IOP Conference Series: Materials Science and Engineering

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To cite this article: Rosli Darmawan 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **555** 012014

IOP Conf. Series: Materials Science and Engineering **555** (2019) 012014 doi:10.1088/1757-899X/555/1/012014

Investigation on the gamma sources integrity inside a dry pit storage

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Abstract. One of the primary concerns in the operation of nuclear related facilities is the safety of the system. Worldwide publicity on a few nuclear accidents as well as the notorious Hiroshima and Nagasaki bombing have always brought about public fear on anything related to nuclear. Thus, investigation and analysis on the safety system shall be continuously conducted to determine the safety condition of the facilities. In the early days, analytical and experimental methods were employed. However, this approach is limited to low risk experimentation. With the advancement of computer technology, specific computer codes were used to predict and analyse high risk safety issues such as the fall-out from a nuclear explosion or analysis of melt down occurrence in a reactor core. This paper discusses a prediction model on a gamma irradiation facility source pit which having failure on its air cooling system. The CFD model predicts the temperature of the gamma sources under such situation to determine its integrity.

1. Introduction

While the stricken Fukushima Daiichi nuclear power plant is bracing for the worst of the reactor unit 1, 2 and 3's melting core, another frightening development unfolded at reactor unit 4. The spent fuel pool containing 1535 fuel assemblies may have been exposed and started to heat up [1]. The worst that can happen is that the exposed spent fuel assemblies heat up and catch fire, which may end up melting the cladding and releasing large amount of radioactive materials into the environment. The above phenomenon was part of the frightening development during Fukushima Daiichi crisis, which also became a major concern that similar cases might happen to any nuclear and radioactive sources storage all over the world.

U.S. based Union of Concerned Scientist elaborated the danger that it might happen in any spent fuel pools of unit 4, 5 and 6 of Fukushima Daiichi nuclear power plant. There is also concerned on the difficulty to conduct repair works on broken cooling mechanism of the pools, since the workers may be exposed to lethal radiation dose for a very short period of time [2]. The spent fuel pool condition of reactor unit 4 was modeled by Wang *et al*. using mass and energy balance to estimate the rate of evaporation of water, water level and the spent fuel temperature. It revealed close agreement with data provided by TEPCO and predicted the time taken to total water loss and fuel degradation [3]. Study on other radioactive waste dry storage facility inside the proposed Yucca Mountain was conducted by Pepper *et al.* [4] through CFD modeling. The model showed that the decay heat from the waste's casks was removed by ventilating air through the drift and conduction through drift walls; whereas thermal heat from radiation found to have little effect on the overall cooling mechanism.

In this study, the condition of a dry storage pit of a gamma-irradiation facility's radioactive source was modeled to assess its integrity under abnormal situation. Under normal shut-down condition, the gamma source is stored inside the dry storage pit and the cooling air system inside the pit will be operated. The air cooling system is kept running to ensure the decay heat from the source is properly dissipated to keep the source temperature under controlled. Without the air cooling system, there is concern on the fate of the source, since the decay heat may increase the pit's temperature. If the temperature exceeded the melting point of the source capsule, the radioactive material may be exposed and released to the surrounding. Therefore, the temperature inside the bunker and the source pit need to be determined to assess the condition of the source. A CFD simulation was conducted to predict the temperature of the source under no-cooling condition as elaborated further in the next section.

2. Methodology

The simulation of the source, rack and air condition inside the pit and bunker was conducted using CFD technique. The physical condition of the system is as illustrated in Figure 1 and the schematic of the modeling system is shown in Figure 2. The system being modeled consists part of the bunker, storage pit, source rack, baffle plate and the sources. All of the walls are considered adiabatic as the bunker and pit's walls are made of high density concrete. The baffle plates are modeled as a single-square entity and the frames holding the sources are ignored for simplicity to reduce computational load. The temperature of the air inside the pit and bunker is set at 30°C according to the actual measurement [5]. The pressure inside the bunker is assumed at ambient. No external force or pressure is imposed on the air, thus it is assumed to be in stationary and in laminar flow condition. All of the walls are considered smooth and no frictional force is exerted on the fluid. The top part of the model is considered as convective wall exposed to free stream air at room temperature. The convective heat transfer coefficient in free stream air is set to $10 W/m^2 K$ as used by Rodriguez *et al.* [6] and Gastelurutia *et al.* [7]. Other fluid properties of the model are shown in Figure 2. The simulations assumed heat source from the gamma sources which is dissipated through conduction and convection via the source rack, baffle plates and air inside the pit to the bunker. Natural convection modeling was conducted using Boussinessique approximation at 30°C condition. The validation of the models was conducted on modeling program verification and numerical solution verification aspects similar to Rosli *et al.* [8].

