Technical Feasibility of Storing 1 Month Old SNF in an Onsite Irradiation Facility – 14233

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ABSTRACT

G-Demption, LLC is developing a novel new addition to the back end of the fuel cycle with its onsite interim storage facility concept. This new addition allows extra value to be generated from the SNF by harvesting the gamma rays given off as the fission products decay. With this new technology nuclear energy will finally be able to complete the “Reduce, Reuse, Recycle” equation. The nuclear industry has long reduced the amount of waste produced by going to higher burnups/cycle lengths, we have reprocessed waste back into fuel for years, and now G-Demption is able to reuse the SNF as a source of gamma rays in an onsite commercial irradiation facility. Gamma ray irradiation services have always been in high demand but cripplingly low supply. G-Demption allows the tripling of commercial worldwide gamma ray supplies and such an increase in supply would not result in price destabilization, although G-Demption facilities could offer the irradiation services for cheaper than the current Cobalt-60 based irradiator fleet.

G-Demption’s SNF storage system is expected to be at cost with current dry storage technologies in terms of annual operating expense and construction costs however, when the sale of $15-20 million dollars worth of gamma rays per year is factored into the overall storage cost G-Demption quickly comes out ahead of current technologies. After remaining in the G-Demption dry storage facility for 6-60 years the SNF would transition back into the government’s long term geological repository or recycling program.

G-Demption technology relies on encasing SNF into thin containers on an individual fuel rod/fuel assembly basis and then spreading these containers out inside of a large open room filled with conveyor systems at the heart of a fortified facility. The thin containers focus on minimizing the shielding of the SNF which allows gamma rays to escape while increasing our ability to prevent fission product release to the environment. This is in stark contrast to the typical SNF storage philosophy of applying maximum shielding at all times.

The conveyor system brings products (such as one time use medical supplies, food, etc) into and out of the high gamma radiation zones around the SNF to deliver desired doses to the products. By spreading out the containers the decay heat can be much more efficiently removed by entirely passive heat rejection systems to the point of allowing the storage of 1 month old SNF. Spreading out the SNF also leads to a high neutron leakage fuel arrangement that greatly enhances criticality safety and reduces operational expenses. The act of encasing the SNF into individual containers provides extra fission product barriers to the environment for increased safety.

This paper will detail the calculation methodologies used to prove the feasibility of safely and economically storing month old SNF inside of G-Demption containers. This will include results from heat removal calculations and results from usable gamma ray source intensity studies. Detailed illustrations of the G-Demption container design and G-Demption irradiation/dry storage facility design will also be included.

Background:

The gamma ray irradiation industry uses nearly $1 billion dollars worth of gamma ray sources primarily for sterilizing one time use medical supplies, irradiating food, and changing the material properties of plastics; however the growth of this industry has been stunted by a stagnant supply of gamma ray sources.

The nuclear power industry has long been searching for an answer to the question of “Nuclear power seems great, but what will you do with all the waste?” from a public relations standpoint. But also from an economic standpoint the interim storage of SNF and the political quagmire between DOE, NRC, and Utilities is an issue in desperate need of resolution.

INTRODUCTION

G-Demption, LLC is developing a novel new addition to the back end of the fuel cycle with its patent-pending onsite interim SNF storage facility concept. This new addition allows extra value to be generated from the SNF by harvesting the gamma rays given off as the fission products decay. By producing a revenue stream from the sale of irradiation services the SNF is able to pay for itself during the interim storage of SNF onsite at nuclear power plants. This helps eliminate the political quagmire of SNF storage because whereas previously a nuclear power plant could expect to spend over $200 million dollars on SNF storage costs during the lifetime of the plant, now they can expect to make an overall profit from the onsite storage of SNF. The SNF storage facility provides inexpensive interim storage, enhances the availability of gamma ray irradiation services, creates local jobs, eliminates the need for a national interim storage facility, and affects the publics perspective of nuclear power in a positive way.

The goal of this paper is to explain the feasibility of this design concept. Included will be a brief overview of the design concept, results from usable gamma ray source intensity calculations, results from heat removal calculations, an overview of the anticipated regulatory framework, and an economic analysis.

BRIEF OVERVIEW OF G-DEMPTION DESIGN CONCEPT

The new SNF storage facility concept revolves around the idea of individually placing SNF assemblies or SNF rods into thin (approximately 1cm thick) Aluminum containers which prevent the escape of fission products into the environment, but allow a significant fraction of the gamma rays produced in the SNF to escape. The Aluminum container is filled with a resin which hardens and encases the SNF in a pseudo-glassification process which further mitigates fission product migration into the environment [note that embodiments of the design which fill the container with air, vacuum, nitrogen, water, etc are possible]. The Aluminum container is then sealed and is now essentially a sealed gamma ray source which can be referred to as an “SNF Bearing Container”. Because of the high thermal conductivity of the Aluminum in the SNF Bearing Container it is advantageous to create a thermally conductive pathway for heat to travel away from the SNF and this is accomplished by coupling the SNF Bearing Container to a long Copper or Aluminum rod which is referred to as a “Thermal Conduction Element” which is essentially a fin. The thermal gradient between the SNF and the Thermal Conduction Element drives the efficient rejection of heat to an external environment such that the SNF stays well below regulatorily defined temperature limits during SNF storage and transportation to prevent cladding degradation.

