REDESIGN, CONSTRUCTION AND COMMISSIONING OF THE DIFFUSER SYSTEM OF TRIGA 2000 REACTOR

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ABSTRACT

REDESIGN, CONSTRUCTION AND COMMISSIONING OF THE DIFFUSER SYSTEM OF TRIGA 2000 REACTOR. In the upgrading activity of TRIGA Mark II reactor, to reduce a nitrogen-16 concentration at the pool surface, a redesign and construction of a new diffuser system were performed. The diffuser system has also been tested and operated successfully. Based on the experimental data, the volumetric flow rate of the diffuser system in main pipe is 60 gallon per minute (GPM) and this result corresponds to the dispersal velocity of 2.56 m/s. For 2000 kW reactor power, the pool top dose rate varied between 30 - 50 mrad/hr. Meanwhile, when the diffuser system is off, the pool top dose increased and the values varied between 110-200 mrad/hr. The dose rate in the pool surface of TRIGA 2000 reactor at 2000 kW power is close to the dose rate of TRIGA Mark II reactor (before upgrading) at 600 kW power.

Key words : design analysis, diffuser system, nitrogen-16 activity, pool dose rate

ABSTRAK

PERANCANGAN ULANG, PEMASANGAN DAN KOMISIONING SISTEM DIFUSER REAKTOR TRIGA 2000. Dalam kegiatan peningkatan daya reaktor TRIGA Mark II, untuk mengurangi konsentrasi nitrogen-16 di permukaan air tangki reaktor telah dilakukan perancangan ulang dan pemasangan sistem difuser yang baru. Uji coba penggunaan sistem difuser ini juga sudah dilakukan dan sistem difuser dapat beroperasi dengan baik. Data percobaan menunjukkan bahwa debit aliran sistem difuser pada pipa utamanya adalah 60 GPM dan harga ini setara dengan kecepatan dispersi nosel sebesar 2.56 m/s. Pengoperasian sistem difuser pada saat daya reaktor 2000 kW menghasilkan laju dosis di permukaan air tangki antara 30 - 50 mrad/jam, sedangkan laju dosis di permukaan air tangki bila sistem difuser dimatikan adalah antara 110 - 200 mrad/jam. Besarnya laju dosis di permukaan air tangki reaktor TRIGA 2000 pada daya 2000 kW mendekati laju dosis di permukaan air tangki reaktor TRIGA Mark II (sebelum dilakukan peningkatan daya) pada daya 600 kW.

Kata kunci : analisis perancangan, sistem difuser, aktivitas nitrogen-16 , laju dosis di permukaan air tangki

INTRODUCTION

In the upgrading activity of TRIGA Mark II reactor, modification of core and cooling system were performed to accommodate the power increase [1]. For TRIGA Mark II (before upgrading), diffuser system and water purification systems are parts of primary cooling system. Meanwhile, for TRIGA 2000 reactor (a new name for TRIGA Mark II after upgrading), primary cooling system, diffuser system and water purification system are separate installation. Comparison of the water system between TRIGA Mark II 1000 kW and TRIGA 2000 are shown on Table 1.

Table 1. Water system comparison

1000 kW reactor	2000 kW reactor
Primary cooling	Primary cooling
- diffuser system	Secondary cooling
- water purification system	Diffuser system
Secondary cooling	Water purification system
Without ECCS	Equipped with passive ECCS

TRIGA Mark II reactor upgrade also includes a redesign of the diffuser system to reduce a nitrogen-16 concentration at the pool surface. The conventional technique for reducing pool top nitrogen-16 activity is to disperse the active plume rising above the core by a flat water nozzle of the diffuser system. Delay and diffusion of the reactor core convection coolant column is enhanced by the action of the coolant discharge nozzle.

In this work, a schematic drawing and components of the diffuser system are supplied by General Atomic [2]. However, they are not provided with a calculation design, detail drawing and installation procedure, so that Center for Research and Development of Nuclear Techniques (CRDNT) has to analyze and redesign the diffuser system for TRIGA 2000 reactor. In the present study, the activity will be conducted to design analysis, construction and commissioning of the diffuser system. This activity is apart of the thermal–hydraulic analysis of TRIGA 2000 reactor.

