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Conceptual Design on N^{16} Decay Chamber for Modified TRIGA-2000 with Plate-Type Fuel

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ABSTRACT

CONCEPTUAL DESIGN ON N^{16} DECAY CHAMBER FOR MODIFIED TRIGA-2000 WITH PLATE-TYPE FUEL. The TRIGA-2000 is a research reactor in bandung that will be modified using plate-type fuel. The reactor core cooling system is changed from the natural convection cooling mode to the forced convection mode. The purpose of the study is to assess the conceptual design for the decay chamber of N^{16} nuclide in the primary cooling system of the reactor. In this design, the hold-up system decays the nuclide of N^{16} resulted from neutron activation product. In the period of 50 seconds, the activity of N^{16} ($T_{1/2}$= 7.13 seconds) decays 7 time from half life to low level. The cube shape of decay chamber is provided a plate with 4 hollows and facility to flush the cavitation bubbles. The decay chamber, which is submerged into the bulk shielding as located outside of the reactor pool. The conceptual design uses the Fluent software compared with the analytical estimation for flow velocity in the decay chamber. The result shows a good agreement range with the analytical estimations. The uniform flow profile can be obtained at the velocity of about 0.4 m/s. Water flow life time of 50 seconds in the decay chamber with the capacity of 3.5 m^3 is able to decay the N^{16} nuclide to low level. This decay chamber is expected to contribute in completing the design of reactor primary coolant system using the forced convection mode.

ABSTRAK

DESAIN KONSEPTUAL RUANG TUNDA N^{16} UNTUK TRIGA-2000 MODIFIKASI ELEMEN BAKAR TIPE PLAT. TRIGA-2000 adalah reaktor riset di bandung yang direncanakan untuk dimodifikasi menggunakan bahan bakar tipe pelat. Sistem pendingin teras reaktor diubah dari moda pendinginan konveksi alam ke konveksi paksa. Penelitian ini bertujuan mengkaji desain konseptual ruang penunda nuklida N^{16} pada sistem pendingin primer reaktor. Dalam desain ini, sistem peluruhan (sistem *hold-up*) akan meluruhkan nuklida N^{16} yang dihasilkan dari produk aktivasi neutron. Dalam perioda 50 detik, aktivitas N^{16} ($T_{1/2}$ = 7,13 detik) meluruhkan 7 kali dari waktu paruh ke level rendah. Bentuk ruang tunda adalah kubus yang dilengkapi pelat dengan 4 lubang dan fasilitas *flushing* untuk membuang gelembung kavitasi. Ruang tunda diletakkan pada *bulk shielding* reaktor yang terletak di luar kolam reaktor. Desain konseptual ini menggunakan perangkat lunak Fluent yang dibandingkan dengan estimasi perhitungan analitis terhadap kecepatan aliran di dalam ruang tunda. Hasilnya menunjukkan adanya kesesuaian antara Fluent dengan estimasi dimana profil alirannya seragam diperoleh pada kecepatan sekitar 0,4 m/s. Waktu tempuh aliran 50 detik melalui kamar tunda dengan kapasitas 3,5 m^3 dapat meluruhkan nuklida N^{16} ke level yang rendah. Desain ruang tunda ini diharapkan dapat memberikan kontribusi dalam melengkapi desain pendingin primer reaktor menggunakan moda konveksi paksa.
Katakunci: Ruang tunda N^{16}, konveksi paksa, kecepatan aliran, TRIGA-2000, FLUENT

1. INTRODUCTION

The TRIGA-2000 Bandung is one of the research reactor in Indonesia that has been operating for more than 50 years. This pool type reactor uses the standard TRIGA fuel element. Its has been upgraded and safely operated at the power of 2000 kWth[1]. However, its operation depends on the fuel supplied by General Atomics (GA). Since GA no longer produces the TRIGA reactor fuel, and in regard with the production of domestic fuel elements, the replacement of the TRIGA reactor core from fuel cylinder to the fuel plate is planned[2,3].

