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Pool Irradiator Safety Review for Genesis-II Systems

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POOL IRRADIATOR SAFETY REVIEW FOR GENESIS-II SYSTEMS

by
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Abstract

This report examines the Genesis II irradiator made by Gray*Star Incorporated, Mississippi Department of Health radiation safety regulations, and Nuclear Regulatory Commission (NRC) inspection guidelines for irradiators. The purpose for this report is to evaluate any hazards which may lead to a catastrophic water loss, evaluate protective action distances during a reduced shielding situation, and evaluate the safety engineering measures incorporated by Mississippi and Federal regulations to ensure the mitigation of risk for pool irradiators. Due to safeguard controls prohibiting release of precise data on emergency response measures and radioactivity of the isotopes utilized this report will be focused on regulations mandating specific engineering controls and manufacturer recommended guidelines for best practices.

Keywords:

Exposure, Gateway, Genesis, Gray*Star, Gulfport, Irradiator, Phytosanitation

Dedication

I wish to thank my family including my beautiful wife Diane, and my wonderful children Wyatt and Clayton for their enduring patience during my pursuit of a professional military career and advanced education. Without their continued support I would not be able to develop or maintain a coherent thought, tie my shoes, make a sandwich, or determine the electron spin quantum number on an atom of Cobalt-60. I truly appreciate every day I get to spend with the most important people in my life.

Acknowledgements

I would like to thank the Gulfport International Airport's Operations Director, Don Shepley, for providing the opportunity for emergency response personnel to visit and observe the operations of the Gateway America food irradiator facility. I would also like to thank BJ Smith and Jason Moak from the Mississippi Health Department's Office of Radiological Safety for their continued insight and technical guidance on radiological safety issues throughout the state. Furthermore, this undertaking could not have been accomplished without specific assistance from the faculty of Montana Tech of the University of Montana's Industrial Hygiene program (Go "Diggers"!). Without the guidance of these personnel and institutions this report would not be possible.

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Glossary of Terms

Term	Definition
ALARA	Acronym for "As Low As Reasonably Achievable." It means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical. Be consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations. These means are in relation to utilization of nuclear energy and licensed materials in the public interest.
Buildup Factor	The factor by which the total value of the quantity being assessed at the point of interest exceeds the value associated with only primary radiation. The total value includes secondary radiations especially scattered radiation. The buildup factor is most commonly used for ionizing photons and may apply to various quantities—e.g., dose kerma, fluence.
Curie (Ci)	The original unit used to express the decay rate of a sample of radioactive material. The curie is equal to that quantity of radioactive material in which the number of atoms decaying per second is equal to 37 billion (3.7×10^{10}). It was based on the rate of decay of atoms within one gram of radium. It is named for Marie and Pierre Curie who discovered radium in 1898. The curie is the basic unit of radioactivity used in the system of radiation units in the United States, referred to as "traditional" units.
Siemen, (micro)	Unit of electric conductance, electric susceptance and electric admittance in the International System of Units (SI).
Phytosanitation	Measures requiring removal or destruction of infected or infested plant material likely to form source of re-infection or re-infestation (Encyclo.co.uk, 2013).
Rad	The original unit developed for expressing absorbed dose, which is the amount of energy from any type of ionizing radiation (e.g., alpha, beta, gamma, neutrons, etc.) deposited in any medium (e.g., water, tissue, air). A dose of one rad is equivalent to the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing tissue. The rad has been replaced by the gray in the SI system of units (1 gray = 100 rad).
TEDE	Total Effective Dose Equivalent: The sum of effective dose equivalent from external exposure and committed expected dose equivalent from internal exposure.

Executive Summary

Gateway America has installed a pool type irradiator for food phytosanitation at the Gulfport international airport. This is the third to be installed in the United States. The Genesis II has an extremely high radiation source ranging from 200,000 to 500,000 Ci's. The shielding requirements provided by the pool containment system have been evaluated and are adequate to prevent exposure to the facility workers and general public. This inherently safe system utilizes thorough safety design planning to ensure no contamination will be unnoticed, and breeches will not occur to cause rapid water loss. Catastrophic conditions including natural disasters, terrorist events, and national emergencies, may cause momentary loss of access to the facility allowing water levels to evaporate off with a resulting reduction in shielding, however these instances are considered rare. Emergency response planning criteria is monitored by the Nuclear Regulatory Commission and catastrophic conditions are highly unlikely on risk management planning considerations. The Genesis II is an overall extremely safe, extremely reliable system with an incredible track record of safety which allows enhanced food distribution to US markets in an efficient and timely manner.

Background

The Gulfport International Airport's cargo facility had a state of the art food irradiator installed for the large quantity of seafood which is shipped through this port. 103,000 pounds of food stuffs were irradiated in the US in 2010 with nearly 8,000 pounds attributed to meat and poultry (FoodIrradiation.org, 2010). The primary foodstuff utilizing this radioactive process of phytosanitation in Gulfport, MS is Gulf Oysters with 53,251 sacks of oysters (roughly 20 pound sacks) harvested in Mississippi and accounted for at inspection stations in 2012-2013 season (Coastal Markers, 2013). Many of these oysters do not undertake irradiation and are served fresh; however, many products that are shipped nationally and even internationally are irradiated. These shellfish are subject to an intense gamma radiation field which kills any biological materials present on or within the product making the product safe for human consumption and effectively enhancing the shelf life. Due to the intensity of the gamma radiation field, numerous safety measures are emplaced to protect workers. The Genesis II model is a level III irradiator considered inherently safe as the source has no moving parts, and great effort would be needed in order for an adverse exposure to occur.

Gulfport International Airport's Operations Director, Don Shepley, inquired on a dilemma during a recent site visit. A common question posed to the airport by first responders is how close may emergency response personnel get to the sources in the event of a catastrophic failure without ill effects due to radiation exposure. This food irradiator had been installed in the cargo facility in 2012. The Irradiator utilizes Cobalt-60 sources consisting of no more than 1,000,000 Curies according to the Genesis II design structure. Optimized calculations utilizing half this quantity (500,000 Ci's) and further estimates considering half-life have been calculated and considered during design and construction phases of this project. The sources are shielded by

15 feet of water enclosed in a pool. During normal operations shielding is adequate up to specified hazard areas with natural background readings being predominant at the surface of the pool. During emergency situations causing a catastrophic failure and total water loss the hazard areas are not known.

This study was conducted on the regulations, construction, safety process, radiation sources, and shielding requirements for the Genesis II irradiator system. The end state is a thorough radiation exposure estimate with associated action distances and calculated stay times for the Gulfport International Airport during a catastrophic water loss situation attributed to natural disaster or catastrophic accident.

1. Food Irradiator Theory

1.1. Phytosanitation by Exposure

The Genesis II Food Irradiation system is based on phytosanitation of harmful organisms from domestic food stuffs by exposing them to large amounts of ionizing radiation. This kills most food-borne bacteria, viruses, and fungi present prior to reaching resale stations. The English Encyclopedia defines Phytosanitation as: Measures requiring removal or destruction of infected or infested plant material likely to form source of re-infection or re-infestation (Encyclo.co.uk, 2013). Food irradiators have increased the shelf life of many products we use in everyday life; however the concept of subjecting food to radiation sometimes incites fear in an uninformed population. Ideally the system utilized (Genesis II) by the Gulfport, MS operation, Gateway America, has a specified range from 2,000 Rad to 5,000,000 Rad (Graystar, 2014).

