Investigation of the radiation of Cs-137 and the half life of Ba-137m in the release water from nuclear reactor

Weixiang Zeng

High School Affiliated to Renmin University, Beijing, 100000, China

Abstract. Nuclear radiation is the release of energy in the form of high-speed charged particles or electromagnetic waves, producing ions. High doses ionizing radiation can damage cells or organs and even cause death. In 2011, a tsunami struck near Fukushima, Japan, caused a serious radiation accident at the Fukushima nuclear power station. This paper investigates the release of treated wastewater from Japan's Fukushima nuclear plant into the Pacific Ocean and focuses the transformation of Cs-137 into Ba-137m and whether Ba-137m poses significant radioactive hazards in order to find out whether the treatment of Cs-137 by the plant is appropriate. Firstly, I simulated and studied the relationship between output signals of the Geiger tube at the different operating high voltage. Then, I have analytically studied the half-life of Ba-137m radiation source and obtained a half-life result through fitting (133 seconds). Finally, some discussion results of the release of treated wastewater were described.

Keywords: nuclear reactor, Cs-137, Ba-137m, radiation.

1. Introduction

Nuclear radiation (also called ionising radiation) is the release of energy in the form of high-speed charged particles or electromag- netic waves, producing ions. High doses ionizing radiation can damage cells or organs and even cause death. Radiation damage usually caused by unshielded radioactive sources, radiation-generating ma- chines without protection, handling radioactive materials, proximity to contaminated surfaces, or personal contamination. According to World Health Organization(2023), high radiation doses cause imme- diate skin redness, hair loss, and burns, and can also result in long- term cataracts and cancer. The accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP) was triggered by the tsunami following the Great Eastern Earthquake on March 11, 2011, resulting in the discharge of radioactive substances into the ter- restrial and aquatic environment. [1] Following the accident, protective measures were implemented, including evacuation, sheltering, stable iodine administration, food and water consumption restrictions, and relocation, and a comprehensive monitoring program was initiated to assess radiation levels in the environment. The contamination occurs through multiple routes [2]:

• Deposited radionuclides run off from catchments through ongoing processes such as precipitation, erosion, floods, and tides(ongoing);

• Radionuclides released into the atmosphere deposited onto the ocean surface (March 2011);

• Groundwater contaminated through contact with the reactor flows into the ocean (May 2011–present);

• unintended release of water containing moderate levels of ra- Dio nuclides (May 2011);

• Water with low levels of radionuclides was intentionally dis- charged from storage tanks (early April 2011);

• unintended release of water containing high levels of radionu- clides occurred (early April 2011).

The FDNPP is located at the conflu- ence of the Kuroshio and Oyashio currents.[3] The Kuroshio current carries warm and saline seawater northward along the southern coast of Japan before turning eastward, while the Oyashio current carries cold and less saline seawater southward. Radionuclide dispersion in the ocean depends on currents, mixing of surface and deep waters, sedimentation, and ocean floor topog- raphy.[1] In shallow shelf waters, dispersion is driven by winds, tides, and freshwater inputs. Thus, the geographical location of FDNPP determines the significance of the accident. Seawater injected to cool the reactors and the structural damage of the pressurized containment vessels led to the releases of radionuclides to the ocean.[2] Marine monitoring from 21

March to 31 July suggests that the highest Cs-137 activity concentration locates at the release point to the seawater and rapidly declines in the first few weeks.[1] The concentration then continues to decrease in the following years. After the accident, sea monitoring programs were established to collect and measure seawater, sediment, marine biota, and fish.[4] The activity concentrations of radio caesium in fish and seafood significantly surpassed the permissible limit of 100 Bq/kg fresh weight in seawater close to the FDNPP. [1] Beyond the 30 km radius from FDNPP, the Cs-137 activity concentrations in seawa- ter have returned to levels observed prior to the accident. Subsequent to the FDNPP accident, extensive investigations were conducted to examine the behaviours of radio caesium in soil-crop systems and in agricultural animal systems. These studies have yielded new insights into the bioavailability of Cs-137. The FDNPP accident released radionuclides that contaminated crops in Eastern Japan with radio caesium and radioiodine.[1] Interception of radionuclides by vegetation depends on density, deposition contributions (dry/wet), radionuclide properties, and rainfall.[5] CR (concentration ratio) is a dimensionless value used to describe the transfer of radionuclides to different environmental compartments, species, and tissues in various contamination scenar- ios. Systematic analysis on the influence of nutrient K+ status on radio caesium activity and CR values showed that most contaminated agricultural soils in Japan had similar or lower CR values compared to international standards. [2] Unlike the aftermath of the Chernobyl accident, no radio ecologically sensitive soils with high radio caesium uptake were found in Japan.[6]