An actual physical measurement of the temperature inside the storage rack on the actual facility was conducted by M Arif [5]. The measurement was taken with the cooling system of the facility turned off for more than 24 hours. The temperature inside the bunker and storage pit was measured using a thermocouple type K. The locations and the results of the measurement are shown in Figure 3 and Table 1. Physical measurement inside the pit proved to be difficult due to the hindrance by the source rack structure and the narrow gap between the pit's wall and the rack. The thermocouple could only get inside the pit up to the middle of the baffle plates (L4), thus leaving the rest of the pit's condition unknown. The modeling attempted to predict the sources' surface temperature based on the known measured values. The modeling was done only on axial distribution since the width of the storage pit is very narrow that the temperature variation is negligible.

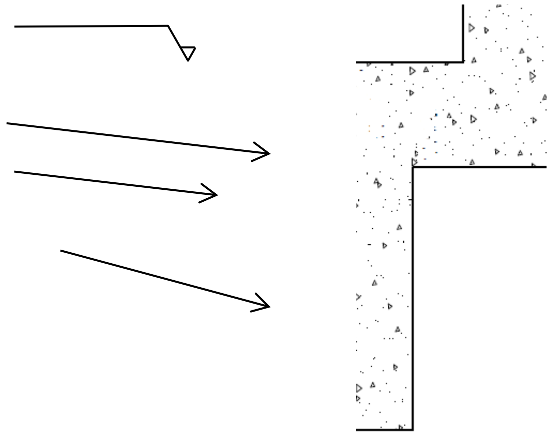

Figure 1. Sectional views of the storage pit showing the baffle plates and the source rack.