The innovation to modify the reactor core using plate-type fuel has been studied which PT INUKI (Industri Nuklir Indonesia) successfully produces the plate-type fuel to be used for RSG-GAS reactor serpong.

In the modification, the reactor core cooling system must be changed from natural

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convection mode to forced convection mode. Currenly, the heat generated is directly transferred through natural convection modes and flowed by the coolant pump to the heat exchanger. In the natural convection modes, the analysis results of thermalhydraulic by plate-type fuel which indicates there is a boiling at reactor power of 2000 kWth[4]. So, the forced convection cooling mode should be operated.

In the forced convection, the primary cooling system is designed to have a downward flow through the core channel for normal operation[1,5,6].

The produced fission neutrons in the reactor core interact with the oxygen atoms present in the water, resulting in the radioactive isotope N^{16} according to the following reaction:

$$8\,O^{16} + 0\,n^{1} \rightarrow 7\,N^{16} + 1\,p^{1} \quad (1)$$

In the reaction (Equation 1), N^{16} produces high-strength radiation of gamma (ɣ) rays (6 MeV) and β particles during its decays[7,8].

In case of natural convection, the N^{16} nuclide decays in the reactor pool, meanwhile, in the forced convection mode the coolant goes straight to the outlet of reactor pool, so during reactor operation the concentration of N^{16} at the reactor may causing radiation risk to the reactor operating personnel[9]. The additional system required for the forced convection mode is utilization of N^{16} decay (hold-up system) that should decay the nuclide from neutron activation products. The coolant water flows through the decay chamber located outside the reactor pool. When the reactor in operating, therefore, the coolant water flows at the mass flow rate of about 70 kg/s.

In reactor operating condition, the primary cooling water containing highly radioactive N^{16} passes the decay chamber for a minimum of 50 seconds. In the period of 50 seconds, the activity of N^{16} ($T_{1/2}$= 7.13 seconds) decays 7 times of its half life to low level[10]. Therefore a vessel (hold-up system) which can decay the activity of N^{16} nuclides shall be provided in the reactor primary coolant system.

The purpose of this study is to assess the conceptually design of decay chamber that is used to decay the N^{16} nuclide for the plate-type fuel modified TRIGA-2000 reactor under forced convection cooling mode. So, the activity of N^{16} decays to low level.

2. METHODOLOGY

Figure 1 shows the vertical section of TRIGA-2000 reactor, the decay chamber will be placed into the bulk shielding beside of reactor pool. This conceptual design of decay chamber is intended for decay the N^{16} nuclides.

The N^{16} decay chamber is an important component of forced convection cooling mode placed on the suction side of the primary coolant pump. The problem to be considered is negative pressure which causes a saturation temperature achieved, meanwhile a bubble will occur. The next problem is the available space for the decay chamber. Several characteristic parameters related with the thermal-hydraulic design are flow rate, temperature and pressure drop[12]. An available space and the easy aspect of construction are also considered. The design of decay chamber includes its dimension data planned to be placed on bulk shielding which expected can also possibility used as temporary spent fuel storage. The following data are considered for the calculation:

a. Dimension of bulk shielding: 3.67 m x 2.74 m x 1.83 m (refers to existing space).
b. Resident time: 50 seconds (7 times decays)
c. Pipe nozzle: 0.1524 m (≈coolant pipe diameter.)
d. Water temperature: 49°C[13].

Figure 2 shows the design calculation step of decay chamber. Based on input data required the design sketch of decay chamber is determined, further the investigation of flow pattern and pressure drop is estimated.

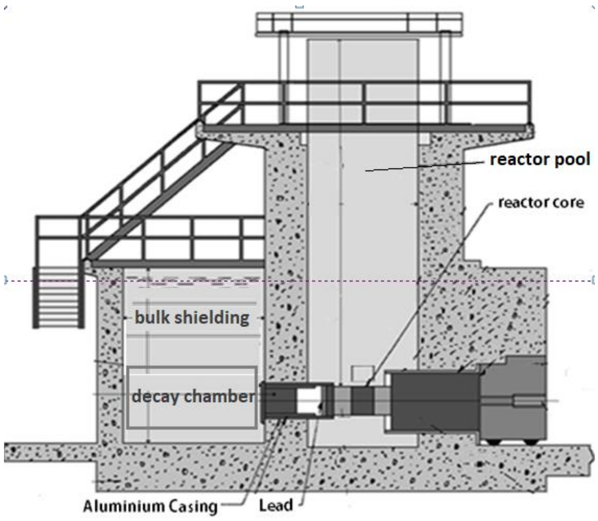

Figure 1. Vertical Section of TRIGA-2000 Reactor Bandung[11].