Optimal fruit radiation applications expose the product to a total dose (TD) around 100,000 R for efficient phytosanitation processes (Gateway America, 2014). This greatly exceeds the radiation dose allowed for exposed workers who are not allowed to exceed 5 Rad per year according to OSHA. See Appendix A for complete FDA exposure guidance for various irradiated food types.

1.2. Irradiator Systems Processes

The Grey Star Genesis II Food Irradiator is a Category III irradiator utilizing a sealed cobalt 60 source which is suspended at the bottom of a water pool containment system. The water pool serves as an engineering control to mitigate the gamma rays from exposing workers. The water functions as a preventive barrier to limit contact with the sources within a specified distance. Foodstuffs are descended into the pool by utilization of a mechanically operated diving bell containment system which inter-latches onto the food storage container. The bell is positioned within a known geometry to the radioactive source permitting optimum gamma exposure to the foodstuffs contained within to effectively phytosanitize the contents.

1.3. Irradiated Food Benefits

Food irradiation has multiple benefits. One benefit is increased shelf life of the products delivered to the markets. Figure 1 listed below compares control tomatoes with irradiated tomatoes showing the advanced spoilage of non-irradiated foods over an extended period.

Irradiation is not only used for spoilage reduction, but also for tuber inhibition in root based products such as onion and potato adding a shelf life extension. A secondary example is in Figure 2 highlighting white button-top mushrooms stored for seven days at room temperature after irradiated with various exposure rates. It is also been determined that food irradiation significantly reduces the levels of harmful microorganisms such as *Salmonella*; *E. coli* O157:H7; *Clostridium perfringens*; *Staphylococcus aureus*; *Listeria monocytogenes*; *Campylobacter jejuni*; and the protozoan parasite *Toxoplasma gondii* (USDA, 1999*)*. The benefits of reduced harmful organisms make the treated foods safer to eat than organic foods.

Figure 1: Non-irradiated vs. Irradiated tomatoes @ 10 days. (Gateway America, 2014).

Figure 2: Irradiated Agaricusbisporus mushrooms: Control (top), 40 kR, 80 kR, 100 kR, 200 kR (7 days at room temperature). (Abhiram, 2012).

1.4. Irradiator Safety

The Genesis II food irradiator is an inherently safe system. The system relies on water shielding as the means to prevent exposure to the source. The source is stabilized and is only moved during lifecycle replacement eliminating a massive shielding chamber to prevent exposures during operations. The source is sealed, preventing corrosion or contamination into the water source, therefore the food is completely free from contamination, and has only been subjected to a high energy field culling harmful pests.

2. Regulatory Practices

2.1. Radiation Protection Control

In the late 1800's scientist started investigating into the properties of radioactive materials. While exploring these properties many ideas were developed on how to benefit mankind with these newly discovered physical traits. Many of the early researchers of these products were however harmed by the unknown risks of over-exposure to the energies associated with radioactivity. The Nuclear Regulatory Commission (formerly the US Atomic Energy Commission) was established to oversee operations which utilized radioactive materials in the United States to ensure that appropriate protective measures are implemented and utilized to protect the workers and the general public from radiation hazards.

2.2. NRC Agreement States

The Atomic Energy Act of 1956, Section 274 permits the NRC to relinquish some of its regulatory guidance to State authority as an "Agreement State." There are presently 37 Agreement States which are permitted by the NRC to regulate specific isotope quantities, monitor radioactive materials in the state, and perform inspections for license compliance issues. Mississippi became an Agreement State on 01 July, 1962 with authority to promulgate regulations, issue licenses, and perform inspections. Federal instillations within Agreement State boundaries are governed by the NRC. Special nuclear materials utilized in power-plants are also solely controlled by the NRC, and agreement states are only permitted some oversight in the inspection programs at the NRC's discretion.

2.3. Radioactive Quantities Exceeding State Control

No specific guidance is issued for radioactive quantities exceeding state control. There are particular commodities such as irradiators and reactors which require federal oversight; however specific activity levels of radioactive isotopes are not regulated federally. License number MS-1063-01 was issued to Gateway America on 20 November, 2012 (NRC, 2013, p.22); Due to safeguard information the actual activity could not be disclosed, however, the manufacturer states that optimal activity for a Genesis II irradiator is listed as 500,000 Ci's of Cobalt-60 due to loss of efficiency at activity levels which exceed this (Rodrigues, 2011, p.3). The Gateway facility is located at Gulfport International Airport which is a privately owned airport. The license for the Gateway facility is issued by Mississippi, but safeguards control for the emergency actions criteria is reviewed and approved by the NRC prior to State license issuance. Therefore Gateway America falls under regulations of both the State of Mississippi and general irradiator guidance posted under the NRC. The NRC also completes an Integrated Materials Performance Evaluation (IMPE) every four years to ensure the State plans are in compliance with NRC guidelines. The last IMPE was completed in 2012 with satisfactory ratings for Mississippi's program with no negative comments (NRC, 2013).

2.4. Radiation Safety Guides

Rule 1.4.6 of Mississippi Code is comparable to OSHA limitations for radiation workers. Radiation workers are not to exceed 5 REM annual Total Effective Dose Equivalent (TEDE). ALARA (As Low As Reasonably Achievable) considerations are also evident in dosimetry planning as exposures accrue consecutively over one's lifetime and overall dose should be limited as necessary. Appendix C of this report details comprehensive guidelines for dosages IAW 10 CFR 20.1201 for other than Full Body (TEDE) dosages. A dosimetry program is required for facility operators under both Federal and State law for irradiator use. Radiation monitoring above the pool is also required. Miss. Code Ann. Subpart 45-14-11 Rule 1.12.9 and 10 CFR 36.25 (8.9.3) state that the dose over the edge of an irradiator pool may not exceed 2mR/hr at 30 inches over the surface (NRC, 1999)(MSDH, 2014).

2.5. Safety Engineering Design

The NRC provides Program Specific Guidance for irradiators regarding required engineering elements for safety design prior to being issued a license to construct and operate a facility. The type of irradiator necessitates what elements are required in the plan. Because the Genesis II is an underwater irradiator and does not require some of the controls normally utilized with above ground radiators or water irradiators whose sources are moved mechanically to the product. NRC mandated engineering controls for pool irradiators include (NRC, 1999):

- The pool must have a personal access barrier with intrusion alarm.
- A physical barrier such as a railing to prevent accidental entrance to the pool.
- Radiation monitoring over the pool to detect abnormal radiation levels.
- Pool Construction of approved design methods (cannot leak and non-reactive).
- Pool cannot have an outlet lower than ½ meter below “low water” level.
- A means to replenish the water in emergency conditions.
- Methods to detect pool contamination where contamination is most likely to collect.
- Water purification system for visual inspection of source and rack (conductivity < 20 microsiemens per centimeter).