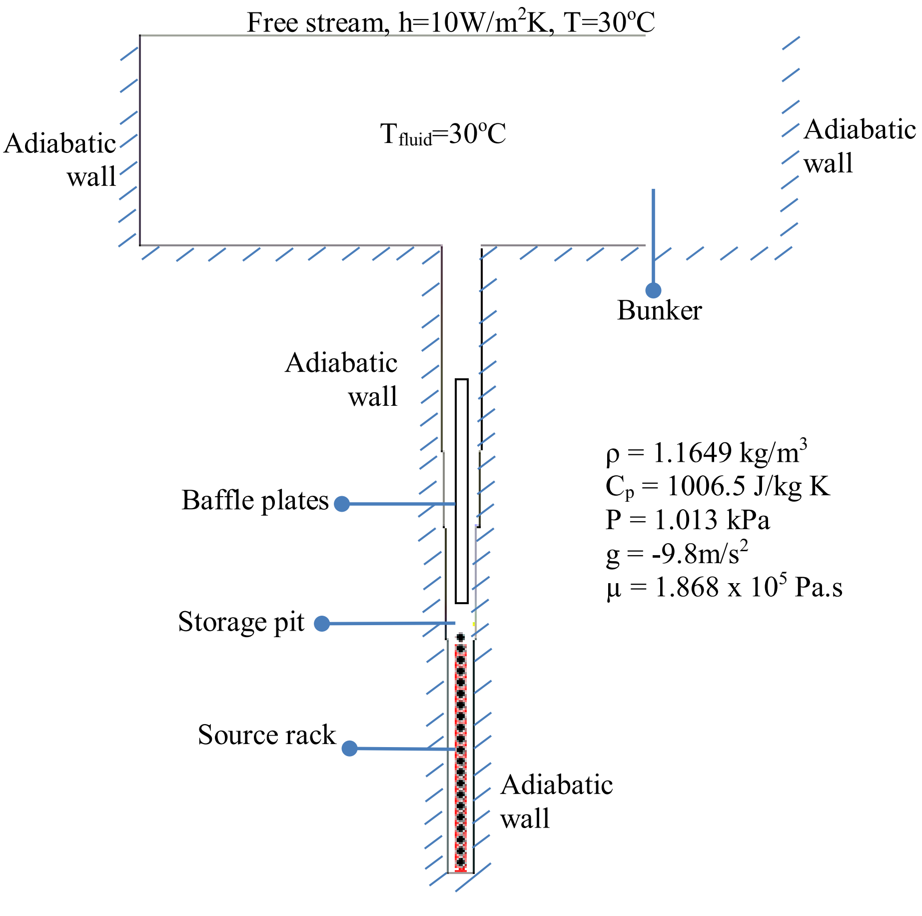

Figure 2. The schematics of the bunker, pit, baffle plates and source rack modelling including the walls conditions and air parameters.

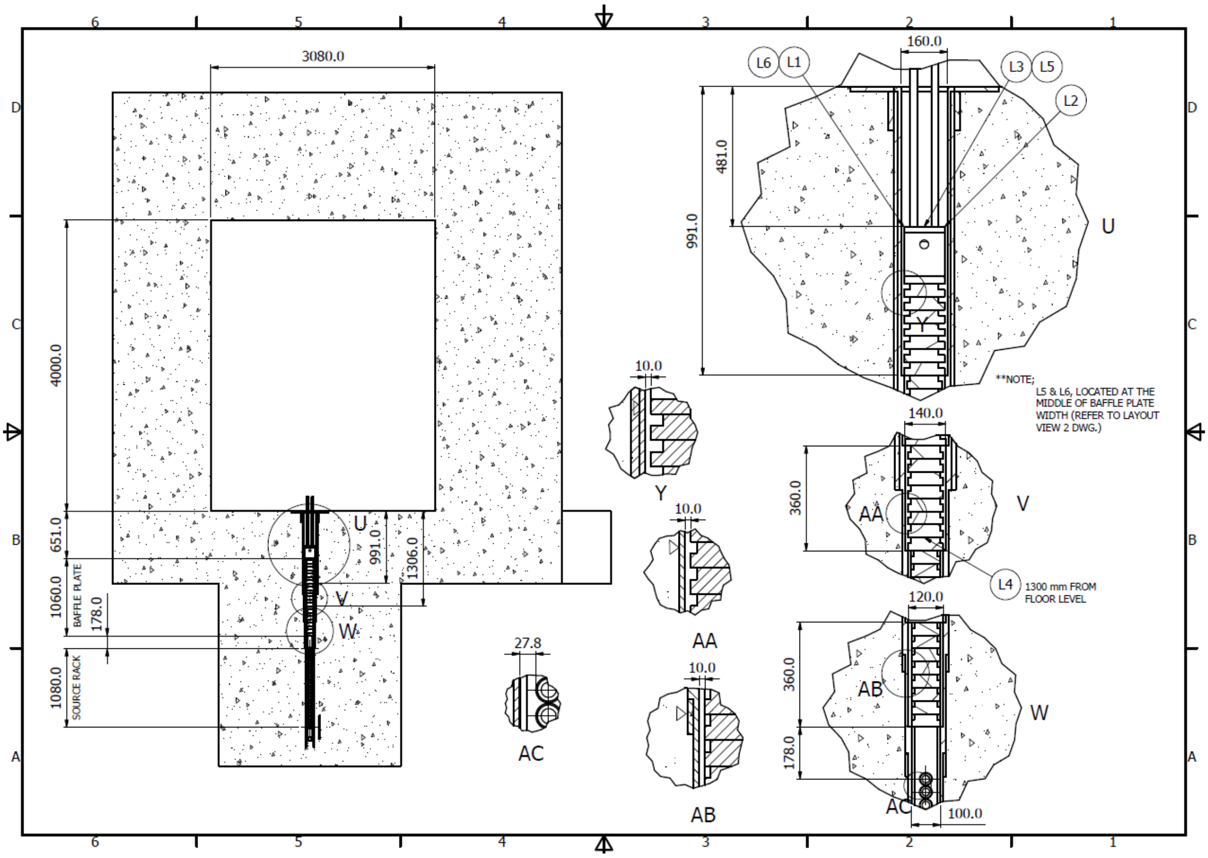

Figure 3. The cross section of the bunker, pit, baffle plates and source rack, showing the physical measurement position for L1 to L6 [5].