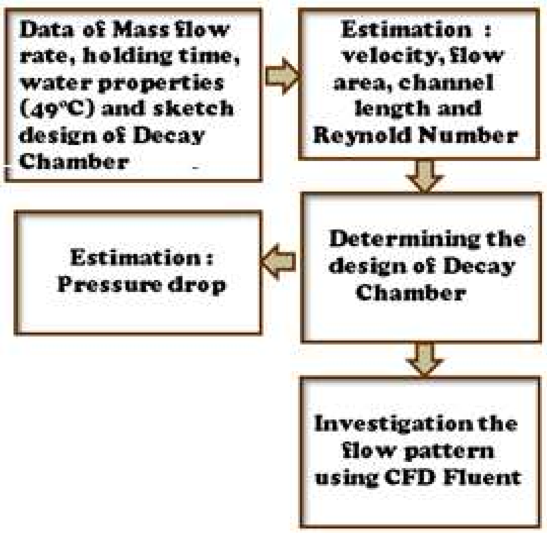

Figure 2. Step of Design Calculation.

Pressure drop (ΔP) is estimated from equation of fluid flow that flows isothermally,

$$\Delta P = (4.f\frac{L}{D} + K)\frac{\rho V^2}{2g} \qquad (2)$$

f is friction factor of turbulence flow, its determined by explicit correlation as function of Reynold number[14]:

$$f = 0.0014 + \frac{0.125}{(Re)^{0.32}} \qquad (3)$$

where,
ΔP: pressure drop, kg/m^2
D : equivalent diameter of square channel
K : loss coefficient of turn flow 180° = 1.5 (dimensionless)
V : flow velocity (m/s)
ρ : density (kg/m^3)
g : constant gravity (m/s^2)

3. RESULTS AND DISCUSSION

Figure 3 depicts a sketch of bulk shielding and position of decay chamber which the cube-shaped (blue box) are divided into 7 spatial segments. In principle, this design is based on the space and the optimum flow cross-section and minimization of the stagnant flow to obtain the length of time from the inlet to the minimum outlet of 50 seconds. The decay chambers are provided by internal hollow plate and flushing facility of cavitation bubbles and non-condensable gas as depicted in Figure 4.

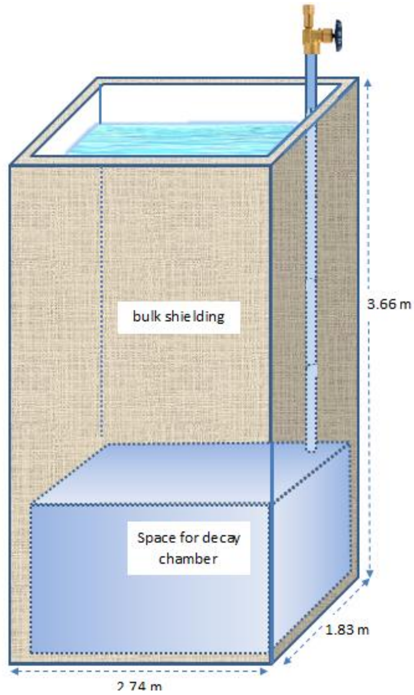

Figure 3. Sketch of Bulk Shielding and Location of Decay Chamber.

