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Routing Design on The Primary Cooling Piping System in Plate-Type Converted TRIGA 2000 Reactor Bandung

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A B S T R A C T

In 2015, research activities to modify TRIGA 2000 Reactor Bandung fuel element from cylindrical to plate-type have been initiated. By using plate-type fuel elements, core cooling process will be altered due to different generated heat distribution. The direction of cooling flow is changed from bottom-to-top natural convection to top-to-bottom forced convection. This change of flow direction requires adjustment on the cooling piping system, in order to produce simple, economical, and safe piping route. This paper will discuss the design of suitable piping routing based on pipe stress and N-16 radioactivity. The design process was carried out in several stages which include thermal-hydraulic data of reactor core to determine the process variables, followed by modeling various pipeline routes. Based on available space and ease of manufacture, four possible alternative routings were determined. Four routings were produced and analyzed to minimize the amount of N-16 radioactivity on the surface of the reactor tank, prolonging the cooling fluid travel time to reach at least five times of N-16 half-life. Subsequent pipe stress analysis using CAESAR II software was conducted to ensure that the piping system will be able to withstand various loads such as working fluid load, pipe weight, along with working temperature and pressure. The results showed that the occurred stresses were still below the safety limit as required in ASME B31.1 Code, indicated that the designed and selected pipeline routing of primary cooling system in the Plate-type Converted TRIGA 2000 Reactor Bandung has met the safety standards.

1. INTRODUCTION

It was planned that the fuel element of TRIGA 2000 Bandung reactor from General Atomic in cylinder-shaped should be replaced by produced plate-shaped fuel element, since General Atomic has already stopped producing the cylindrical-type fuel element, while the domestic production was capable of making only plate-type fuel element being used in RSG-GAS Reactor Serpong. This modification resulted in different core cooling process, due different heat distribution in the core. The direction of coolant flow in the reactor core changes from bottom-to-top natural convection to top-to-bottom forced convection, and this causes a change of the cooling fluid piping route [1,2].

To provide the simplest routing changes, easy to apply, economical and fulfilling the safety requirement, new primary cooling piping routing must be redesigned [3,4]. The design and selection process was started from core thermohydraulic data processing to obtain the temperature, pressure and

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other variables affecting the reactor operation, continued with designing several piping route alternatives, considering the radiation dose limit [5-8] and pipe stresses according to ASME B31.1 Code for Power Piping [9,10].

In general, the cooling of TRIGA 2000 Reactor Bandung is conducted in two stages. First stage is accomplished by primary cooling system which transfers the heat from reactor tank to heat exchanger, and the second stage is done by secondary cooling system which transfers the heat from heat exchanger to the cooling tower, and then to the atmospheric air. Both systems use water as the heat transfer media. The primary cooling fluid is moving from the reactor tank exit near the top of the tank to primary pump, and continued to the heat exchanger before entering the reactor tank.

In this paper, the discussion will be focused on the primary cooling system design. During the operation, the primary cooling piping system will get various load from the working fluid, its own weight, working temperature and pressure and other loads from earthquake, wind, and others [3]. These loads will cause the piping system integrity failure if the apparent stresses are higher than the allowable stresses. Finite element analysis of the chosen piping route showed that the piping system complies with ASME B3.1 Power Piping code and withstands the sustained and expansion loads during its operation. It can be concluded that the piping route will fulfill both mechanical and radioactivity safety requirements in the plate-type TRIGA reactor.

2. METHODOLOGY

The primary cooling piping system routing of plate-type TRIGA is described in Figure 3. It was intiated by the collection of dimension data, available spaces, and the operation variables obtained from thermal-hydraulic analysis. Piping routings were made after considering the available spaces and equipments position, continued with piping length calculation, N-16 travel duration and pipe stress analysis.