Table 1. Measured temperature inside the bunker and storage pit [5]

Location	PROBE 1 - T1 (°C)	PROBE 2 - T2 (°C)	Notes
Ambient	28.7	28.7	Outside bunker/room
Room	30.2	30.2	Inside bunker/room
L1	29.5	29.3	Edge of top plate
L2	29.3	29.5	Edge of top plate
L3	29.6	29.6	In between guide rail
L4	30.0	30.8	Deepest position achieved
L5	29.1	29.2	Middle of Top baffle plate
L6	30.6	30.7	Edge of Top baffle plate

3. Results and discussion

The simulation of the source, rack and air condition inside the pit and bunker was conducted on three different models as shown in Figure 4, 6 and 8. The first model was without the baffle plates to simulate a simpler version of the modeling. The second model was with the full baffle plates and the third model was with a simulated baffle plates. The full baffle plates model represented the whole length of the baffle plates above the source rack. However, due to the 2D nature of the modeling, it did not represent the true geometry of the baffle plates, where this model only represented by a single square configuration. As will be discussed further, this representation did not result in a trend similar to the measurement made in the actual facility. Therefore, the third model; a modified version of the baffle plates was modeled which showed close agreement with the actual measurement.

The result of the simulation without the baffle plates is shown in Figure 4, Figure 5 and Table 2. The temperature profile shows that the temperature inside the bunker is around 30^{0}C, almost similar to the measured value. The temperature remains the same at L3, which is at the top of the baffle plates. The temperature started to increase near L4 which is at the middle of the baffle plates, and continue to rise to about 32.8^{0}C at the sources' surface. Although, the results show close temperature values between the simulation and the measurement, however, the values show different trend as shown in Table 2. The actual measurement shows lower temperature at L3 compared to the temperature inside the bunker and at deepest position L4; whereas the simulation results shows that the temperatures inside the bunker and L3 are the same before increase at L4 and at the sources. Thus, this model's prediction does not represent the actual condition at the bunker and storage pit; and the predicted temperature value of the source at 32.85 ^{0}C might not be accurate.

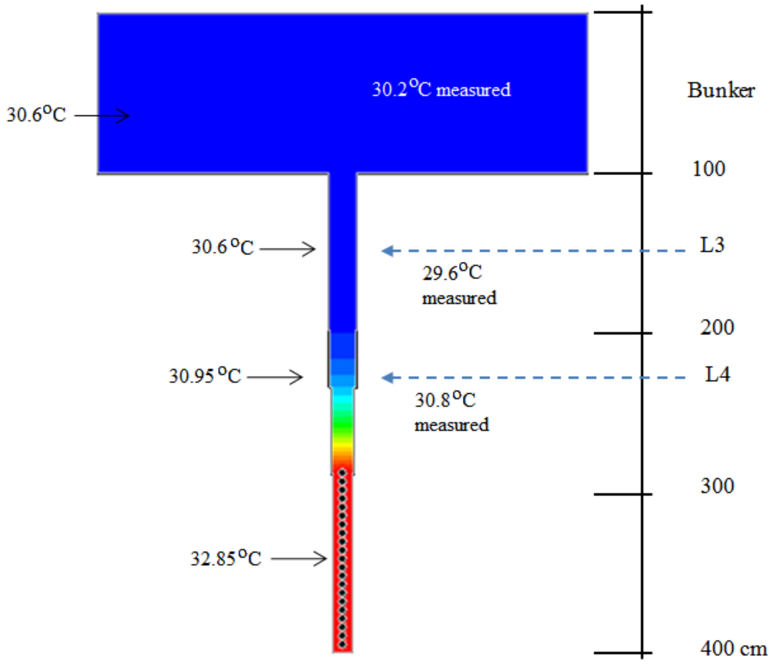

Figure 4. Temperature contour of the model without baffle plates showing measurement positions at bunker, L3 and L4 for comparison.