Fire Prevention and power failure are not key issues for underwater irradiators due to the status of the source being under water. This is concurrent with the system being inherently safe, and these issues would not affect any short term effects caused by these situations.

2.6. Inspection and Enforcement

Section 274 (AEA-1954) authorized Agreement States responsibility to conduct inspections and regulate isotopes in their borders through mutual agreement with the Nuclear Regulatory Commission as specified in the NRC Agreement States section. Other Federal agencies also share responsibility when dealing with radioactivity including the FDA controlling food products which utilize radiation, and OSHA regulating occupational exposures. Overall, the NRC has the primary responsibility for the inspection process ensuring that FDA and OSHA regulations are enforced. The State conducts inspections to ensure compliance with these guidelines as well, with the NRC performing their oversight inspections on the individual states regulation inspection programs ensuring that compliance is adequately implemented. So even though this is a mutual cooperative effort between states and varying agencies, the NRC reserves the right to have inspection and enforcement authority over radiological issues as a “leading agency”.

3. Typical Operations

3.1. Engineering Design Specifications

The Genesis II pool is constructed of a stainless steel inner tank (7' x 8' x 22'), placed inside an in ground outer steel tank. Both of these tanks are seamless limiting water leakage. After both tanks are in place concrete fills the void between the two tanks to ensure water does not escape the barrier. The concrete must be poured to specific guidelines in order to prevent voids in the material. A precisely engineered rack is constructed at the bottom of the pool to suspend the Cobalt-60 source 15 feet below the minimum water mark.

An overhead hoist and trolley system is utilized to maneuver diving bells in and out of the irradiator pool. The product is latched into the diving bell, and lowered into the pool. Once in the pool the product is maintained at the specified proximity to the radiation source for a time period regulated by the Food and Drug Administration for optimal product treatment.

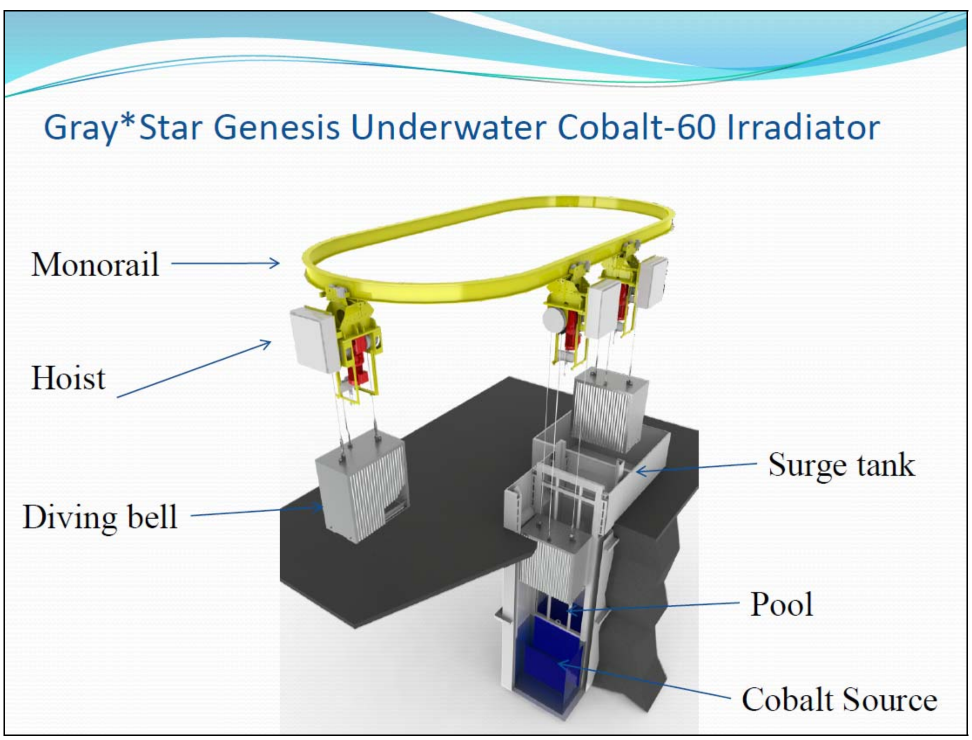

Figure 3: Genesis II System Sketch. (HTFG, 2012).

3.2. Source Material Specifications

A sealed Cobalt 60 source is utilized for the Gateway America facility. Genesis II system specifications state maximum activity up to 1 Million Curies; however the manufacturer suggests anything over 500,000 Curies will result in a loss of efficiency (Rodrigues, 2011, p.3). Cobalt 60 has a 5.3 year half-life. Once the total activity has decayed to less than 200,000 Curies replacement of the source is necessitated in order to maintain peak operating capacity. Under Mississippi Code Annex 45-14-11 Rule 1.12.7 the source must be corrosion resistant double encapsulated, non-soluble, leak tested, and able to withstand temperature, pressure, impact, vibration, bend, and puncture stresses (MSDH, 2014, p.515).

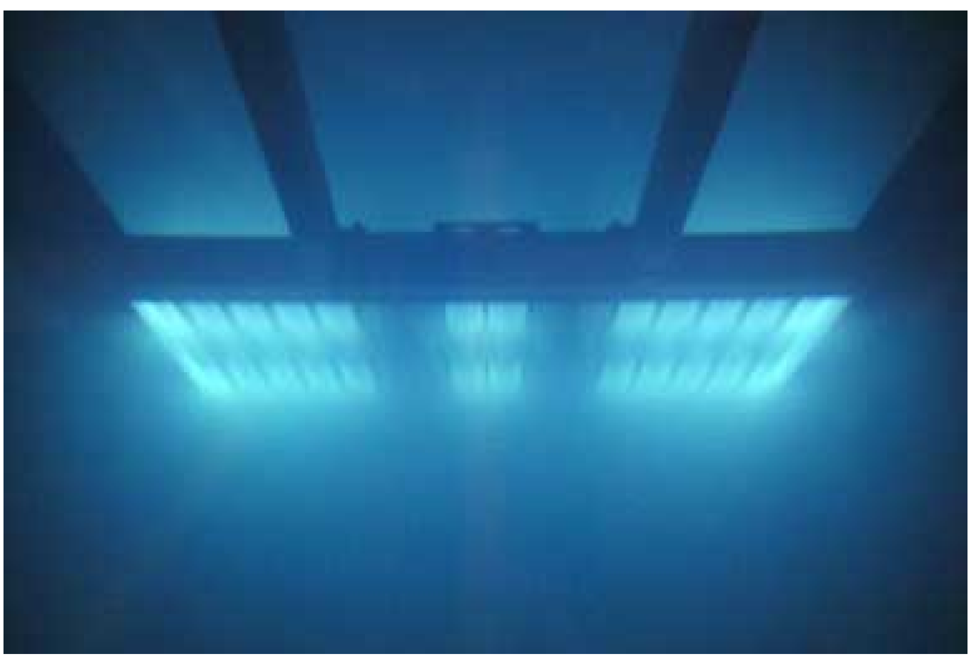

Figure 4: Cobalt 60 Source at bottom of irradiator pool. (Graystar, 2012).