DESIGN ANALYSIS

The design of the diffuser of TRIGA 2000 reactor is based on the ability of the diffuser system to reduce a nitrogen-16 concentration at the pool surface. In the design of the diffuser system, ideally, a sufficiently deep stagnant water layer is created below the pool water surface which confines nitrogen-16 activity to lower pool regions and also acts as a shield [3].

Following a power upgrade to 500 kW of the Ohio State University Research Reactor (OSURR), by using the COMMIX-1A code, a sufficiently deep stagnant water layer can be created below the pool water surface by choosing the dispersal velocity between 0.51 - 1.53 m/s and the plume can be dispersed more effectively by increasing the dispersal mass flow rate. Meanwhile, the variation in the dispersal orientation has little effect on the pool velocity distribution [3]. The static pressure head at the core of the Ohio State University Research Reactor is the same as TRIGA 2000 reactor core (~ 1.5 bar absolute). In order to obtain the volumetric flow rate or dispersal velocity of the diffuser system, it is necessary to consider the axial velocity of coolant water caused by various reactor power. In this work, considering the dispersal velocity, reactor power and static pressure head of OSURR reactor, the dispersal velocity of the diffuser system of TRIGA 2000 reactor are choosen between 2.2 - 6.36 m/s (or 50 - 150 GPM volumetric flow rate in the main pipe) with the dispersal inclination angle of 0 degree. This value is quite conservative because the axial velocity of coolant water by natural circulation at 2000 kW reactor power is only two times of the axial velocity of coolant water at 500 kW reactor power [4].

By using the dispersal velocities, we can determine the system head curve of the diffuser system. For the determination of required diffuser pump total head, it is

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also necessary to calculate friction head losses along pipelines connected to the pump [3].

Friction Head Loss of Straight Pipe, h_f (m)

The friction head loss along a straight pipe is expressed by :

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \quad (1)$$

where : f = friction coefficient
D = pipe internal diameter (m)
L = pipe length (m)
V = average velocity inside pipe (m/s)
g = acceleration of gravity (m/s^2)

For an accurate calculation, the value of friction coefficient obtained by solving equation 2 for the turbulent region. The Moody's chart is also convenient to obtain the values of friction coefficient in term of Reynolds number and the relative roughness ε/D.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{2.51}{\mathrm{Re}\sqrt{f}} + \frac{k}{3.7D}\right] \quad (2)$$

where : k = roughness of pipe internal surface (mm)
D = pipe internal diameter (mm)
Re = Reynolds number

Head Loss at Piping Elements

Piping elements and valves produce head losses depending on respective configuration all in accordance with equation 3 which states the value of head loss is proportional to the square of flow velocity.

$$h_f = f\,\frac{V^2}{2g} \quad (3)$$

where : h_f = head loss (m)
f = head loss coefficient
V = flow velocity is determined at representative cross section (m/s)
g = acceleration of gravity (m/s^2)

Head Loss at Pipe Inlet, h_i (m)

$$h_i = f_i \frac{V^2}{2g} \tag{4}$$

where : f_i = inlet loss coefficient [4]
V = velocity after inlet (m/s)

Head Loss at Elbow, h_b (m)

$$h_b = f_b \frac{V^2}{2g} \tag{5}$$

where : f_b = elbow loss coefficient [6]
V = flow velocity (m/s)

The values of f_b are given by the equation which is a function of ratio of radius of curvature R to diameter D and turning angle θ [6]:

$$f_b = \left[0.13 + 1.847\left(\frac{D}{R}\right)^{3.5}\right](\theta/90)^{0.5} \tag{6}$$

Head Loss at Tee, h_t (m)

$$h_t = f_t \frac{V^2}{2g} \tag{7}$$

where : f_t = loss coefficient for tee [6]
V = flow velocity (m/s)

The values of f_t depend on the type and size of tee [6].

Head Loss at Valves , h_{fv} (m)

$$h_{fv} = f_v \frac{V^2}{2g} \tag{8}$$

where : f_v = valve loss coefficient
V = flow velocity upstream of valve (m/s)

The values of f_v depend on the type and size of valves [6].