This SNF Bearing Container is then transported to the SNF storage facility however this new storage scheme presents unique challenges and opportunities during the transportation and storage process [note that an onsite storage scheme is described in this paper but the concept could be applied at locations off of the nuclear power plant site]. Since the age of SNF dictates the intensity of the gamma ray signal the new storage concept attempts to use much younger SNF than current industry standards. The gamma ray intensity and economic analysis seen later in this paper assume the use of SNF that has been discharged from the reactor only one year prior to being placed inside of the SNF storage facility. However the use of one month since discharge from reactor SNF is viewed to be technically feasible and economically desirable in the context of this new storage scheme. The idea of handling such young SNF is not unheard of from a technical standpoint, however the idea of making the transfer from fuel pool to dry storage occur with such freshly discharged SNF is unique to this storage concept. Others have posited the acceleration of SNF to dry storage in the wake of Fukushima however this was still in the realm of 3-10 years since discharge from reactor. The reason this storage scheme can accomplish such aggressive timelines comes from the concept of using a much lower SNF storage density than traditional drycask storage such that there is more room for heat dissipation during storage and transportation. Lower density means more trips to transport the equivalent amount of SNF and this can be deemed as more expensive than traditional dry storage however something to keep in mind is that this is all to facilitate the generation of revenue from the sale of gamma rays and when this revenue is taken into account one is able to spend more on SNF transportation/operations while still coming out ahead overall economically.

The much lower SNF storage density inherently prevents criticality accidents without an overreliance on neutron poisons due to the high neutron leakage geometry. Since criticality accidents are now a much less likely scenario, compared to traditional SNF storage and handling techniques that use high density packing arrangements, much of the complicated criticality analysis work, test handling runs, mockups, etc can be avoided and the process of handling SNF becomes much less risky, complicated, and expensive because it becomes more routine and streamlined.

Minor modifications to existing dry cask transportation equipment and techniques may be implemented to enable the transportation of SNF with higher thermal heat loads on a more frequent schedule. The obvious solution being to simply transport one fifth of the normal capacity of a typical transport container, if each SNF assembly is now five times as thermally hot, to stay under your rated thermal limits of the transportation container. A more novel solution proposed in this concept [and seen in Figure 1] is to transport SNF Bearing Containers rather than SNF assemblies. Since the SNF is already encased inside of a sealed container it is possible to credit this container as the main barrier to fission product release into the environment. By coupling Thermal Conduction Elements to the SNF Bearing Containers and placing penetrations in the top of the shielded transport container that are aligned above each SNF Bearing Container the Thermal Conduction Elements are able to stick out of the shielded transport container and allow the heat generated by the SNF to directly travel up through the Thermal Conduction Elements and out into the environment while still preventing high radiation areas from developing outside of the shielded transport container.

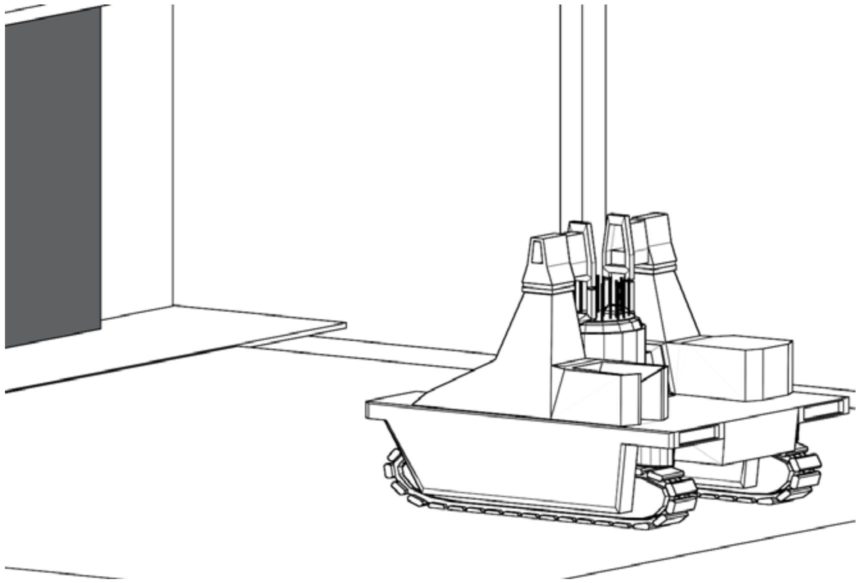

Figure 1: Modified Dry Cask Transportation Vehicle Concept

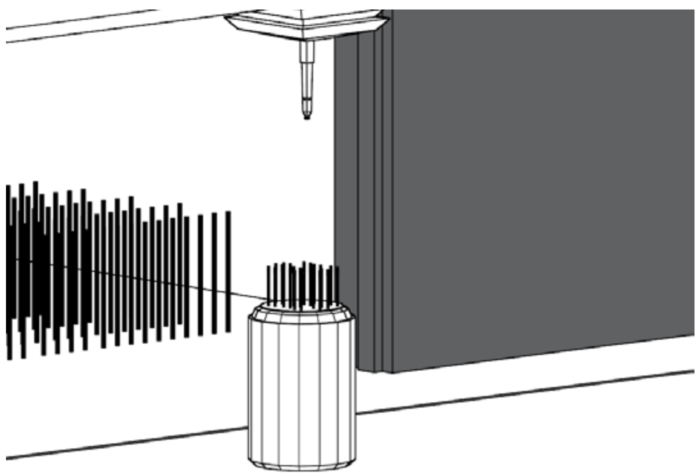

Figure 2: Overhead Crane set to maneuver SNF bearing containers from their transportation cask to their position in the Irradiation Facility. Thermal Conduction Elements for passive cooling are also visible in this picture as illustrated by black rods.

The shielded transport container and the SNF Bearing Containers within it are transported to a transfer bay outside of the SNF storage facility which contains several remotely operated overhead crane systems that are used to quickly transfer SNF Bearing Containers into their respective positions inside of the SNF storage facility.

