Estimation of Fuel Rod Drop Velocity in Spent Fuel Storage Pool During CANDU Bundle handling

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1. Introduction

In domestic CANDU reactors, approximately 16 spent fuel bundles per unit are discharged daily into spent fuel pools for cooling and storage. Given the high frequency of these handling operation, there is a potential risk of individual fuel rods becoming detached from the bundle assembly.

If a fuel rod is displaced, it undergoes a free-fall motion through the cooling water until it reaches the pool floor. Accurately calculating the terminal velocity of such a falling rod is essential evaluating its structural integrity upon impact. This study aims to provide precise velocity estimation as critical input data for future safety assessments and fuel cladding durability analyses.

2. Assumption

As shown in figure 1, which illustrates the configuration of the spent fuel pool, the spent fuel bundles are positioned on a fuel tray atop the transfer workstation, approximately 2.2 m above the pool floor. During the transfer process into the storage basket using fuel handling equipment, the bundles are managed at a maximum height of 3 to 4 m. Consequently, to ensure a conservative safety margin, this study assumes a maximum drop height of 4 m for all velocity evaluations and impact analyses.

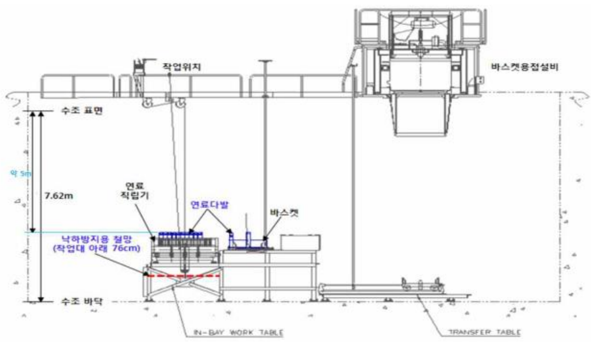

Fig. 1. Equipment Schematic for the transfer workstation

3. Methodology

The net force acting on a spent nuclear fuel rod falling inside the pool consists of gravity(F_g), buoyancy(F_b) and drag(F_d).

$$F_{net} = F_g - (F_b - F_d) = mg - \rho_w V g - \frac{1}{2}\rho_w v^2 A C_d$$

The acceleration is derived from above equation:

$$a = \frac{F_{net}}{m} = \frac{F_{net}}{\rho_s V} = \frac{\left((\rho_s - \rho_w)\, Vg - \frac{1}{2}\rho_w v^2\, AC_d\right)}{\rho_s V}$$

where, ρ represent the densities of the rod and water, respectively, A is the projected area, and C_d is drag coefficient. Calculations were performed using MATLAB with 0.001 second intervals to account for the velocity-dependent nature of drag.

4. Conclusions

The terminal velocity of fuel rod was evaluated for three drop modes from a conservative height of 4 meters:

Vertical drop : 4.8 m/s (highest velocity)
Diagonal drop : 2.7 m/s
Horizontal drop : 1.28 m/s

For a conservative mechanical integrity assessment, the vertical drop terminal velocity was rounded up and assumed to be 5 m/s. This value serves as the primary input for calculating impact stress on the fuel cladding.