Finish all calculations and finalise the design of the container allowing for the error analysis, complete the final design section in the project report include final calculations, schematics and errors.

Week 17:

This week is allocated to allow as a buffer week in case of any problems encountered throughout the project. If not, problems are encounter then it shall be used as a pre-finalisation of my final report and check of error analysis.

Week 18:

Finalise and check all research, calculations, errors, designs and report. Produce project analysis and conclusion. Submit project report.