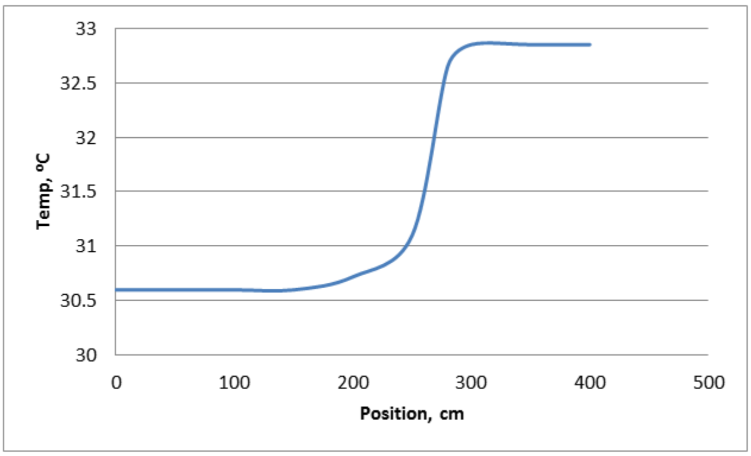

Figure 5. Temperature profile of the model without baffle plates.

Table 2. Comparison on temperatures between simulation and actual measurement for the model without baffle plates.

Position	Temperature, °C	
	Simulation	Measured
Bunker	30.60	30.2
L3	30.60	29.6
L4	30.95	30.8
Source	32.85	NA

Table 3. Comparison on temperatures between simulation and actual measurement for the model with full baffle plates.

Position	Temperature, °C	
	Simulation	Measured
Bunker	29.60	30.2
L3	25.49	29.6
L4	25.22	30.8
Source	33.85	NA

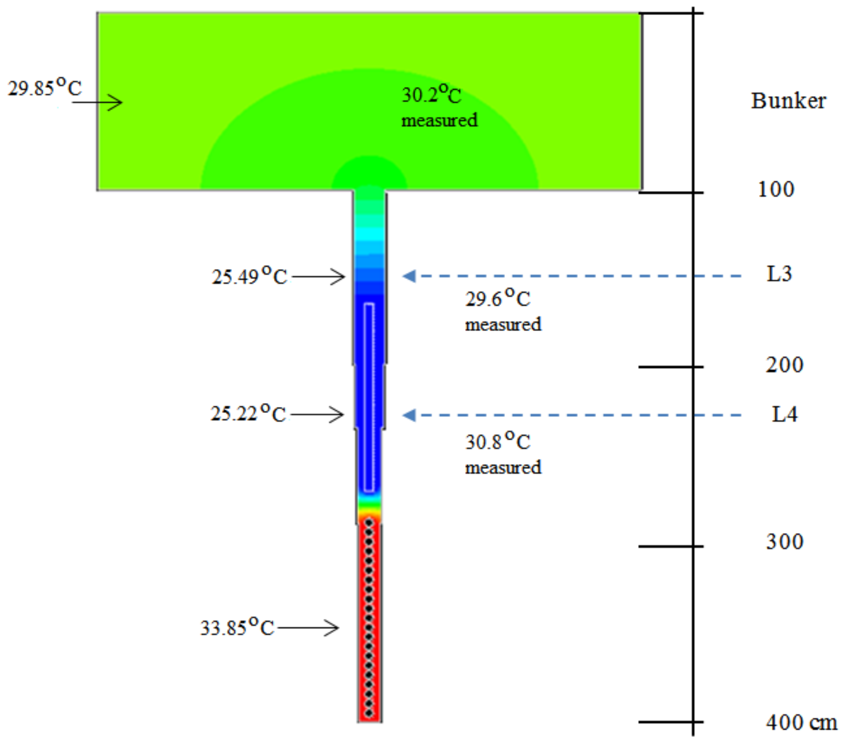

Figure 6. Temperature contour of the model with full baffle plates showing measurement positions at bunker, L3 and L4 for comparison.