3.3. Water Level (Shielding) Criteria

The minimum water level is equivalent to the floor level of the facility (15 feet above the source). Normal operations have water levels between the minimum level and the “0 Bell” mark. The tank allows for water expansion above the normal operations level to the “1 Bell” and “2 Bell” levels, with bell levels accounting for water displacement in the pool as levels will rise when bells are added. This permits 2 containers to be irradiated simultaneously. Alarms are sounded if the water level falls low enough to permit a 1 mR/hr rate at .5 meters above the surface of the pool by an overhead detection system. Radioactive leak testing is accomplished by a continuous detector in the water circulation system screening for presence of Beta particles.

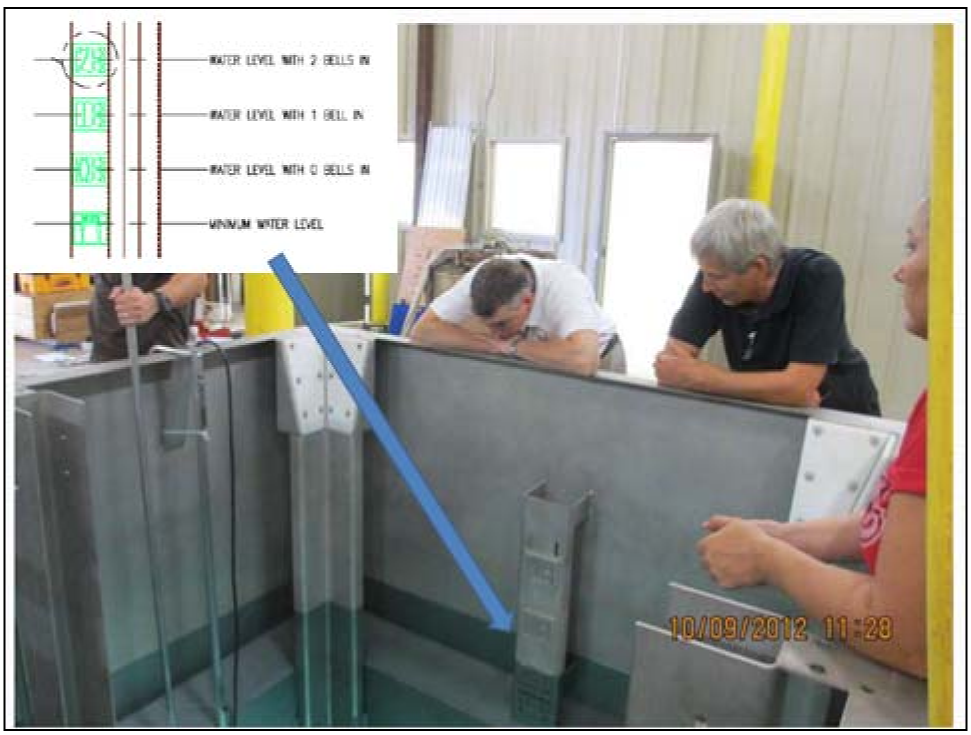

Figure 5: Water Level Marks at Pa’ina, HI. (HTFG, 2012).

3.4. Hazard Area Identification

Under normal operations the hazard areas are marked with Grave Danger signage for Very High Radiation Areas (VHRA: Areas in which could receive 500 Rads per hour at 1 meter from the source, 10 CFR 20-1602). The pool has an orange Hazard area to maintain clearance during operation, prohibiting interfering with the overhead system possibly knocking personnel into the pool (Figure 6). At surface levels the radiation exposure is less than background. Gulfport, MS is at Sea Level with normal background gamma radiation levels measured between 6-10 uR/hr with an AreaRae Gamma Sensor and FLIR Identifinder.

Figure 6: Gray*Star proximity orange hazard area. (HTFG, 2012).

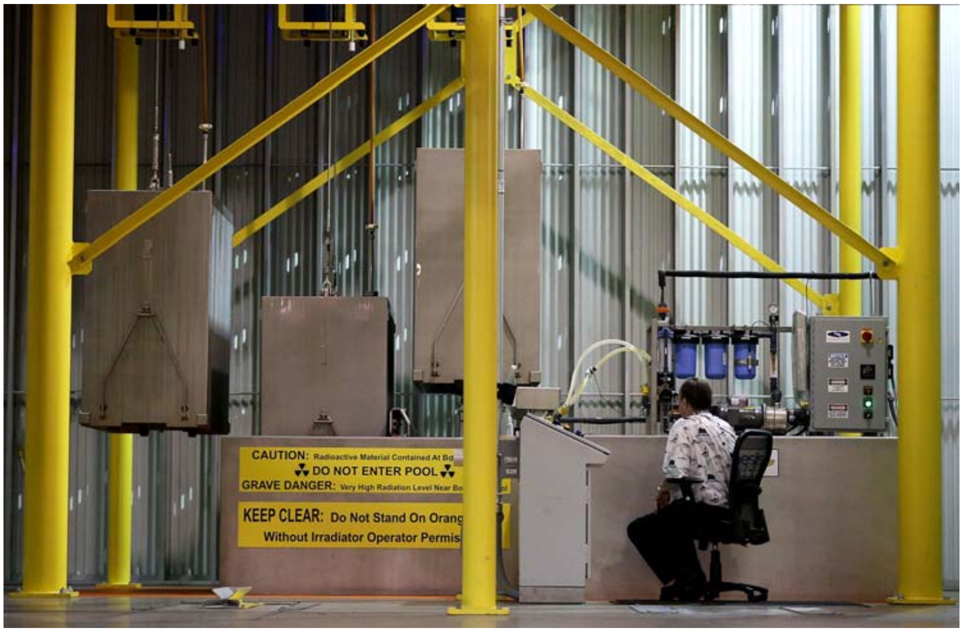

Figure 7: Gateway America Irradiator. Gulfport, MS. (Washington Post, 2014).

3.5. Exposure Assessment

NRC has noted in the past that "personnel exposures during the use of irradiators are less than 5% than the limits described in Title 10 CFR, Part 20," Standards for Radiation Protection. (NRC, 2007, p.C-8) Under normal operating conditions with containment water at optimal levels the gamma exposure at 500,000 Ci's does not exceed background radiation at sea level. Rad Pro Calculator estimates that based on 500,000 Ci's of Cobalt-60 with a distance of 15 Feet (4.6 meters) from the source and equivalent water shielding (15 feet) radiation dose rates will not exceed 1 uR/hr.

4. Non-Typical Operations

4.1. Life Cycle Source Change Out

Once the activity of the Cobalt 60 source is less than 200,000 Ci's a source change out is required. The new source is shipped in a lead lined steel cask provided from an isotope vendor and shipped with NRC and DOT regulations regarding shipment of radiological materials. Once on site the shipping cask is maneuvered by fork lift to the overhead hoist. The hoist than lowers the entire cask into the pool. The supplier utilizes a 20 foot extension tool to open the container while submerged, take the new isotope out, replace the old isotope on the rack, and secure the old isotope in the shipping cask. Due to water levels at exceeding the minimum water requirements no significant dose is incurred by the operators. The source is shipped exclusive use open transport with a maximum of 200 mR/Hr at the surface of the cask and 10 mR/Hr 2 feet from any surface (USNRC, 2003).