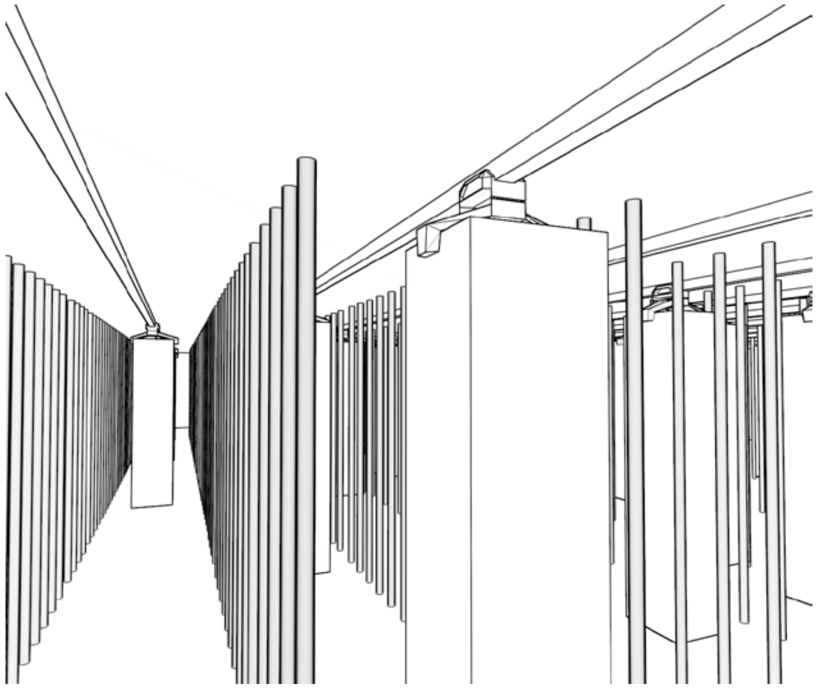

Figure 3: Independent overhead conveyors transport products between rows of SNF bearing containers in the Irradiation Room.

During normal operation the SNF Bearing Containers reside in a level of the SNF storage facility referred to as the “Irradiation Room” which contains conveyor systems which transport products into and out of the Irradiation Room as seen in Figure 3. The rows of SNF Bearing Containers are spaced roughly 0.5-1 meter apart and provide an even dose of gamma rays to the products being transported through the rows of SNF Bearing Containers via an overhead conveyor system.

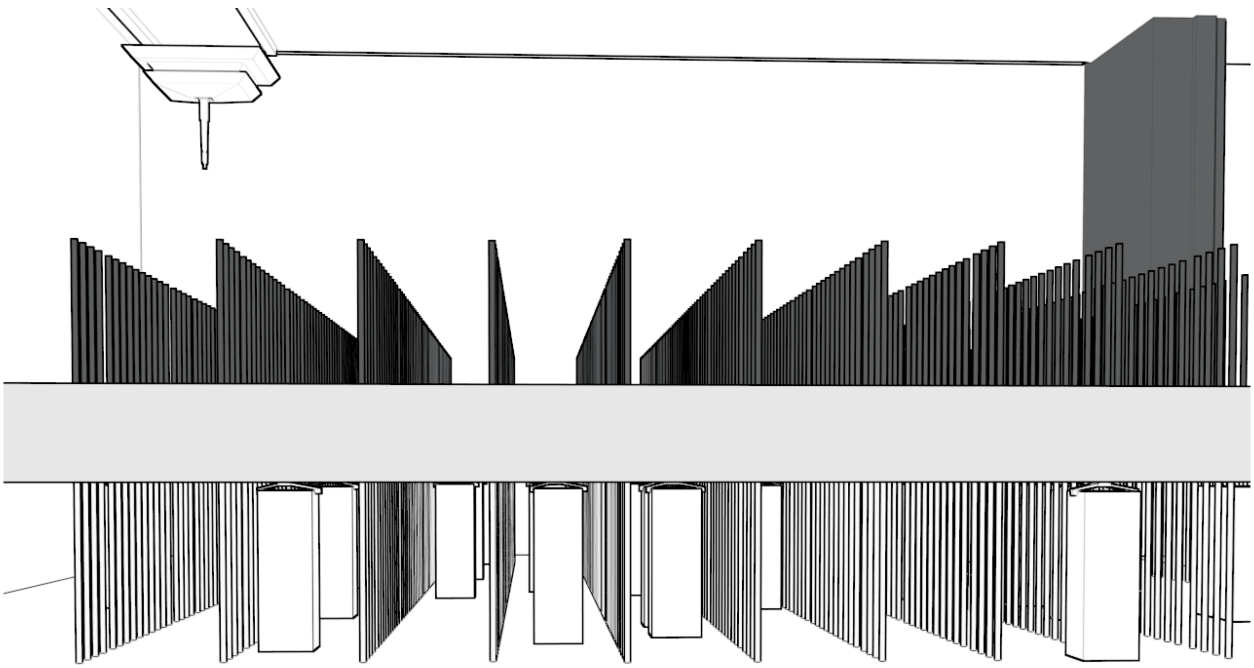

Figure 4: Cutaway view of facility with top level and irradiation room level.

Referring to Figure 4 the majority of the SNF storage facility can be seen. The top level of the facility houses the overhead crane systems which perform fuel handling operations and is also the area where Thermal Conduction Elements are located. The Thermal Conduction elements are coupled to the SNF Bearing containers and protrude out into the top level of the SNF storage facility through penetrations in the roof of the Irradiation Room such that heat is transported from the SNF to the top level of the facility where air cooling is sufficient to passively and indefinitely cool the SNF. The roof of the Irradiation Room provides sufficient shielding to allow personnel to access the top level of the facility.