2. Radiation Influence of The Nuclear Reactor

2.1. Formatting the title

It should not be indented. Leave 28 mm of space above the title and 10 mm after the title. According to int (2020), the plant releases a wide spectrum of ra- dionuclides including Xe-133 (5.2 d), Cs-136 (13.6 d), Te-132 (3.26 d), I-132(2.3 h), and I-133 (20.8 h). The Cs-137 and Cs-134 within the radionuclides determine doses to people in the long term. Cesium-137 is spontaneously produced when other radioactive materials absorb neutrons and undergo fission and its decay emits beta particles. [7] The decay of cesium-137 into barium-137m emits moderate-level gamma radiation and barium-137m eventually decays to a stable form of bar- ium. The process is represented by equation 1.

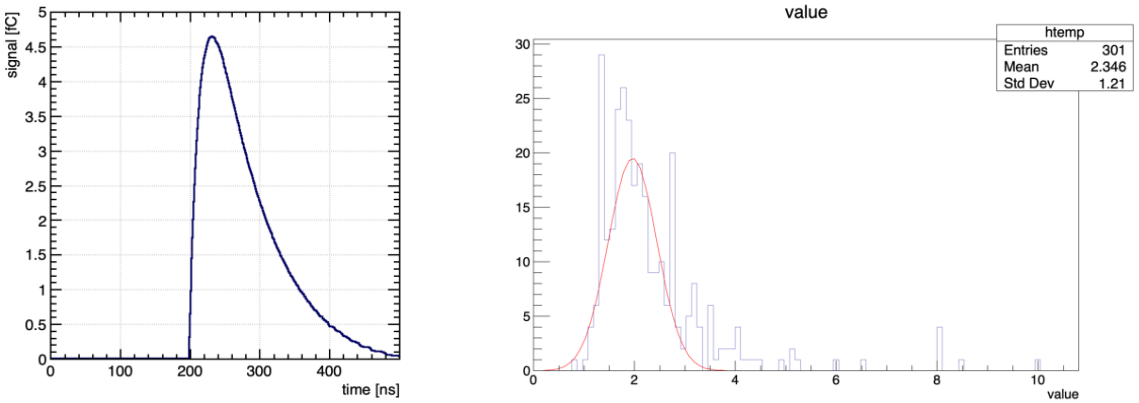
$$^{137}_{55}Cs \rightarrow {}^{137m}_{56}Ba + e^{-} + \overline{\nu_e} \quad (1)$$

Exposure to Cs-137 increases the risk for developing cancer due to the exposure to gamma radiation. By entering the body through inhalation or ingestion, internal exposure exposes body's soft tissues, particularly muscle tissue, to the beta particles and gamma radiation, increasing cancer risk. Cesium-137 has a 30-year half-life. The plant use resin to deal with the Cs-137.