Several aspects must be considered during the routing process, they are:

(a) Minimum modification of current piping system to reduce the cost due to new component safety requirements
(b) Keep all existing irradiation facilities
(c) Minimum modification of equipments location due to operational reasons
(d) The direction of coolant flow in the reactor core from top to bottom is attempted to used the existing pump capability.
(e) Radioactive exposure of N-16 on top of reactor tank should fulfill IAEA safety requirement (20 mSv/year) [5]
(f) If the piping system is through the spent fuel storage, it should be sufficient after modification.

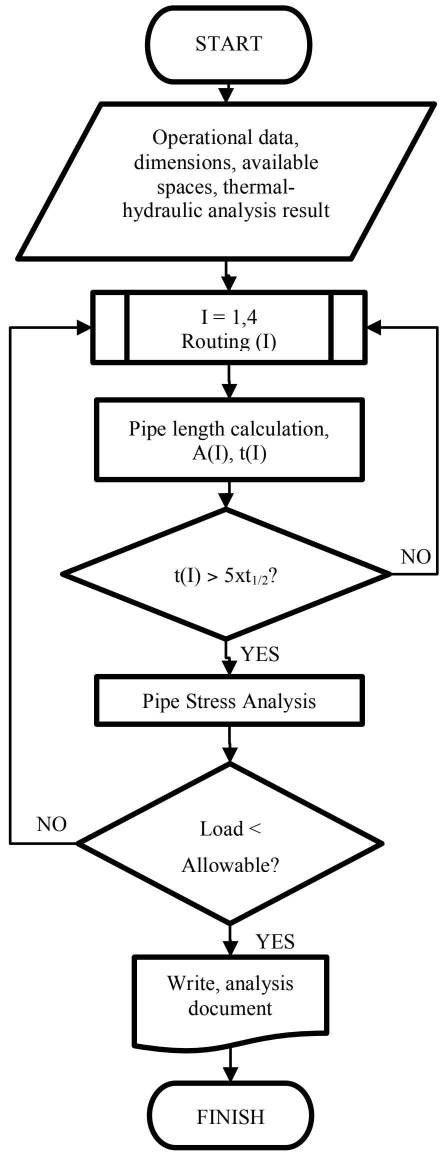

Fig. 1 Flowchart of Plate-type TRIGA reactor primary cooling piping system routing process.

Because the primary system will use forced convection, the fluid flow rate will increase and the N-16 fission product flowrate (and thus the radioactive exposure on top of the reactor tank) will also increase. To solve this problem and fulfill the requirement (e), the pipe length to the pump must be increased by designing additional pipe bundle in the temporary spent fuel storage (bulk shielding) as shown in Figure 4.

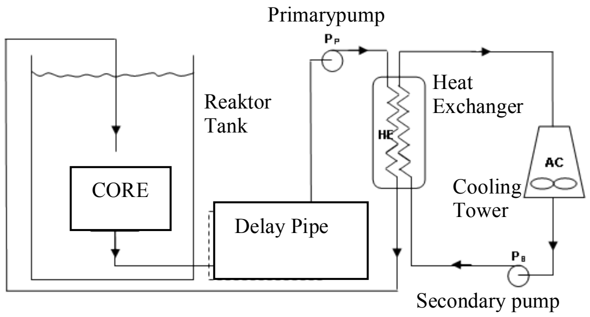

Fig.2 Modified cooling fluid system in Plate-type TRIGA Reactor [2].

In order to obtain the (a)-(d) requirements, Pump-HE routing was not modified, while HE-Reactor Tank routing was slightly modified by moving the reactor tank entry pipe to the top of reactor core, and the cooling fluid exit was also altered from the top to the bottom of the reactor tank, as shown in Figure 5, due to different cooling process as previously mentioned in the Introduction section. The piping system was altered to the bottom of the reactor tank to primary pump, continued to heat exchanger and then entering the top of reactor core tank.