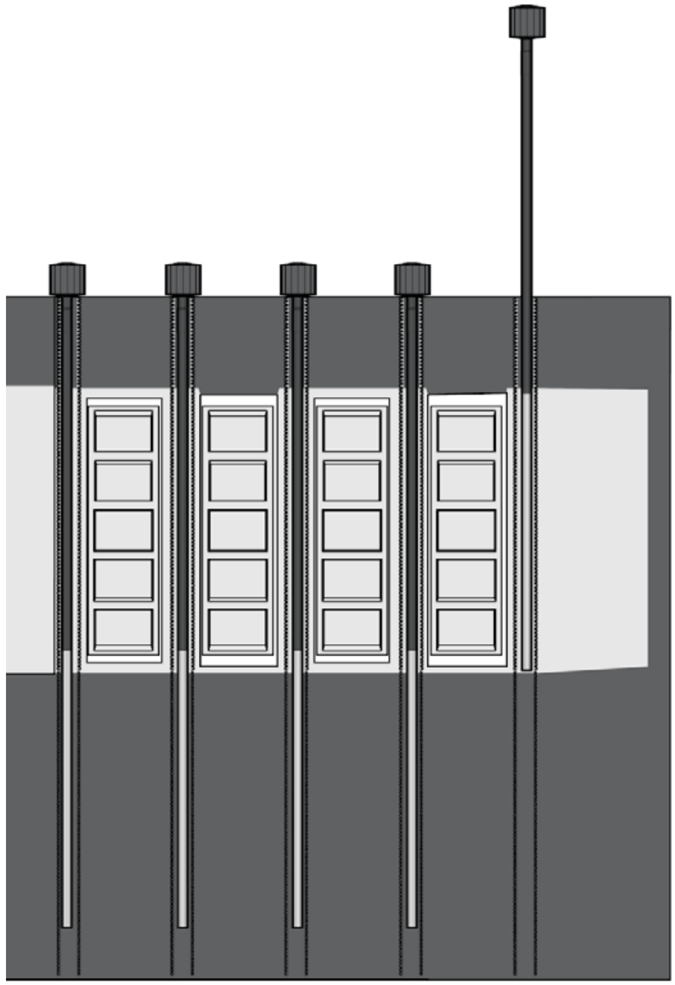

Figure 5: Illustration of bottom level of the facility for reducing radiation levels in the irradiation room. It also illustrates the full range of motion of SNF Bearing Containers (white cylinders) and their attached Thermal Conduction Elements (black cylinders)

There is also a bottom level of the SNF storage facility which is illustrated in Figure 5 that allows radiation levels in the Irradiation Room to be substantially reduced to allow maintenance on the overhead conveyor systems if necessary by lowering the SNF bearing containers into small borehole storage areas. The Thermal Conduction Elements are sized such that the SNF Bearing Containers can be fully lowered into the lower level of the facility and still be able to transport heat generated by the SNF to the top level of the facility via thermal conduction. The use of Copper in the Thermal Conduction Elements acts as a gamma shield that reduces streaming of gamma rays through the Thermal Conduction Elements.

The amount of space the facility occupies varies based on the embodiment of the design concept. For example, if the SNF Bearing Containers each only store a single SNF rod, such that the maximum amount of gamma rays can be harvested, then 3 refuelings worth (approximately 45,000 fuel rods) can be stored inside of an area of 1,500 m^2. As another example, if the SNF Bearing Containers each contain an entire PWR fuel assembly then 50 years worth (roughly

1,500 assemblies) of SNF can be stored inside of a 440 m^2 area. Another embodiment features storing 6 years worth of PWR fuel assemblies in a 70 m^2 area to create a roughly 3 MCi Cobalt-60 equivalent irradiator. As a reference, a typical dry cask storage pad takes up about a 1,850 m^2 area.

A product processing area is located behind a labyrinth shielding structure such that workers can load and unload the products from the conveyor system easily after the products have been transported through the Irradiation Room and treated. This product processing area and any associated office buildings would increase the footprint of the SNF storage facility at the power plant.

USABLE GAMMA RAY SOURCE INTENSITY CALCULATIONS

To determine the overall usability of the gamma ray signals coming off of the SNF Bearing Containers we sought to confirm that the gamma ray energy spectrum was high enough on average to effectively sterilize large packages of products, then to determine if the neutrons emitted by the SNF would substantially damage the products that are being irradiated, and finally that a large enough amount of gamma rays are able to be harvested to make this exercise worthwhile economically.

To begin it was noted that the average energy spectrum of the gamma rays emitted by the SNF was above 0.66 MeV which is the energy of gamma ray emitted by Cs-137. Since Cs-137 has been used in gamma ray irradiation effectively in the past it was concluded that the SNF gamma ray spectrum would be effective as well.

In regards to neutrons damaging the products undergoing gamma ray irradiation it was found that the neutron emission rate is dependent on burnup and time since discharge of the SNF from the reactor. In the worst case scenario the amount of neutrons emitted per assembly is seen to be around 1E9 neutrons per second. When spread out over a large area, and given the short amount of time the products are actually in the Irradiation Room, the level of neutrons given off by the SNF is taken as being of no practical consequence to activation or product damage concerns with regards to the products being irradiated. Therefore in the vast majority of cases SNF can effectively be used as an alternative to traditional gamma ray sources such as Co-60 and Cs-137.

The most complicated analysis that had to be done was determining how many gamma rays were being produced by the SNF and of those how many gamma rays penetrate out of the SNF Bearing Containers, attenuated and unattenuated, such that they can be absorbed by the products meant to be irradiated. MCNP models for a 17x17 PWR fuel assembly, 8x8 BWR fuel assembly, and an individual fuel rod were constructed as shown in Figure 6. The SNF was modeled to be sitting in water with 0.5 cm of water between it and a 1cm thick Aluminum container.