Figure 8: Cobalt-60 Shipping cask. Pa'ina, HI. (HTFG, 2012).

4.2. Emergency Response Operations

NRC requires the licensee to provide emergency response criteria for their operations. Prior to receiving an NRC license the owner must submit emergency action criteria to the NRC for approval. “No license for possession and use of sealed sources will be issued unless satisfactory emergency procedures have been developed.” (NRC, 2007, p.C-13 to C-17, “Off Normal Operation”). These emergency response procedures include engineering controls for the radioactive source, the pool requirements, and storage facilities; Law enforcement and emergency response coordination are also required. These plans are considered “SGI” (Safeguards Information), which is information not distributed to the public due to security concerns instituted after the 9-11 terror attacks. When this report requested specifics on the Gulfport response plans, Gateway America denied access and disclosure of specific Emergency Response plans for the Gulfport facility due to proprietary rights and Safeguards Information (SUNSI, 2014).

4.3. Catastrophic Event Considerations

Numerous questions have surfaced regarding Genesis II irradiators including likeliness and associated risks of aircraft crashes, proximity to risk of tsunamis, fault line considerations for earthquakes, water loss effects, and terrorist related events. Replies to these question state that the likelihood of an aircraft to hit directly on a Genesis II facility is one in every 5000 years (2.1×10^{-4}) (NRC. 2007, p.C-14). Likelihood of earthquake, flood and fire damage wouldn’t result in the shielded source leaving its containment 20 feet below ground. Loss of a source due to terrorism is unlikely due to Acute Radiation Sickness within minutes of contact with the source. The greatest threat is to a loss of water to the containment system and impact on first responders. Loss of water would result in a collimated beam of radiation directly above the pool with intensity increasing proportionately with water (shielding) loss. Cobalt-60 is a spontaneous heat emitter which could effectively accelerate the evaporation process of its shielding water if unattended for long periods; 330,000 Ci's of Cobalt-60 creates 17,334 BTU/hr of decay heat. (NRC, 1998, p. 3.4-2, 3.4.1.1.3). Evaluation of Post Hurricane Katrina studies of Gulfport Airport has invalidated this argument. The airport was fully operational within a week after the storm negating the inability to restore shielding water due to inaccessibility after major devastation.

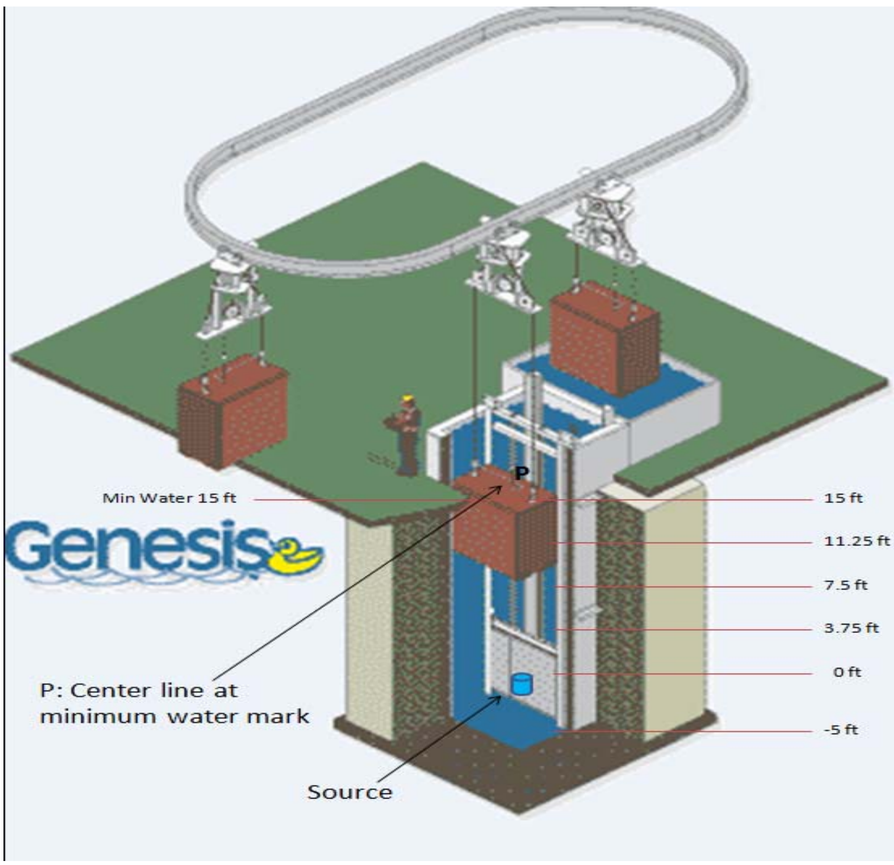

Figure 9: Genesis II System Sketch (Depth included). (Graystar, 2014).

4.4. Exposure Assessments

The water shielding allows for this exceptionally large (500,000 Ci's) source to be mitigated to background levels at the areas in which workers are normally exposed. The background in Gulfport at Sea level was determined to be between 6-8 uR/hr utilizing an

AreaRae gamma sensor. To estimate the approximate hazard area we will utilize the dose rate calculation in Equation 1.

$$H = \frac{\Gamma . A}{R^2} B.e^{-(\mu/\rho).d.L} \quad mSv/h$$

H = equivalent dose rate at P
Γ = 0.351 $mSv.m^2/h.GBq$ for Co-60
A = Co-60 activity source in GBq, in this case 500,000 Ci's = 1.85E7 GBq
R = distance (m) between the punctiform source and P
B = Build-up factor of the medium in which the source is in, in this case: water
μ/ρ = mass attenuation coefficient for photons of 1 MeV = 0.0706 cm^2/g (Appendix E)
d = medium density, for water = 1 g/cm^3 (Appendix E)
L = distance (cm) between the punctiform source and P inside the attenuation material (water)

Equation 1: Dose Rate with Shielding. (Rodrigues, 2011).

Estimates are made with a 500,000 Ci's Cobalt-60 Source 15 feet below the minimum water mark. Exposure assessments are based on the Dose Rate at a distance of 15 feet above the source (labeled P, Figure 7) with decreasing water levels at the minimum level, ¾, ½, ¼, and non-shielded.

$H = [(0.351)(1.85E7)/(4.57m^2)]$ B. $e^{-(.0706)(1)(457cm)}$

$H = [6493500/20.8849]$ B. $e^{-(32.2642)}$

$H = (310918.4147)$ B. $e^{-(32.2642)}$

Buildup predications need to be determined prior to continuing. This is a correction factor to ensure more precise measurements. Buildup eliminates under estimates of dose rates obtained with shielding formulas that rely on linier attenuation coefficients, and over-estimates from shielding formulas reliant on absorption attenuation (absorptionhttp://www.radprocalculator.com/Files/ShieldingandBuildup.pdf). Many differing formulas have been utilized for correcting this condition. This example utilizes the Taylor Buildup formula as follows in Equation 2 (See Appendix D for Taylor constants).