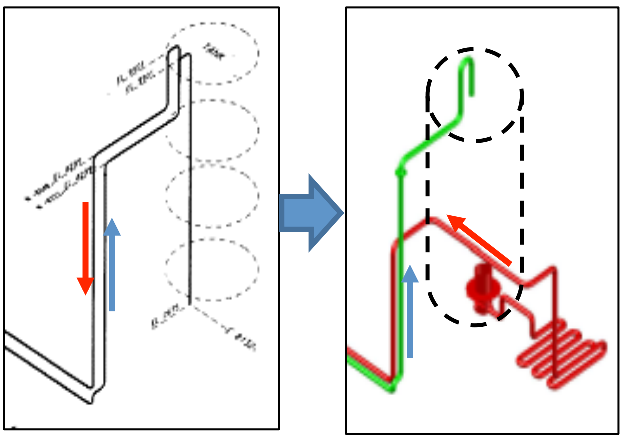

Fig.3 Original (left) and modified (right) cooling fluid system in Plate-type TRIGA Reactor.

The objective of designing the pipe bundle in the bulk shielding was to place the bundle as close as possible to the reactor tank, thereby increasing the space usage effectiveness. The number of rows in the bundle should satisfy the requirement (e), but not exceeding the requirement of spent fuel storage space requirement (f). Four routing alternatives were chosen, which differed in the number of rows in the bundle: one row for Routing No. 1, two rows for Routing No. 2, three rows for Routing No. 3, and four rows for Routing No. 4 as shown in Figure 4.

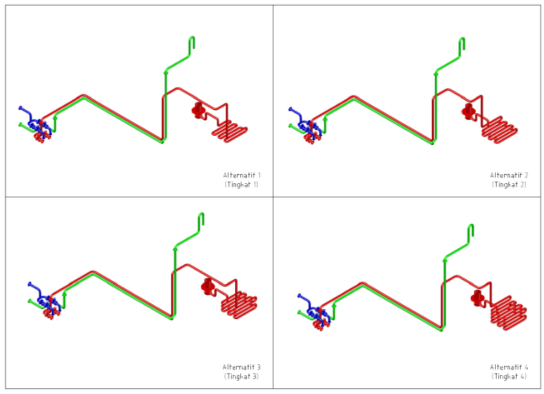

Fig.4 Original (left) and modified (right) cooling fluid system in Plate-type TRIGA Reactor.

Using the pump flow rate from thermohydraulic analysis results, subsequent calculation on the piping system length could obtain the velocity distribution in the pipe and used to predict the travel time of N-16 from the reactor core to the surface of reactor tank by the radioactivity decay equation [2]:

$$A/A_o = e^{-\lambda t} \qquad \text{(Eq. 1)}$$

with

A = Activity after decay (Ci)

A_o = Initial activity in the core (Ci)

λ = $0.693/t_{1/2}$, with $t_{1/2}$ as the half-life of N-16 (7.35 s)

t = travel (delay) time of N-16 from reactor core to tank (s).

The route selection of piping system coolant was then continued with pipe stress analysis, to ensure no failure in the piping system if various loads occurred during the reactor operation. In this case CAESAR II as a FEM (finite element method) based software was used to conduct analysis, based on ASME B31.1 Power Piping Code for industrial and commercial energy piping. The piping system stress analysis was conducted for three routes of reactor core to pump nozzle (Core-Pump model), pump to heat exchanger nozzle (Pump-HE model) and heat exchanger to reactor tank nozzle (HE-Tank model). Various piping data were used as software input, including:

1. Piping and components location
2. Working fluid 999.2 kg/m3
3. Working temperature 70 °C
4. Working pressure 4.0816 kg/cm2
5. Piping material (Aluminum alloy B241 6061 T6)
6. Nominal pipe diameter (4” and 6”)
7. Pipe thickness (according to ANSI Standard)
8. Pump type (centrifugal) (Peerles A 80, flowrate 950 gpm)

9. Heat Exchanger type (Baltimore Air Coil, EC7 plate-type)
10. Required valves, flanges and reducers
11. Pump and HE nozzle deflection data.