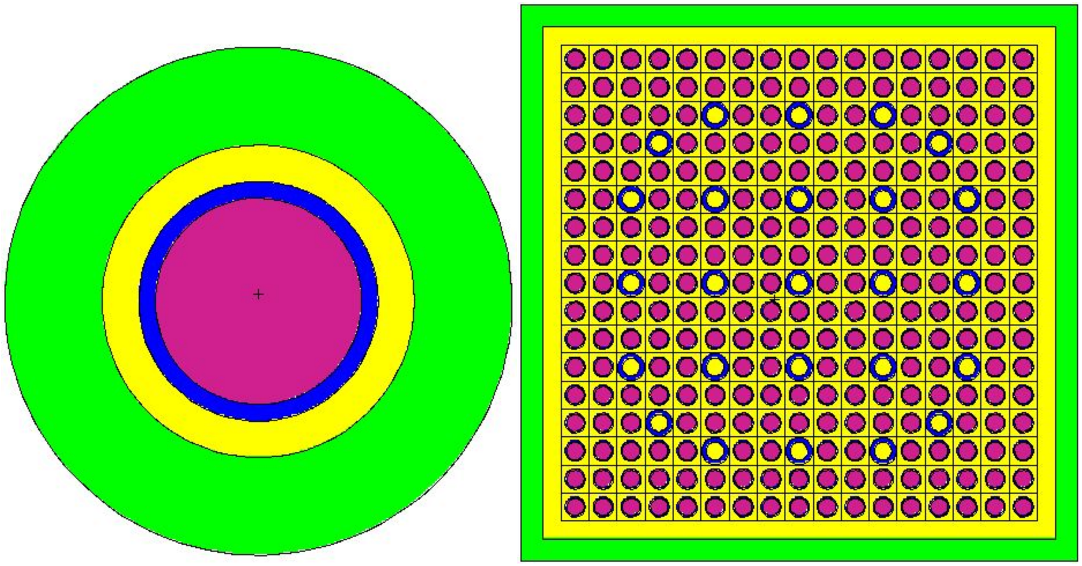

Figure 6: MCNP models (not to scale) of an individual fuel rod SNF Bearing Container and a 17x17 PWR SNF Bearing Container where yellow represents a fill material (water, Helium, or resin), Pink represents Uranium, Blue represents Zirconium based cladding, and Green represents the Aluminum container.

Gamma rays were isotropically generated within each fuel rod and the current of gamma rays escaping the outside of the Aluminum container was measured with an F1 tally in MCNP. The tally was split into several energy bins such that it was possible to tell what percentage of gamma rays escaped without being attenuated, the percentage that escaped with 90% of original energy, 70%, 20%, etc. Only one gamma ray source produced by a specific radioisotopes decay within the SNF could be produced and calculated at a time so the calculation became an iterative process where 0.6 MeV photons were simulated, then 1.2 MeV, then 1.33 MeV, 0.4 MeV, etc.

For each iteration the percentage of photons that escaped at each portion of their original energy was recorded and shown in the MCNP output file. (See the following example in Table 1 below for 0.512 MeV photons in an individual rod)

Table 1: MCNP output

Energy Bin	Tally Result
0.00E+00	0.00E+00
1.00E-02	4.67E-06
1.00E-01	8.02E-03
2.00E-01	2.52E-02
3.00E-01	3.42E-02
3.50E-01	1.89E-02
4.00E-01	2.16E-02
4.50E-01	2.44E-02
5.00E-01	2.70E-02
5.11E-01	5.87E-03
5.12E-01	2.50E-01

Table 2: Psuedo-buildup factor data processing

Energy Bin	Tally Result	Energy Bin times Tally Result
	0.00E+00	
0.00E+00	4.67E-06	0.00E+00
1.00E-02	8.02E-03	8.02E-05
1.00E-01	2.52E-02	2.52E-03
2.00E-01	3.42E-02	6.84E-03
3.00E-01	1.89E-02	5.67E-03
3.50E-01	2.16E-02	7.57E-03
4.00E-01	2.44E-02	9.75E-03
4.50E-01	2.70E-02	1.21E-02
5.00E-01	5.87E-03	2.93E-03
5.11E-01	2.50E-01	1.28E-01
5.12E-01		

The way to interpret this result from the MCNP output file is that for every one photon that was simulated 0.25 photons escaped with an energy between 0.512 & 0.511 MeV. For every one photon that was simulated 0.0216 photons escaped with an energy between 0.4 & 0.35 MeV. Etcetera.

These energy bins were then used to calculate a conservative, MCNP simulated, pseudo-buildup factor. It is conservative in the fact that a lower Riemann sum approach is taken as will be described. Each tally result is multiplied by the lower portion of its energy bin as shown in Table 2 which applies the pseudo-buildup factor calculation procedure to the 0.512 MeV photon source results from Table 1.

The amount of energy escaping the SNF Bearing Container per source photon from unattenuated 0.512 MeV gamma rays is thus the value at the bottom of the “Energy Bin times Tally Result” column [highlighted in yellow in Table 2]. The amount of energy escaping the SNF Bearing Container per source photon from attenuated photons would therefore be the summation of all other values in the “Energy Bin times Tally Result” column divided by the bottom value in the “Energy Bin times Tally Result” column. The ratio of these two values (ie all the summation of all the values in the “Energy Bin times Tally Result” column except the bottom value, divided by the bottom value in the “Energy Bin times Tally Result” column) will be the percentage of gamma ray energy not accounted for if you were to only account for the unattenuated signal of gamma rays. This is exactly what the Health Physics field does when measuring a signal from a detector with a peak at a certain energy but also several other partial energy events at other energies in the detector readout which they use to construct a buildup factor. The difference being that we are using MCNP to conservatively derive a value whereas in conventional Health Physics one can just look up empirical/experimental data.

After performing this step of the calculation for 0.512 MeV gamma rays traveling through the SNF, water, and Aluminum associated with the SNF Bearing Container the ratio is found to be 0.373 which means the pseudo-buildup factor is 1.373. This means that there is an additional 37.3% of signal escaping the SNF Bearing Containers from attenuated gamma rays compared to just calculating the unattenuated 0.512 MeV gamma rays that escape the SNF Bearing Containers. This pseudo-buildup factor will be important because later we will only focus on calculating the unattenuated gamma rays and then simply account for the attenuated gamma rays by multiplying the result by the corresponding pseudo buildup factor.