Calculation of Buildup by Taylor [6, p. 415]:

$$B(\mu L) = A_1 . e^{-\alpha 1 \mu L} + (1 - A_1) . e^{-\alpha 2 \mu L} \qquad (3)$$

For water and photons of 1 MeV:

A_1: 19.601; $-\alpha 1 = 0.0904$; $\alpha 2 = -0.0252$
μ = linear attenuation coefficient = 0.0706 cm^{-1}
μL = mean free path = 0.0706xL
L = distance between the punctiform source and the point P inside the attenuation material (cm)

Therefore:

$$B(\mu L) = 19.601 . e^{0.0904x0.0706xL} + (1 - 19.601) . e^{0.0252x0.0706xL}$$

Equation 2: Buildup by Taylor. (Rodrigues, 2011).

$B = 19.601.\ e^{(0.0904)(0.0706)(457cm)} + (1 - 19.601).\ e^{(0.0252)(0.0706)(457cm)}$

$B = 19.601.\ e^{2.91668368} - 18.601.\ e^{.81305784}$

$B = 362.224529 - 41.94139064$

$B = 320.2831384$

Continuing on:

$H = (310918.4147)\ B.\ e^{-(32.2642)}$

$H = (310918.4147)\ 320.\ e^{-(32.2642)}$

$H = (310918.4147)\ (3.112E-12)$

H = 9.67E-7 mSv/hr @ 457cm with 457cm of H_2O

H = .00967uR/hr @ 15 feet with 15 feet of H_2O

The end result with this much shielding is a dose rate reduced to less than background from approximately 30,000 R/hr @ 15 feet. This ensures continuous operations without exposing workers.

Another method to perform a dose rate analysis is by utilizing the "Rad Pro Calculator". This program utilizes differing algorithms to come up with similar Dose Rate computations. One difference is the Buildup Factors used providing slightly different results; buildup factors have been refined over the past few decades for optimal used depending on utilization of absorption coefficients and attenuation factors. Another significant difference is the simplified linier attenuation coefficient in equation one utilizing a 1 MeV threshold rather than the optimized complex 1173 MeV and 1337 MeV dual thresholds associated with Cobalt-60. Taking the same parameters Rad Pro calculator gives the following response for 500,000 Ci's at 15 feet distance with 15 feet of H_2O Shielding (Figure 10).

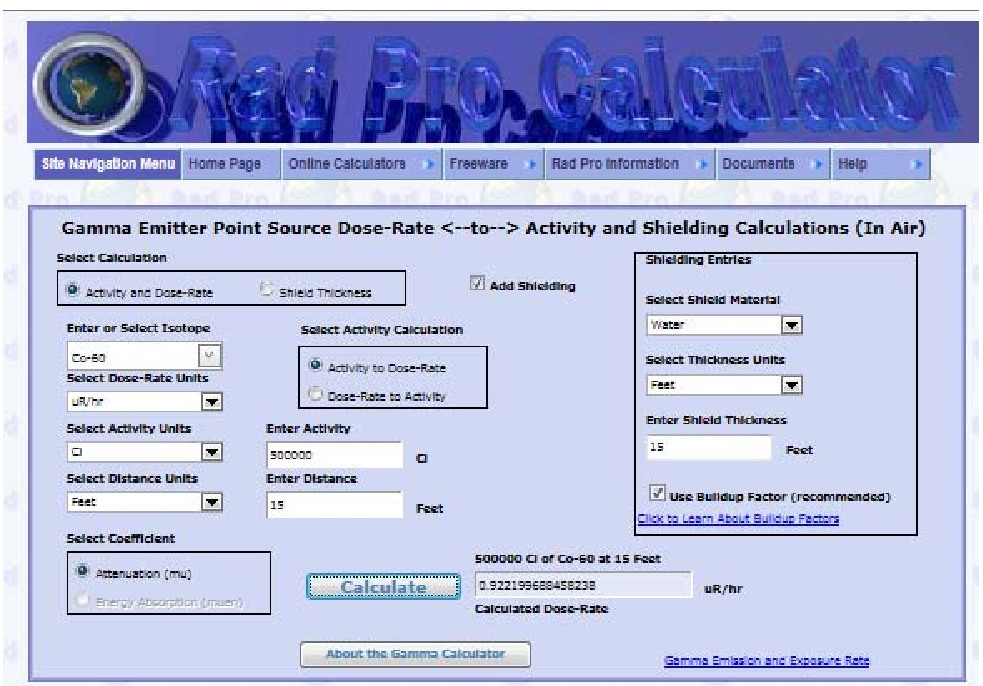

Figure 10: 500K Ci's of Co-60 @ 15 feet with 15 ft $H_2$0 Shielding. (RPC, 2014)

Table 1: Exposure Assessments. (Rad Pro Calculator, 2014)

Dose Rate based on water shielding depth and activity pre, during, and post decay.			
	Year Zero	Year 2	Year 7
Water Shielding Activity vs. Depth	500,000 Ci's	384,377 Ci's	200,000 Ci's
Minimum H2O, 15 feet	0.922 uR/hr	0.709 uR/hr	0.323 uR/hr
Three-Quarters, 11.25 feet	1.010 mR/hr	.777 mR/hr	.404 mR/hr
Half, 7.5 feet	399 mR/hr	307 mR/hr	159.5 mR/hr
One Quarter, 3.75 feet	427 R/hr	328 R/hr	171 R/hr
No Water, source exposed	30,571 R/hr	23,502 R/hr	12,228 R/hr
Population exposure estimates for linier vertical beam above source.			
5R Dose Rate Limit	784 feet	713 feet	558 feet
2mR Public Exp. Limit	4700 feet	4617 feet	4098 feet
Dose Rates at initial 500,000 Ci Activity, 2 year decay, and 7 year decay.			
Dose Rates are assumed at 15 feet above source with shielding buildup factor.			
See appendix X for Rad Pro Calculator worksheet print up.			

With minimal water in place at a depth of 15 feet, the dose rate at the top of the pool will be less than background with a new source at highest activity levels. If the water was permitted to dissipate there would be a corresponding increase in dose rate levels at the surface. The predominance of the radioactive energy will radiate in a vertical column straight up in the air disregarding some outward scattered radiation reflecting off of existing structures and other scattering effects. Should the pool be allowed to drain below the depth of the source one could predict a dose of 5R/hr in a line exceeding 500 feet into the air.

4.5. Stay Times

Due to the extremely intense radiation field culminating in a vertical column, the stay times associated with an empty pool is negligible. Any direct exposure will result in an intense accumulated dose exceeding standardized occupational exposure rates. Under the life cycle replacement activity of 200,000 Ci's, merely peering into an empty pool at a distance of 15 feet would accumulate an exposure rate of 3.4 R/Second (12,228 R/hr, /60 minutes/hr, /60 seconds/min). Under these circumstances the area immediately around the area should be kept clear to prevent Line-of-Sight within the pool containment area until appropriate water levels have been restored (minimum 15 feet) in accordance with the facilities emergency response guidelines approved by the NRC prior to license issuance.

5. Conclusions

The Genesis II has an extremely high radiation source ranging from 200,000 to 500,000 Ci's.