Based on the volume of available space, the decay chamber is designed as a sketch as shown in Figure 4 with the notations of flow directions are as below:

- Flow from left (inlet nozzle) to channel A
- Flow at channel A : direction to right
- Flow go down to channel B1.
- Flow at channel B1 : direction to left
- Flow to side (to channel B2)

- Flow at channel B2 : direction to right
- Flow go down to channel C2
- Flow at channel C2 : direction to left
- Flow to side (to channel C1)
- Flow at channel C1 : direction to right
- Flow go down to channel D1
- Flow at channel D1 : direction to left
- Flow to side (to channel D2)
- Flow at channel D2 : direction to right

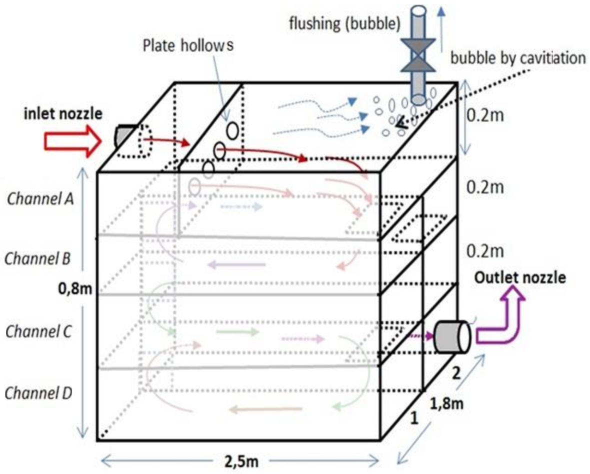

Figure 4. Design Sketch of Decay Chamber.

Table 1 shows the calculated result based on existing data as shown in the methodology in which the flow life time of 50 seconds was considered. The channels B, C and D are divided into 2 parts while the channel A is not sealed plate, so channel A has larger flow area (0.36 m^2) therefore flow velocity lower (0.20 m/s) than other channels.

Table 1. Calculation Result of Operating Parameter

Parameter	Channel A	Channel B, C, D
Mass flow_rate, kg/s	70	70
Flow area, m^2	0.36	0.18
Flow velocity, m/s	0.20	0.39
Life time of 50 second	12.857	37.143
Channel length, m	2.50	14.20
Total vol (3.5 m^3)	0.9	2.6

Meanwhile, Table 2 shows the estimation of pressure drop based on the analytical calculation (equation 2). The total pressure drop from inlet to outlet decay chamber is considered very small (0.0417 bar).

In the design sketch as shown in Figure 4, flow velocity in channel A is expected to be lower than Tayler bubble velocity of 1.96 m/s [15]. Therefore the conceptual design on the upper channel (channel A) has a larger cross section (lower flow velocity) to allow the bubble to move upward. Further, Figure 5 indicates flow pattern and flow direction in the channel A simulated using Fluent software. This figure depicts the flow pattern is less uniform. Therefore the plate with 4 hollows were provided in channel A as shown in Figure 6 by Gambit software.

Table 2. Estimation of Pressure Drop

Parameter	Channel A	Channel B, C, D
Dia equiv.(m^2)	0.36	0.3272
Flow area (m^2)	0.36	0.18
Flow velocity (m/s)	0.19	0.39
Density (kg/m^3)	992	992
Channel length (m)	2.50	15.00
Viscosity (kg/m.s)	0.000596	0.0006
Reynold number (-)	105940	211879
Gravity const (m/s^2)	9.80665	9.8067
K loss coeff.(-)	9.0	3.0
Friction factor (-)	0.0045	0.0039
Tot.pressure drop (0.0417bar)	0. 0006	0. 0411

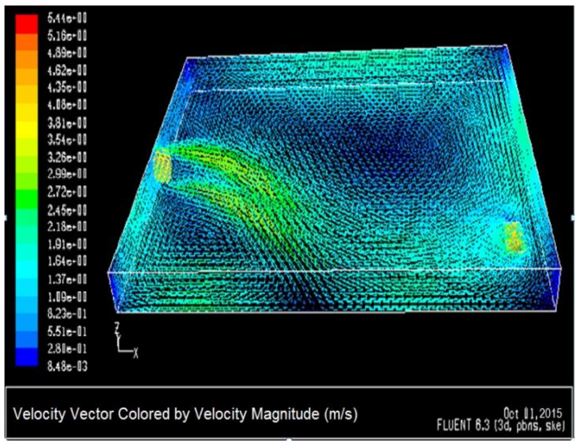

Figure 5. Flow Pattern, Channel A (Without Plate Hollow).