The next step is to incorporate the number of 0.512 MeV photons being generated in 1 year old spent nuclear fuel every second. This number may be taken from published data based on SNF isotopic composition, or output from a computer simulation such as ORIGEN/SCALE/CASMO etc. This number is traditionally given in photons/second per metric ton of Uranium (MTU). It is known that there are only 3.186 kg of uranium in a spent nuclear fuel rod so we divide this number by 1000kg per MTU to obtain a value of photons/second per fuel rod. We next multiply this number by the percentage of 0.512 MeV photons that escape unattenuated to obtain the number of photons that escape the SNF Bearing Container every second. Next we multiply by the energy of the unattenuated photon (0.512 MeV in this case) to obtain the amount of energy escaping the SNF Bearing Container every second from full energy photons. The next step is to multiply this result by the pseudo-buildup factor to account for energy escaping the SNF Bearing Container from attenuated photons. This result is in MeV/second and so we convert it to Joules/second (watts) by multiplying by 1.602e-13 Joules/MeV.

This whole procedure is then repeated for every different energy of gamma ray produced within the SNF by different decay modes of different isotopes. All of these results (contributions from each energy of gamma ray associated with each different radioisotope contained within the SNF) are summed together to obtain the total gamma ray signal (in watts) coming out of each SNF Bearing Container. This value is then multiplied by the number of 1 year old SNF Bearing Containers in the facility to determine the total gamma ray signal from 1 year old SNF stored in the facility. This calculational process is repeated for the case of 3 year old SNF, 5 year old SNF, etc and results are again summed together to obtain the total gamma signal inside of the SNF storage facility from the varying aged SNF stored in the SNF Bearing Containers.

After this calculational procedure the gamma source intensity produced by each typical discharge of SNF from a nuclear reactor after 1 year of aging before transportation to the SNF storage facility as stored in the form of BWR assemblies, PWR assemblies, and individual SNF rods are shown in Figure 7. For reference the source strength found in a typical 3 MCi Cobalt 60 irradiation facility is also shown in Figure 7.

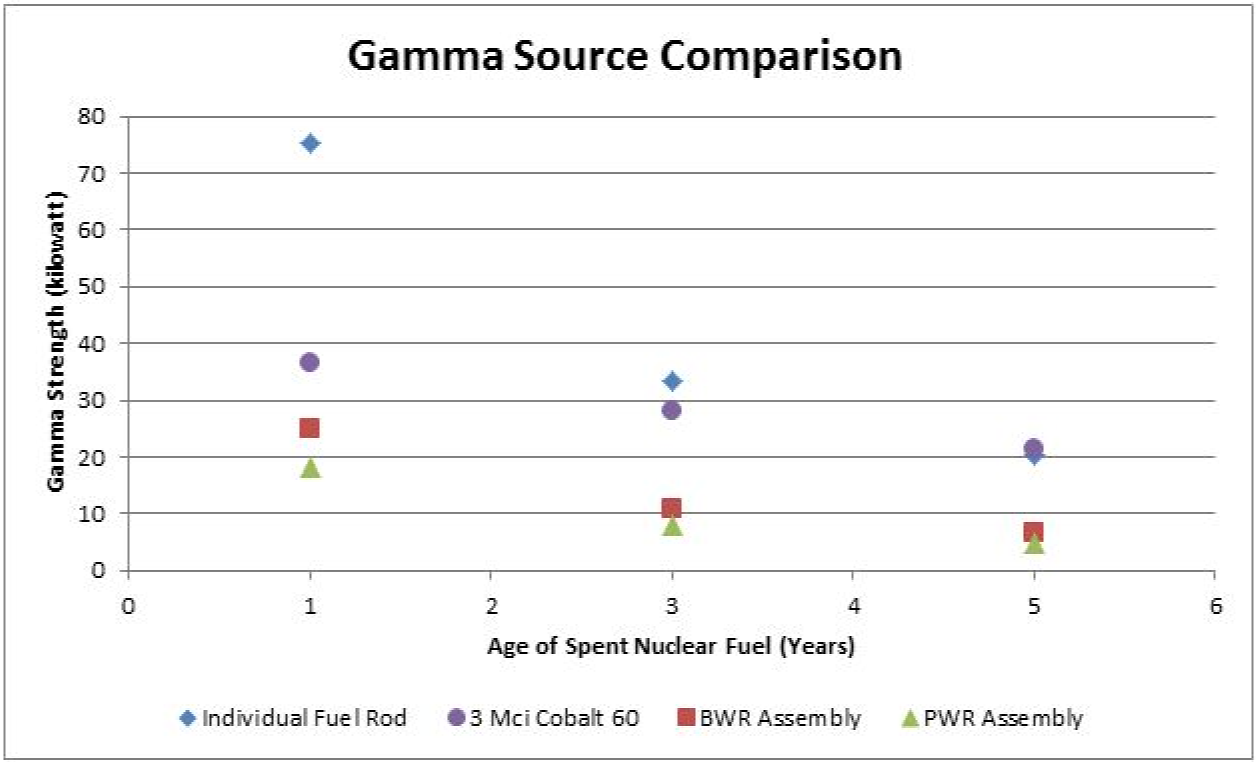

Figure 7: Gamma strength associated with one refueling worth of SNF Bearing Containers

Note that the attenuation of the gamma rays is much larger and the usable signal much lower for the same amount (1 refueling's worth) of SNF stored in PWR/BWR assembly form compared to individual fuel rod form. This is because Uranium is an excellent gamma ray shield and much of the gamma signal produced by SNF rods in the center of an assembly simply gets deposited in the Uranium of the surrounding SNF rods within the assembly.