Catastrophic conditions may cause momentary loss of access to the facility allowing water levels to evaporate off with a resulting reduction in shielding, however these instances are considered rare. Protective action distances are adequate with the barrier systems and warning signs in place while shielding water is at optimal levels; significant reduction of water will be associated with an immediate hazardous area directly overhead of the pool. The shielding requirements provided by the pool containment system are adequate to prevent exposure to the facility workers and general public. This inherently safe system utilizes thorough safety design planning to ensure no contamination will be unnoticed, and breeches will not occur to lose shielding rapidly. Emergency response planning criteria is monitored by the Nuclear Regulatory Commission and catastrophic conditions are highly unlikely on risk management planning considerations. In my opinion The Genesis II is an overall extremely safe, extremely reliable system with an incredible track record of safety.

6. Recommendations

This report finds that the Genesis II irradiator is an inherently safe system with little to no chance of a catastrophic water loss occurring. NRC guidance calculates catastrophic disasters to be incredibly low with hardly any chance the source will be exposed. Source change out procedures should be scheduled in coordination with local emergency responders as precautionary measures for potential exposure conditions. Approved emergency response procedures are in place and inspected regularly by NRC and state radiation safety officials. Negative public perception is a key motivator in the legal actions that have plagued other Genesis II facilities in Milford Township, Pennsylvania and Pa'Ina, Hawaii. I recommend the Gateway America plant continue to inform the emergency response populations around Gulfport with administrative tours so that they are informed of the potential hazards of this facility, and start reassurance measures to inform the general population of the minimal risk potential and enhanced economic value of this key industrial asset on the Mississippi Gulf Coast.

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Appendix A: 21 CFR 149 Food Irradiation Guidance (USDA, 2012)

Use	Limitations
1. For control of *Trichinella spiralis* in pork carcasses or fresh, non-heat-processed cuts of pork carcasses	Minimum dose 0.3 kiloGray (kGy) (30 kilorad (krad)); maximum dose not to exceed 1 kGy (100 krad).
2. For growth and maturation inhibition of fresh foods	Not to exceed 1 kGy (100 krad).
3. For disinfestation of arthropod pests in food	Do.
4. For microbial disinfection of dry or dehydrated enzyme preparations (including immobilized enzymes)	Not to exceed 10 kGy (1 megarad (Mrad)).
5. For microbial disinfection of the following dry or dehydrated aromatic vegetable substances when used as ingredients in small amounts solely for flavoring or aroma: culinary herbs, seeds, spices, vegetable seasonings that are used to impart flavor but that are not either represented as, or appear to be, a vegetable that is eaten for its own sake, and blends of these aromatic vegetable substances. Turmeric and paprika may also be irradiated when they are to be used as color additives. The blends may contain sodium chloride and minor amounts of dry food ingredients ordinarily used in such blends	Not to exceed 30 kGy (3 Mrad).
6. For control of food-borne pathogens in fresh	Not to exceed 4.5 kGy for

(refrigerated or unrefrigerated) or frozen, uncooked poultry products that are: (1) Whole carcasses or disjointed portions (or other parts) of such carcasses that are "ready-to-cook poultry" within the meaning of 9 CFR 381.l(b) (with or without nonfluid seasoning; includes, e.g., ground poultry), or (2) mechanically separated poultry product (a finely comminuted ingredient produced by the mechanical deboning of poultry carcasses or parts of carcasses)	non-frozen products; not to exceed 7.0 kGy for frozen products.
7. For the sterilization of frozen, packaged meats used solely in the National Aeronautics and Space Administration space flight programs	Minimum dose 44 kGy (4.4 Mrad). Packaging materials used need not comply with 179.25(c) provided that their use is otherwise permitted by applicable regulations in parts 174 through 186 of this chapter.
8. For control of foodborne pathogens in, and extension of the shelf-life of, refrigerated or frozen, uncooked products that are meat within the meaning of 9 CFR 301.2(rr), meat byproducts within the meaning of 9 CFR 301.2(tt), or meat food products within the meaning of 9 CFR 301.2(uu), with or without nonfluid seasoning, that are otherwise composed solely of intact or ground meat, meat byproducts, or both meat and meat byproducts	Not to exceed 4.5 kGy maximum for refrigerated products; not to exceed 7.0 kGy maximum for frozen products.

9. For control of *Salmonella* in fresh shell eggs.	Not to exceed 3.0 kGy.
10. For control of microbial pathogens on seeds for sprouting.	Not to exceed 8.0 kGy.
11. For the control of Vibrio bacteria and other foodborne microorganisms in or on fresh or frozen molluscan shellfish.	Not to exceed 5.5 kGy.
12. For control of food-borne pathogens and extension of shelf-life in fresh iceberg lettuce and fresh spinach.	Not to exceed 4.0 kGy.
13. For control of foodborne pathogens, and extension of shelf-life, in unrefrigerated (as well as refrigerated) uncooked meat, meat byproducts, and certain meat food products	Not to exceed 4.5 kGy.
14. For control of food-borne pathogens in, and extension of the shelf-life of, chilled or frozen raw, cooked, or partially cooked crustaceans or dried crustaceans (water activity less than 0.85), with or without spices, minerals, inorganic salts, citrates, citric acid, and/or calcium disodium EDTA	Not to exceed 6.0 kGy.

Appendix B: Irradiator Emergency response planning requirements (MSDH, 2014)

Due to safeguard information the emergency response criteria for the Gateway facility is For Official Use Only and not disclosed to the general public. This excerpt from the Miss Code details Emergency response planning criteria for irradiators in Mississippi. So even though the specific plan cannot be accessed the following conditions are provided for.

Miss. Code Ann. Subpart 45-14-11

Subchapter 12 Licensing and Radiation Safety Requirements for Irradiators

Rule 1.12.19 Operations and Emergency Procedures (P. 525)

1. The licensee shall have and follow written operating procedures for:
    a. Operation of the irradiator, including entering and leaving the radiation room;
    b. Use of personal dosimeters;
    c. Surveying the shielding of panoramic irradiators; Monitoring pool water for contamination while the water is in the pool and before release of pool water to unrestricted areas;
    d. Leak testing of sources;
    e. Inspection and maintenance checks required by 1.12.23;
    f. Inspection of moveable shielding required by 1.12.8(8), if applicable.
2. The licensee shall have and follow emergency or abnormal event procedures, appropriate for the irradiator type, for:
    a. Sources stuck in the unshielded position;
    b. Personnel overexposures;
    c. A radiation alarm from the product exit portal monitor or pool monitor;
    d. Detection of leaking sources, pool contamination, or alarm caused by contamination of pool water;
    e. A low or high water level indicator, an abnormal water loss, or leakage from the source storage pool;
    f. A prolonged loss of electrical power;
    g. A fire alarm or explosion in the radiation room;
    h. An alarm indicating unauthorized entry into the radiation roon, area around pool, or another alarmed area;
    i. Natural Phenomena, including an earthquake, a tornado, flooding, or other phenomena as appropriate for the geographical location of the facility, and;
    j. The jamming of automatic conveyor systems.

3. The licensee may revise operating and emergency procedures only with Agency approval and if all of the following conditions are met:
    a. The revisions do not reduce the safety of the facility;
    b. The revisions are consistent with the outline or summary of procedures submitted with the license application;
    c. The revisions have been reviewed and approved by the radiation safety officer; and
    d. The user or operators are instructed and tested on the revised procedures before they are put into use.