2.2. Simulation of Geiger-Müller Tube

The experiment utilizes Geiger Counter, which contains Geiger-Müller Tube and and processing electronics displaying the detected radiation, barrier, and radiation source, shown in figure 3. The Geiger–Müller is the sensing element of the Geiger counter instru- ment used for the detection of ionizing radiation. The G-M tube con- sists of a chamber filled with a gas mixture at low pressure. When ion- izing radiation strikes the tube, it directly ionizes the gas molecules or indirectly ionizes them through secondary electrons produced in the tube's walls, creating ion pairs in the gas. The voltage accelerates positive ions towards the cathode and electrons towards the anode, creating a strong electric field. As the anode is approached, the elec- tric field strength increases, resulting in electron avalanches and gas multiplication. The pulse of current generated by the avalanche can be measured in the form of a voltage pulse across an external resistor. Such signals can be shown by Garfield++, shown in figure 1a. The avalanche discharge ends as positive ions move away from the anode wire, forming a space charge that prevents further avalanche gener- ation. Geiger-Müller tubes

provide two types of radiation readout: counts and radiation dose. The counts display shows the number of ionizing events detected, while the radiation dose display measures dose rate using an energy-compensated tube. The experiment uses. the former one. To examine the impact of wire voltage on the re- sults, I performed Gaussian fitting on approximately 300 signals for each voltage value, shown in figure 1b. I simulated and executed the Gaussian fit on the signal from the Geiger-Müller detector when the wire voltage was set to 2900V, 2950V, 3000V, 3050V, 3100V. The results are shown in Figure 2, indicating that the voltage has negli- gible impacts and the experiment is executed in the Geiger counting region.



(a) Sample signals produced by Geiger-Müller tube

(b) Sample Gaussian Fitting at 3000V

Figure 1. Signals and Gaussian Fitting of Geiger-Müller tube.

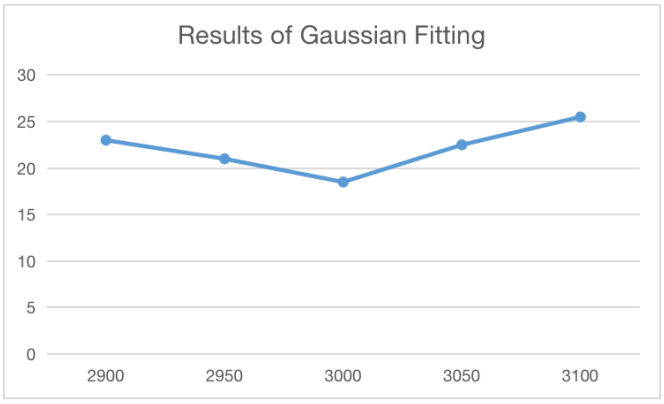


Figure 2. Results of Guassian Fitting.

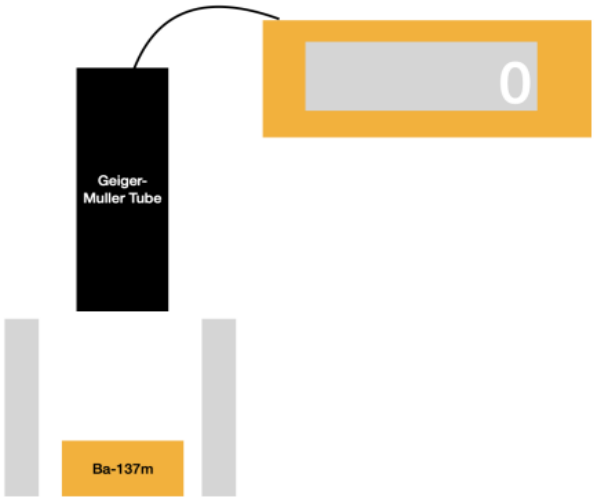


Figure 3. Diagram of the Experimental Study.