In one implementation of this SNF storage concept facility construction costs and facility size are substantially reduced by only storing six years worth of SNF from a single nuclear reactor in the irradiation facility and every two years the oldest SNF in the facility is exchanged for a fresh shipment of one year old (freshly cooled) SNF. In this way the SNF storage facility's gamma source is refueled whenever the reactor is refueled and the gamma strength in the facility can be kept relatively high with reduced costs, reduced facility size, and reduced SNF storage capacity. The total harvestable gamma ray signal inside of a G-Demption irradiation facility that only stores six years worth of SNF at a time that was discharged by a single nuclear reactor is shown in Figure 8. Note that this SNF storage scheme would become even more attractive at multi-reactor unit sites which are producing 2-3 times as much fresh SNF as a single unit.

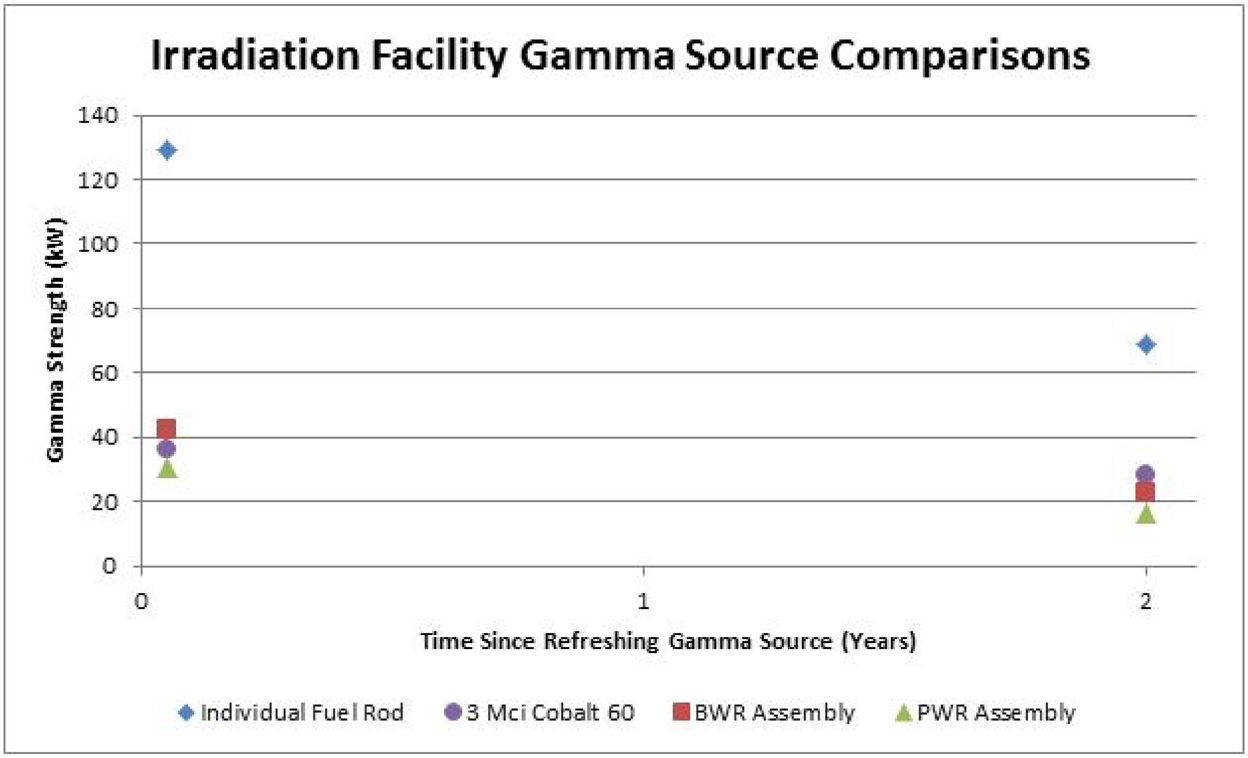

Figure 8: Gamma strength associated with three refuelings worth of SNF Bearing Containers where SNF is shuffled in and out of the facility every refueling

The marketplace value of a kilowatt of gamma rays is conservatively taken to be $200,000 per kilowatt; an estimate based on a value of $2.45 per Curie of Cobalt-60. Since the sterilization industry is a service industry, there is a large markup that this $200,000 per kilowatt estimate is not taking into account and the price of Cobalt-60 has risen from the referenced $2.45 per Curie price quoted here due to higher demand and lower supply of this isotope in recent years. That is to say that this pricing/value estimate is fairly conservative.

Typical Dose Rates:

The irradiation facility produces a lower power density and lower intensity radiation areas compared to a typical large Cobalt-60 irradiator. In the case of a 170 PWR assembly based facility (6 years worth of SNF and the equivalent of 3MCi worth of Cobalt-60) the average achievable dose rate to the 230 cubic meters of product exposed to the irradiation room at any given time is roughly 0.25 Gray per second. In this scenario it would take between 11-42 hours to achieve a 30kGray dose to products depending on which area of the facility the products were processed in [one third of the facility is composed of younger SNF which creates much higher radiation areas]. As a reference, a typical Cobalt-60 irradiation facility takes hours (roughly 4-6 hours) to achieve a 30kGrey dose to products.

In the case of a facility composed of 45,000 individual fuel rods (6 years worth of SNF stored in a different form and the equivalent of 8 MCi worth of Cobalt-60) the average achievable dose rate to the 5,600 cubic meters of product exposed to the irradiation room at any given time is roughly 0.04 Gray per second. In this scenario it would take between 3-12 days to achieve a 30kGray dose to products depending on which area of the facility the products were processed in.