Appendix C: Annual Dose Limits for Radiation Workers (10 CFR 20.1201)

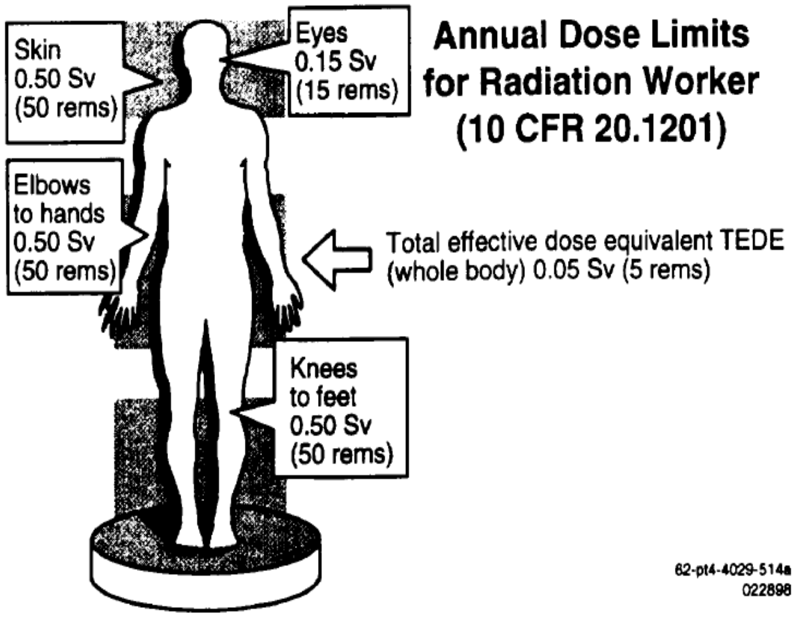

Figure 8.8 Annual Dose Limits for Radiation Workers.

Appendix D: Taylor Dose Buildup Factor Constants (Oak Ridge National Labs, 1966)

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Table 1. Buscaglione-Manzini* Coefficients for Taylor Dose Buildup Factor Formula

Material	E_0 (MeV)	A	$-\alpha_1$	α_2	Maximum Percent Deviation
Water	0.5	100.845	0.12687	- 0.10925	- 27.4 μx = 10
	1	19.601	0.09037	- 0.02522	- 10.8 μx = 10
	2	12.612	0.05320	0.01932	+ 4.2 μx = 1
	3	11.110	0.03550	0.03206	+ 1.7 μx = 1
	4	11.163	0.02543	0.03025	+ 0.8 μx = 20
	6	8.385	0.01820	0.04164	- 0.5 μx = 2
	8	4.635	0.02633	0.07097	+ 0.6 μx = 7
	10	3.545	0.02991	0.08717	- 0.7 μx = 1
Aluminum	0.5	38.911	0.10015	- 0.06312	- 12.2 μx = 10
	1	28.782	0.06820	- 0.02973	- 8.6 μx = 10
	2	16.981	0.04588	0.00271	- 5.2 μx = 10
	3	10.583	0.04066	0.02514	- 2.5 μx = 10
	4	7.526	0.03973	0.03860	+ 1.8 μx = 20
	6	5.713	0.03934	0.04347	+ 1.6 μx = 20
	8	4.716	0.03837	0.04431	- 1.3 μx = 15
	10	3.999	0.03900	0.04130	+ 1.2 μx = 20
Barytes Concrete	0.5	33.026	0.06129	- 0.02883	+ 7.5 μx = 2
	1	23.014	0.06255	- 0.02217	+ 8.9 μx = 20

Appendix E: Linear Attenuation Coefficients (Martin, 2003)

Table 7-2. Photon Attenuation (μ) and Mass Energy-Absorption (μ_{en}/ρ) Coefficients for Selected Materials (J. H. Hubbell and S. M. Seltzer).

	Dry Air (Sea Level) ($\rho = 0.001205\ g/cm^3$)		Water, Liquid ($\rho = 1.00\ g/cm^3$)		Aluminum ($\rho = 2.699\ g/cm^3$)	
Energy (keV)	μ (cm^{-1})	μ_{en}/ρ (cm^2/g)	μ (cm^{-1})	μ_{en}/ρ (cm^2/g)	μ (cm^{-1})	μ_{en}/ρ (cm^2/g)
10	0.0062	4.742	5.329	4.944	70.795	25.43
15	0.0019	1.334	1.673	1.374	21.4705	7.487
20	0.0009	0.5389	0.8096	0.5503	9.2873	3.094
30	4.26E-4	0.1537	0.3756	0.1557	3.0445	0.8778
40	2.99E-4	0.0683	0.2683	0.0695	1.5344	0.3601
50	2.51E-4	0.0410	0.2269	0.0422	0.9935	0.1840
60	2.26E-4	0.0304	0.2059	0.0319	0.7498	0.1099
70*	2.10E-4	0.0255	0.1948	0.0289	0.6130	0.0713
80	2.00E-4	0.0241	0.1924	0.0272	0.5447	0.0551
100	1.86E-4	0.0233	0.1707	0.0255	0.4599	0.0379
150	1.63E-4	0.0250	0.1505	0.0276	0.3719	0.0283
200	1.49E-4	0.0267	0.1370	0.0297	0.3301	0.0275
300	1.29E-4	0.0287	0.1186	0.0319	0.2812	0.0282
400	1.15E-4	0.0295	0.1061	0.0328	0.2504	0.0286
500	1.05E-4	0.0297	0.0969	0.0330	0.2279	0.0287
600	9.71E-5	0.0295	0.0896	0.0328	0.2106	0.0285
662*	9.34E-5	0.0293	0.0862	0.0326	0.2024	0.0283
800	8.52E-5	0.0288	0.0787	0.0321	0.1846	0.0278
1,000	7.66E-5	0.0279	0.0707	0.0310	0.1659	0.0269
1,173*	7.05E-5	0.0271	0.0650	0.0301	0.1526	0.0261
1,250	6.86E-5	0.0267	0.0632	0.0297	0.1483	0.0257
1,333*	6.62E-5	0.0263	0.0611	0.0292	0.1435	0.0253
1,500	6.24E-5	0.0255	0.0575	0.0283	0.1351	0.0245
2,000	5.36E-5	0.0235	0.0494	0.0261	0.1167	0.0227
3,000	4.32E-5	0.0206	0.0397	0.0228	0.0956	0.0202
4,000	3.71E-5	0.0187	0.0340	0.0207	0.0838	0.0188
5,000	3.31E-5	0.0174	0.0303	0.0192	0.0765	0.0180
6,000	3.04E-5	0.0165	0.0277	0.0181	0.0717	0.0174
6,129*	3.01E-5	0.0164	0.0274	0.0180	0.0713	0.0173
7,000*	2.83E-5	0.0159	0.0258	0.01723	0.0683	0.0170
7,115*	2.82E-5	0.0158	0.0256	0.0172	0.0680	0.0170
10,000	2.46E-5	0.0145	0.0222	0.0157	0.0626	0.0165