Net Positive Suction Head ,NPSH

For satisfactory pump operation, it is necessary to examine the suction condition prevailing at the pump inlet. The suction condition is best expressed in terms of available net positive suction head (NPSH), which is calculated by equation 9.

$$NPSH_{av} = H_a - H_s - H_l - H_v \tag{9}$$

where : $NPSH_{av}$ = NPSH available, m
H_a = absolute pressure head acting on suction liquid level, m
H_s = actual suction head, m
H_l = friction loss head in suction pipe, m
H_v = saturated vapor pressure head, m

RESULTS AND DISCUSSIONS

Design and construction steps

Design analysis and construction of the diffuser system of TRIGA 2000 reactor have been performed. Based on the schematic drawing of the diffuser system (supplied by General Atomic) and available space around a reactor tank, the detail drawing for the diffuser system have been developed. Figures 1, 2 and 3 show the detail drawing of a top view, side view and piping component in the pool tank of the diffuser system, respectively.

All of components of diffuser system supplied by General Atomic have also been installed. The diffuser pumps is placed in northeast of the reactor tank and the diffuser nozzles located about 30 cm above the reactor chimney (see Figure 3). As indicated in Figure 3, the diffuser system has two flat water nozzle with the dispersal inclination angle of 0 degree. The diffuser system specifications of TRIGA 2000 reactor are:

- 1 (one) loop 2" piping network
- 1 (one) re-circulation (centrifugal) pump
- 2 (two) nozzles
- 2 (two) 2" isolation gate-valve
- 2 (two) 2" flow control globe-valve
- 1 (one) foot valve (back flow preventer)