HEAT REMOVAL CALCULATIONS

To prove the feasibility of the concept, from the standpoint of keeping the SNF cool, a conservative one dimensional transient heat transfer calculation was set up and run to steady state. A simple first order explicit numerical scheme was implemented and thermal conduction as well as natural convection correlations were used to account for the transfer of heat between the SNF Bearing Container, air in the Irradiation Room, and structural concrete. The ultimate heat sink was modeled as 38°C stagnant air by making it a boundary condition at the roof of the Irradiation Room and at the other outer structural concrete. Heat transfer from the full length of the Thermal Conduction Elements to the top level of the SNF storage facility was not modeled for simplicity but this is expected to be a substantially conservative simplification such that the following proof of concept cooling calculation results account for the bounding scenario with significant room for margin. This calculation also didn't take into account any active safety systems or passive air cooling provided by air inlet/outlet vents. Note that during normal operation the products being brought in and out with the conveyor system will be an effective means of carrying thermal energy out of the Irradiation Room and any small active cooling system (if necessary) would be only for the sake of keeping the products being irradiated in a cool environment and not for the sake of preventing SNF degradation during storage.

The cooling calculation was run with 15,000 SNF Bearing Containers that contained individual SNF rods. An internal heat generation rate of 40 watts and 165 Watts was used to represent 200 day old and 15 day old SNF respectively. The end product of the calculation is the steady state SNF cladding temperature and steady state Irradiation Room air temperature with the results shown in Table 3.

Table 3: Results from conservative heat removal calculations for single fuel rod SNF Bearing Containers

Time Since SNF Discharge from Reactor (Days)	SNF Heat Generation (Watts)	Temperature of air in Irradiation Room (°C)	Temperature of SNF cladding (°C)
15	165	369	396
200	40	120	131

The NRC states in Interim Staff Guidance-11, Revision 3 (2003) that for off normal and accident conditions the maximum cladding temperature should not exceed 570 °C and that the maximum calculated fuel cladding temperature should not exceed 400 °C for normal conditions of storage. It can be seen from the table above that the 15 day old SNF stays below this regulatory limit and the 200 day old SNF doesn't come close to the regulatory storage temperature limit even with these conservative assumptions. This illustrates the power of individually encasing the SNF rods and spreading them out over an area in terms of heat removal capabilities compared to traditional dry cask storage. It also proves the feasibility of using very young SNF such that even higher amounts of gamma rays could be harvested compared to starting with 1 year old SNF as was assumed in the gamma ray intensity and economic analysis in this paper. PWR assembly SNF Bearing Container cooling calculations are planned for the future.

OVERVIEW OF REGULATORY FRAMEWORK

It is expected that regulatory hurdles to the technology would be minimal due to the use of standard, routine, proven SNF handling methods.

The NRC has plenty of experience regulating ISFSI's and regulating sealed radiation sources. The likely regulatory path forward would be a combination of 10 CFR 36 "LICENSES AND RADIATION SAFETY REQUIREMENTS FOR IRRADIATORS" and 10 CFR 72 "LICENSING REQUIREMENTS FOR THE INDEPENDENT STORAGE OF SPENT NUCLEAR FUEL, HIGH-LEVEL RADIOACTIVE WASTE, AND REACTOR- RELATED GREATER THAN CLASS C WASTE". A preliminary regulatory gap analysis of the design concept found that all of the stipulations of 10 CFR 72 could be reasonably expected to be met while only a few regulations of 10 CFR 36 could not be instantly met. The regulations of 10 CFR 36 were designed with small pencil radiation sources in mind which are drastically different from the 4 meter tall SNF Bearing Container sources envisioned by this design concept. Therefore thermal shock tests and bend tests stipulated by 10 CFR 36 are expected to be failed, however a strong case can be made that such tests do not correlate to the safety basis for SNF Bearing Container sources since these tests were originally designed to test the safety of a completely different type of sealed radiation source.

The design's focus on increasing safety by encasing the SNF and establishing several new barriers to the release of fission products into the environment should be viewed as a progressive safety feature in beyond design basis accident evaluations.

ECONOMIC ANALYSIS

For a typical 1 GWe LWR the upfront cost of an ISFSI in the form of a dry cask storage pad and associated equipment is between $20-30 million. It then costs roughly $6 million per year to operate the facility. After a 40 year lifespan the Utility will have spent roughly $260 million on the dry cask storage facility for interim storage. For the G-Demption ISFSI/Irradiation facility design concept the utility would spend $40-50 million upfront in the form of the SNF storage facility/irradiation facility and all its associated equipment. It would then cost roughly $12 million per year to operate the overall facility but during the operation of the irradiation facility $15 million of revenue per year is generated for a $3 million profit per year. After the 40 year operating life of the G-Demption facility the Utility has made $70 million in profit while storing their SNF by recovering value from their SNF whose gamma rays were otherwise going wasted.

Note that if implemented at a multi-reactor unit nuclear power plant the construction and operations costs would not dramatically increase, however the annual revenue from increased gamma ray sales would vastly increase; nearly doubling for a two unit reactor site and nearly tripling for a three unit reactor site. This means that the G-Demption design concept is much more economically attractive to multi-unit sites.

The global supply of Cobalt-60 is roughly 300 MCi or 4,500 kilo-watts. Since each large light water reactor could add roughly 90 kilowatts of gamma ray supply to the market, and given the substantially high demand for these gamma rays, it is not anticipated that the market will be flooded and prices should remain stable. In fact, with the introduction of large new gamma ray supplies several new novel ways of using these gamma rays may develop and increase market demand for them. The incremental increase of supply as more reactors implement this gamma harvesting technology should also help prevent any sudden dumps of supply onto the market and keep prices stable.

CONCLUSION

The safety basis and feasibility of the G-Demption design concept with regards to cooling the SNF was proven through a conservative calculation which found that the SNF cladding temperature is kept below regulatory limits. The usability of the gamma signal was demonstrated through references to experimental data found in the literature and the size of the gamma ray signal was found by a complex, but conservative, calculational procedure which showed that each LWR could produce roughly 90 kilo-watts of gamma ray signal. The G-Demption SNF storage facility concept introduces the concept of recovering value from SNF during storage by selling gamma ray irradiation services after turning SNF into sealed gamma ray sources. It was seen that there is a substantially large economic incentive for utilities to implement this design concept at their nuclear power plants and no insurmountable regulatory or technical hurdles have been discovered to date.

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