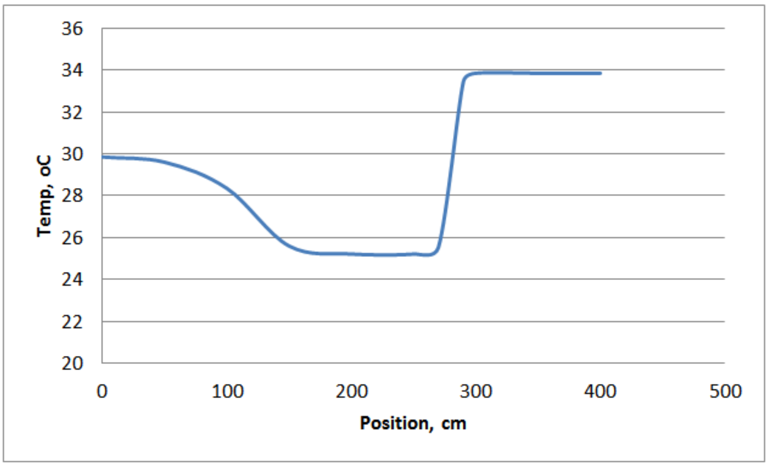

Figure 7. Temperature profile of the model with full baffle plates.

The result of the simulation with the full baffle plates is shown in Figure 6, 7 and Table 3. The temperature profile shows that the temperature inside the bunker is at 29.6^{0}C, which is a little bit lower than the measured value. The temperature starts to decrease entering the pit, and predicted at 25.49°C at L3 which is at the top of the baffle plates. The temperature decreases further to 25.22°C at L4 which is at the middle of the baffle plates and then suddenly rises up to 33.85^{0}C at the sources' surface. The results of the simulation deviate further from the actual measurement, which shows lower temperatures inside the bunker, at position L3 and L4. The trend shown in Table 3 also differed between the simulation results and the actual measurement. The measured values show that the temperature decrease at L3 and increase again at L4. The predicted values on the other hand shows decreasing trend from the bunker to L4. Thus, this model's prediction does not represent the actual condition at the bunker and storage pit and the predicted temperature value of the source at 33.85 ^{0}C might not be accurate.

As discussed earlier, since both models did not show promising results, another modelling was attempted. A model which consists of both the baffle plates and the source rack was created. In order to simulate the temperature profile similar to the actual measurement, a simulated baffle was created. Several configurations of the baffle plates were modelled and the results were compared with the actual measurement. After several attempts, simulated model in Figure 8 found to have a similar trend with the measured values. This was accomplished by modifying the baffle plates' dimension and position inside the pit. The result of the simulation with the simulated baffle plates is shown in Figure 8, 9 and Table 4. Two simulation results with different sources' temperature are presented. Table 4 shows that both of the simulations have similar trend with the actual measurement. The temperatures at L3 are lower than the temperatures inside the bunker and L4. The temperature profile for simulation 1 and simulation 2 shows that the temperature inside the bunker is at 30.55^{0}C and 30.1°C respectively. These predicted results of the bunker's temperature are very close to the measured value of 30.2°C. The temperature starts to decrease entering the pit and predicted at 29.25°C for simulation 1 and 28.94°C for simulation 2 at L3 which is at the top of the baffle plates. These predicted results at L3 are also very close to the measured value of 29.6°C. The temperature starts to increase near L4 and predicted at 30.58°C for simulation 1 and 30.52°C for simulation 2 at L4. These predicted results at L4 are also very close to the measured value of 30.8°C. Finally, with the promising result of the model inside the bunker, L3 and L4; which shows very close agreement with the measured values; the sources' surface temperature are predicted at about 33.85°C for simulation 1 and 34.85°C for simulation 2. These two predicted temperatures are much lower than the melting temperature for stainless steel cladding of the gamma sources. Therefore, the simulation shows that without the cooling mechanism inside the storage pit, the integrity of the gamma sources are still intact and sufficiently cooled by natural convection.