As load inputs, the operational load (weight, temperature, pressure, deflections), sustained loads (pressure, weight and mechanic loads) and thermal expansion loads were used to determine whether the routing has fulfilled the design requirements.

3. RESULT AND DISCUSSION

One of the main requirements of plate-type TRIGA reactor cooling system piping is that the N-16 radiation from the water surface in reactor tank does not exceed 20 mSv/year[11]. To fulfill the requirement, it is mandatory that the duration for cooling fluid to flow from reactor core to reactor tank water surface is more than five times the half-life of N-16. It was conservatively assumed that the pipe internal friction is negligible and the fastest rate of fluid flow is 3.216 m/s with decay constant of λ=0.094 l/s. The result is presented in Table 1.

Table 1. Calculation Result of N-16 Delay Time in Various Piping Alternatives

Route Alternative	Pipe Length (m)	A/Ao Fraction	Delay Time (s)
1	89.60	0.073	27.85
2	102.19	0.050	31.77
3	118.30	0.032	36.77
4	130.70	0.022	40.63

It can be seen that Route 3 piping is reducing the N-16 activity to 0.032 (3.2%), adequate to fulfil the 5 x $t_{1/2}$ N-16 requirement of 36.75 s delay time during operation of the reactor. It can also be observed that Route 4 shows longer delay time, but the cost will be higher due to its requirement of longer pipe.

It was identified that the dominant accumulated radiaton is originated from the neutron exposure of reactor core and the gamma ray exposure of N-16 in cooling fluid to the bulk shielding. According to MCNP calculation result, during the reactor operation of 2 MW power, it was predicted that the neutron and gamma exposure on top of the bulk shielding due to additional piping in delay pipe will increase to 8 μSv/h neutron exposure and 120 μSv/h gamma exposure. Considering the staffs working on top of the bulk shielding, the dose limit for the staffs must fulfill the IAEA standard of maximum 20 mSv/year or equal to 10 μSv/h; therefore, an additional lead (Pb) shield is needed [12].

For N-16 producing gamma ray with 6 MeV energy, Pb has a Tenth Value Layer (TVL) of 5 cm, i.e. by adding Pb with such thickness the exposure of N-16 should be reduced to one tenth. Therefore, adding 10 cm of Pb on top of the bulk shielding will greatly reduce the 120 μSv/h gamma exposure to 1.2 μSv/h, fulfilling the requirement in IAEA standard. Since the calculation was based on the assumption that the staffs are working eight hours a day, five days a week, the shield thickness can be reduced if the staffs working hours will be reduced.

Since Route 3 piping showed adequate results in safety aspect, subsequent calculation of primary cooling fluid piping was conducted on Route 3. Overall piping system was divided into three models of core-to-pump nozzles, pump-to-heat exchanger (HE) nozzles, and HE-to-reactor tank nozzles as shown in Figure 5 to Figure 7, respectively. The piping supports were placed based on the available spaces in existing system, and the piping stress results for the three models can be seen in Table 2.