2.3. Study of the radiation source

The research conducts the study of the half-life of Ba-137m on the virtual lab of gigaphysics. The experiment utilizes a Geiger-Müller tube, which receives electrons emitted by the decay of Ba-137m. Firstly, the research performed a measurement of background ra- diation. To account for radiation in the air and building materials, this paper set the radiation source to none (background), selected no barrier type, and set the count duration to 10 seconds. This pays- per began counting the number of background particles that hit the counter within the specified duration. Finally, the research recorded the obtained result 9. Then, this paper changed the radiation source to Ba-137m. The research clicked on "Show timer" and then immediately clicked on "Start count" to obtain and record Ba-137m counts in ten seconds. Subsequently, the research repeated this experiment every thirty sec- onds for the next eight minutes. Later, the research records the actual counts by subtracting the background counts from the counts ob- tained earlier. To obtain the half-life of Ba-137m, this paper generated a plot, shown as Figure 4, using Python based on recorded data. According to figure 4, there were 400 counts in 10 seconds at seconds and 200 counts at 357 seconds. Because it takes 133 seconds for the activity of Ba-137m to drop by half, from 400 to 200, the half-life of Ba-137m is 133 seconds, indicating a relatively brief decay period.

Table 1. Counting data

Elapsed time (in seconds)	Counts in 10 seconds (including background)	Counts in 10 seconds (excluding background)
0	1076	1067
30	991	982
60	860	851
90	709	700
120	680	671
150	555	546
180	469	460
210	445	436
240	397	388
270	333	324
300	291	282
330	239	230
360	230	221
390	189	180
420	177	168
450	142	133
480	131	122

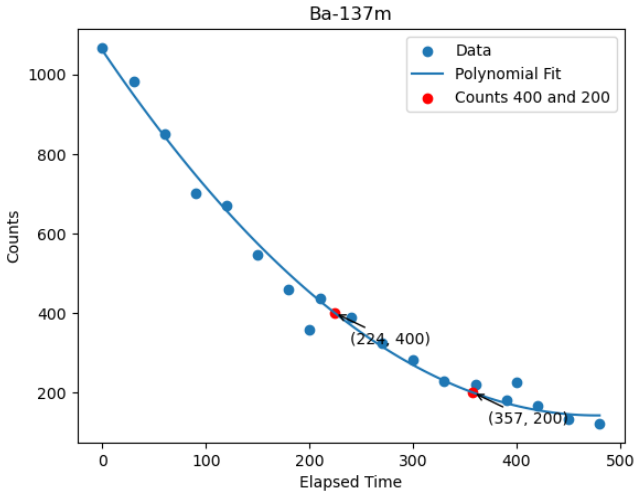


Figure 4. Ba-137m counts.

3. Conclusion

Recently, Japan's Fukushima nuclear plant has started releasing treated wastewater into the Pacific Ocean. One of the important ra- dioactive isotopes present in the treated wastewater is Cs-137, which is a man-made isotope with a half-life of 32 years. It undergoes p decay and transforms into Ba-137m. The plant utilizes resin to absorb Cs-137, and the Ba-137m adsorbed onto the resin will be extracted by seawater, which serves as a weakly acidic salt solution. In this context, it is vital to understand the half-life and decay scheme of Ba-137m in order to assess the appropriateness of the plant's treatment of Cs-137. Through experimentation, this paper has de- termined that the half-life of Ba-137m is only 133 seconds, and it decays through gamma emission (662 keV) into stable Ba-137, which poses no radioactive hazards. If the government effectively handle Cs-137 treated to discharge into the sea, then the impact of discharge into sea is acceptable.

References

[1] 2020, Environmental Transfer of Radionuclides in Japan following the Acci- dent at the Fukushima Daiichi Nuclear Power Plant. No. 1927 in TEC- DOC Series, INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna.

[2] 2015, The Fukushima Daiichi Accident. Non-serial Publications, INTERNA- TIONAL ATOMIC ENERGY AGENCY, Vienna.

[3] Yasuda I., 2003, Journal of Oceanography, 59, 389.

[4] Nuclear Regulation Authority (NRA) 2013, Implementation Guides on Sea Area Monitoring in FY2013.

[5] 2009, Quantification of Radionuclide Transfer in Terrestrial and Freshwa- ter Environments for Radiological Assessments. No. 1616 in TECDOC Series, INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna.

[6] Fesenko S. V., et al., 2007, The Science of the total environment, 383, 1.

[7] Environmental Protection Agency 2002, EPA Facts About Cesium-137.

[8] World Health Organization Accessed [2-October-2023], Ionizing Radiation and Health Effects.