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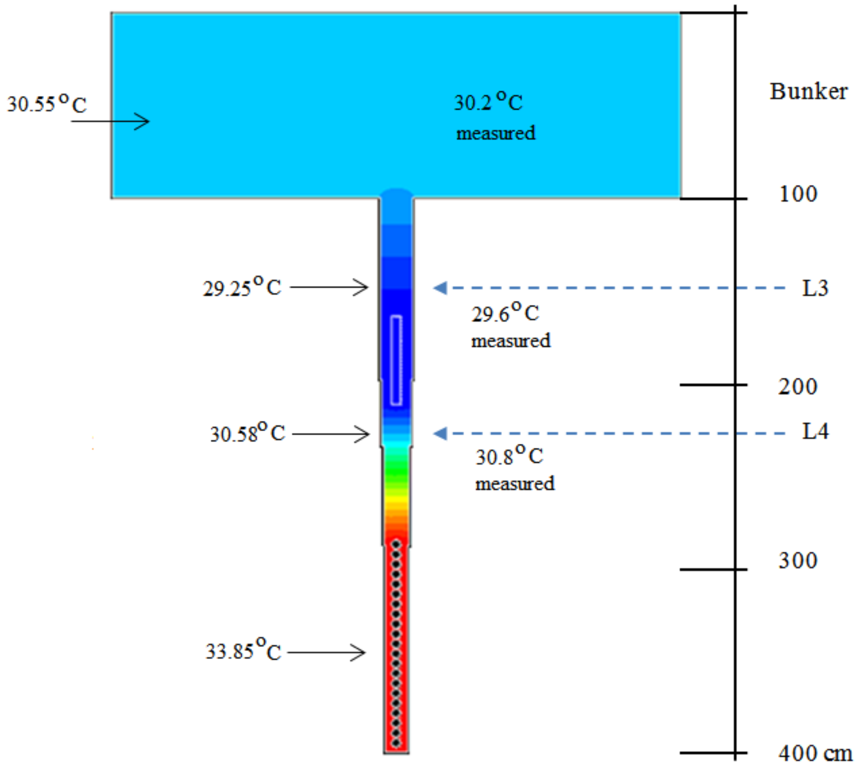

Figure 8. Temperature contour of the model with simulated baffle plates showing measurement positions at bunker, L3 and L4 for comparison.

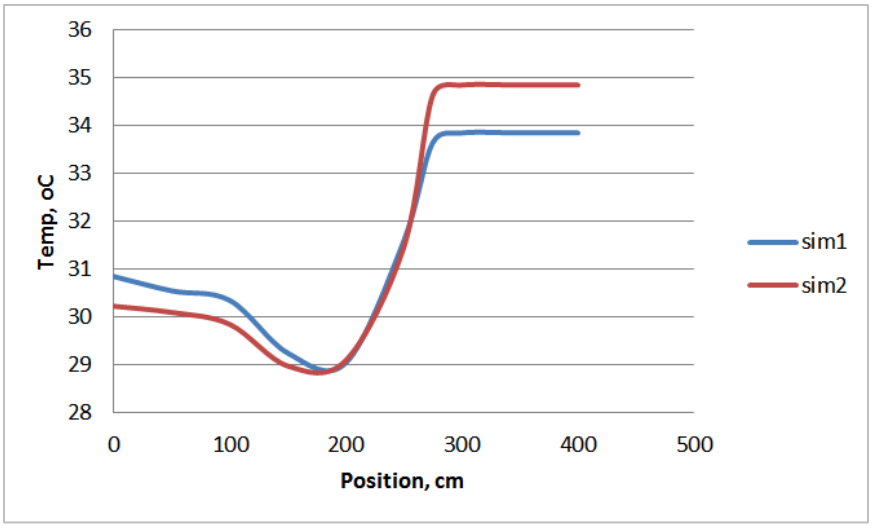

Figure 9. Temperature profile of the model with simulated baffle plates.

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Table 4. Comparison on temperatures between two simulations and actual measurement for the model with simulated baffle plates.

Position	Temp, °C		
	Simulation 1	Simulation 2	Measured
Bunker	30.55	30.1	30.2
L3	29.25	28.94	29.6
L4	30.58	30.52	30.8
Source	33.85	34.85	NA

4. Conclusion
A CFD modelling of natural cooling through natural convection was simulated inside a dry storage pit of a rack of gamma sources. The model successfully predicted the surface temperature of the gamma sources under ambient condition with the cooling system switched off. The simulation shows a close agreement with the measured values inside an actual gamma irradiation facility. The model predicted that the ambient air natural convection may keep the sources' surface temperature at about 34°C, which is much lower than the melting temperature of the stainless steel cladding, thus ensure the integrity of the sources.

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