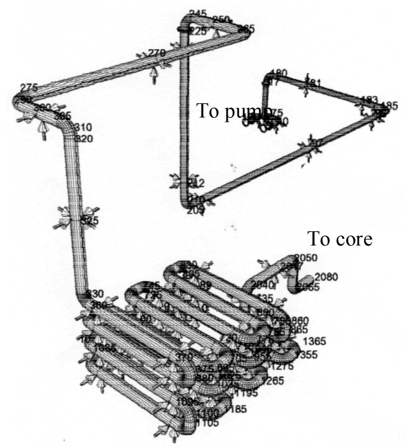

Fig. 5 Detail of Route 3: Core-Pump model

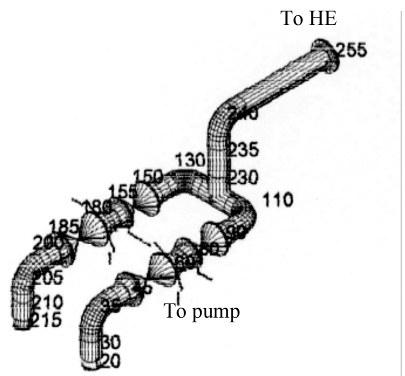

Fig. 6 Detail of Route 3: Pump-HE model

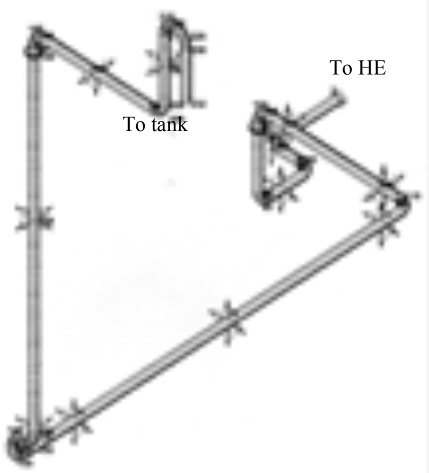

Fig. 7 Detail of Route 3: HE-Tank model

Table 2. Maximum Pipe Stress at Route 3 Models

Load Type	Core-Pump Sus.	Core-Pump Exp.	Pump-HE Sus.	Pump-HE Exp.	HE-Tank Sus.	HE-Tank Exp.
Node Number	198	189	73	120	193	129
Bending Stress (MPa)	4.6	33.3	11.9	71.1	14.1	46.3
Torsional Stress (MPa)	0.2	4.5	0.3	8.3	1.0	9.9
Axial Stress (MPa)	2.2	2.2	2.2	2.7	2.6	2.1
Code Stress (MPa)	6.7	33.3	12.2	71.1	16.1	49.1
Allowable Stress (MPa)	75.2	185.8	75.2	183.9	75.2	182.1
Code stress %	8.9	17.9	16.2	38.7	21.5	27.0

Note: Sus.: Sustained Load and Exp.: Expansion Load.

It can be seen from the table that the maximum stresses were occurred in the Pump-HE model, with 12.2 MPa and 71.1 MPa for sustained and expansion load, respectively, equal to 16.2% and 38.7% of allowable stresses. The results indicated that the apparent stresses do not result in the integrity failure of piping system. The analysis of force and moment in the pump nozzles of 4” and 6” diameter and the ones received by the nozzles of heat exchanger were also analyzed and compared with allowable force and moment as shown in Table 3. It is understood that there should be no failure in the pump and heat exchanger nozzles since no force and moment were exceeding that of allowable force and moment in the x, y and z directions

Table 3. Force and Moment at Pump and Heat Exhanger Nozzles

Load	Pump: 4” Nozzle	Pump: Allowable for 4” Dia	Pump: 6” Nozzle	Pump: Allowable for 6” Dia	Heat Exchanger (HE): HE Nozzle	Heat Exchanger (HE): Allowable
Force (N), Moment (Nm)						
F_X	17	1425.3	921	2491.7	70	4630
F_Y	-586	1781.5	-795	3117.6	967	4630
F_Z	39	1157.6	16	2048.3	-92	3780
M_X	18	1329.0	-91	2305.3	-386	2880
M_Y	-7	1003.5	-1	1763.0	64	2880
M_Z	6	678.1	9	1179.7	16	4075

All three analyses indicated that the chosen primary cooling fluid piping system routing has fulfilled the requirements of piping system design, i.e. according to the ASME B31.1 code. The final system routing is shown in Figure 8.