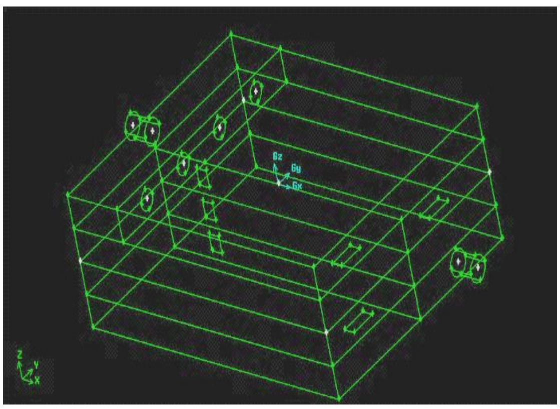

Figure 6. Sketch of Decay Chamber Design Provided With 4 Hollows.

Based on investigation result of flow pattern as well as flow life time of 50 seconds passed through the channel A, B, C and D can be obtained. But on the other hand, it should be discussed here that in the steady state reactor operation, the temperature of the decay chamber will be equal to the outlet coolant temperature of reactor core i.e. 49°C. So that the water temperature in the bulk shielding rise to 49ºC as well. Therefore, in above water pool of bulk shielding should be thermal insulated (thermal shielding). It is intended to avoid rising pool bulk shielding temperature that can increase the rate of pool water evaporation[16].

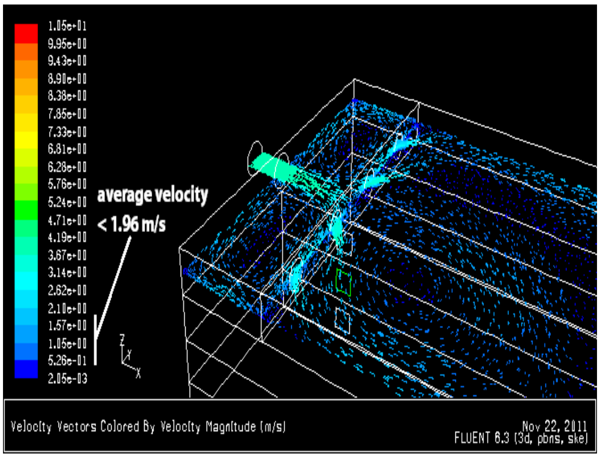

Figure 7. Velocity Pattern and Flow Channel A.

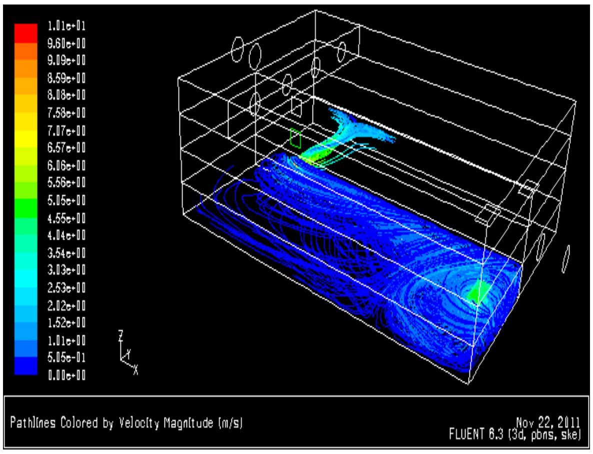

Figure 8. Flow pattern of channel D1.

4. CONCLUSION

The conceptually design of decay chamber was described. The design of decay chamber with the capacity of 3.5 m^3 and uniform flow velocity of about 0.4 m/s has been analyzed. The decay chamber with water flow lifetime of 50 seconds is able to decay the activity of N^{16} nuclide to low level. It is expected to contribute in completing the design of reactor primary coolant system using the forced convection mode. However, a thermal insulation should be provided in above water pool of bulk shielding.

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