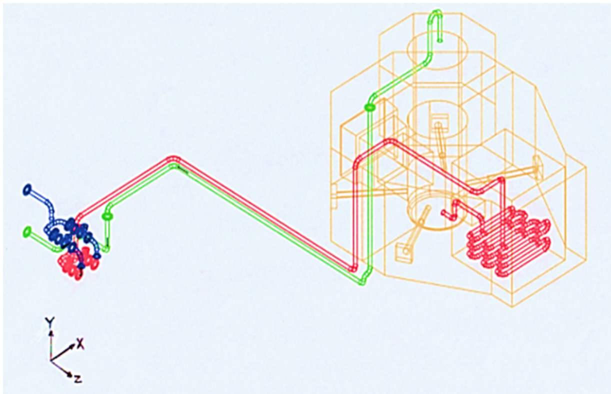

Fig.8 Isometric drawing of selected primary coolant piping route

4. CONCLUSIONS

Design and selection of primary coolant piping route in the plate-type TRIGA reactor has been conducted. The chosen piping route showed the coolant travel duration of 36.77 s, more than the required duration of 5 x $t_{1/2}$ N-16 as stated in the design requirement, resulted in the reduction of N-16 activity to the level of 3.2%. It is necessary to add a 10 cm thick lead shield over bulk shielding to ensure the safety of radiation workers.

Finite element analysis of the chosen piping route showed that the piping system complies with ASME B3.1 Power Piping code and withstands the sustained and expansion loads during its operation. It can be concluded that the piping route will fulfill both mechanical and radioactivity safety requirements in the plate-type TRIGA reactor.

5. ACKNOWLEDGEMENT

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6. REFERENCES

1. HP Rahardjo, VIS Wardhani, "The Critical point of Reactor TRIGA 2000 Bandung to TRIGA Reactor Fuel Plates". Proc.15th Seminar Nasional sains and nuclear technology Batan-Bandung, 2015, pp.137-142.
2. VIS Wardhani, HP Rahardjo, "Pengaruh Bentuk *Routi*ng Perpipaan Sistem Pendingin Primer Reaktor TRIGA Konversi terhadap Penurunan Aktivitas N-16 di Permukaan Tangki Reaktor", Journal of Nuclear Reactor Technology Tri Dasa Mega 18, 2016, pp. 145-154.
3. HP Rahardjo, "Piping Flexibility Analysis of the Primary Cooling System of TRIGA 2000 Bandung Reactor due to Earthquake". Jurnal Atom Indonesia 37. 2011, pp. 83-89.
4. PN Tambe, KK Dhande, Prof..NI Jawadar, "Flexibility and Stress Analysis of Piping System using CAESAR II-Case Study", International Journal of Engineering Reseacrch & Technology 3, 2014, pp. 370-374.
5. P Ortiz-Lopez, G Rojan and EB Padgorsak, "Radiation Protection and Safety in Radiotherapy", IAEA Publication (ISBN 92-0-107304-6), 2012, pp. 549-609.
6. N Sadeghi, Estimation of reactor power using N-16 production rate and its radiation risk assessment in Tehran research reactor (TRR). Journal Nuclear Enineering and Design 240. 2012. 3607-3610.
7. JM Kebwaro, Y Zhao, CH He. Simulation of 16O(n,p)16N reaction rate and nitrogen-16 inventory in a high performance light water reactor with one pass core. Journal Applied Radiation and Isotopes 94. 2014; 35-39.
8. Laporan Analisis Kecelakaan: Reaktor TRIGA 2000 Bandung Revisi. 3 LP-01-RE-001. 2006. pp. 11-19 (in Indonesia).
9. J. Priss and I Klevtsov, "The Program Strength Calculation in Pipeline", Proceeding of Intrernational Symposium 10th Tropical Problems in the Field of Electrical and Power Engineering, 2011, pp. 209-212.
10. ASME, ANSI B31.1, "Power Piping", American National Standard", a-2002 ADDENDA, 2003.
11. Pierson B.D., Griffin H.C., Flaska M., Katalenich J.A., Kitchen B.B., Pozzi S.A. Benchmarking of Repeatability of a Pneumatic Cyclic Neutron Activation Analysis Facility Using 16O(n,p)16N for Nuclear Forensics. International journal of Applied radiation and isotopes. 2015; 96. pp. 20-26
12. IAEA Safety Standard Radiation Protection and Safety of Radiation Source: International Basic Safety Standard. 2011.