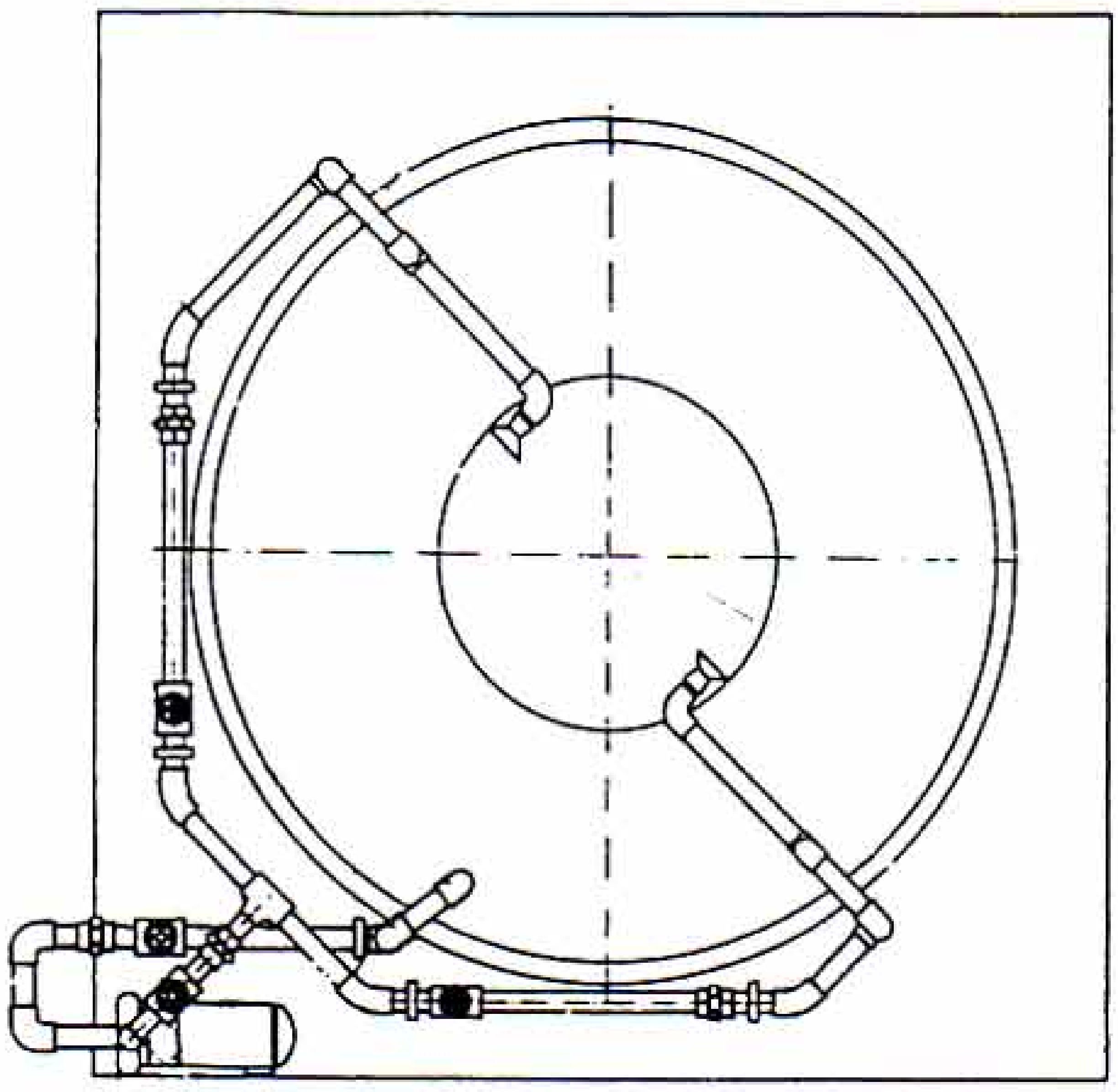

Figure 1. Top view of the diffuser system

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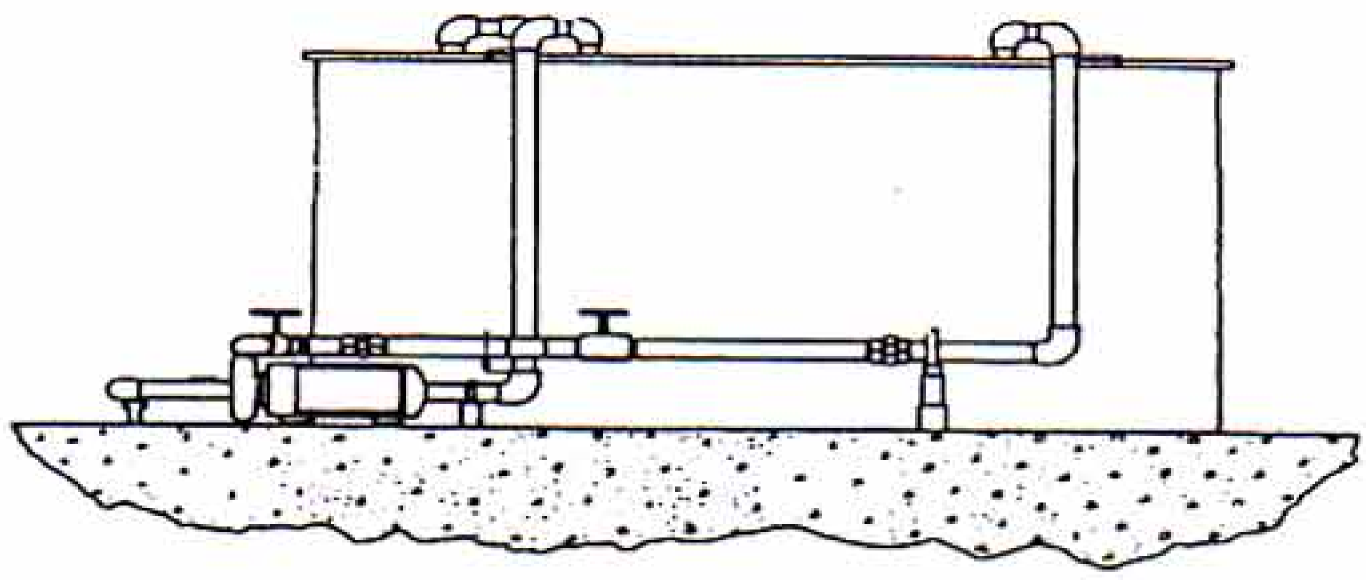

Figure 2. Side view of the diffuser system

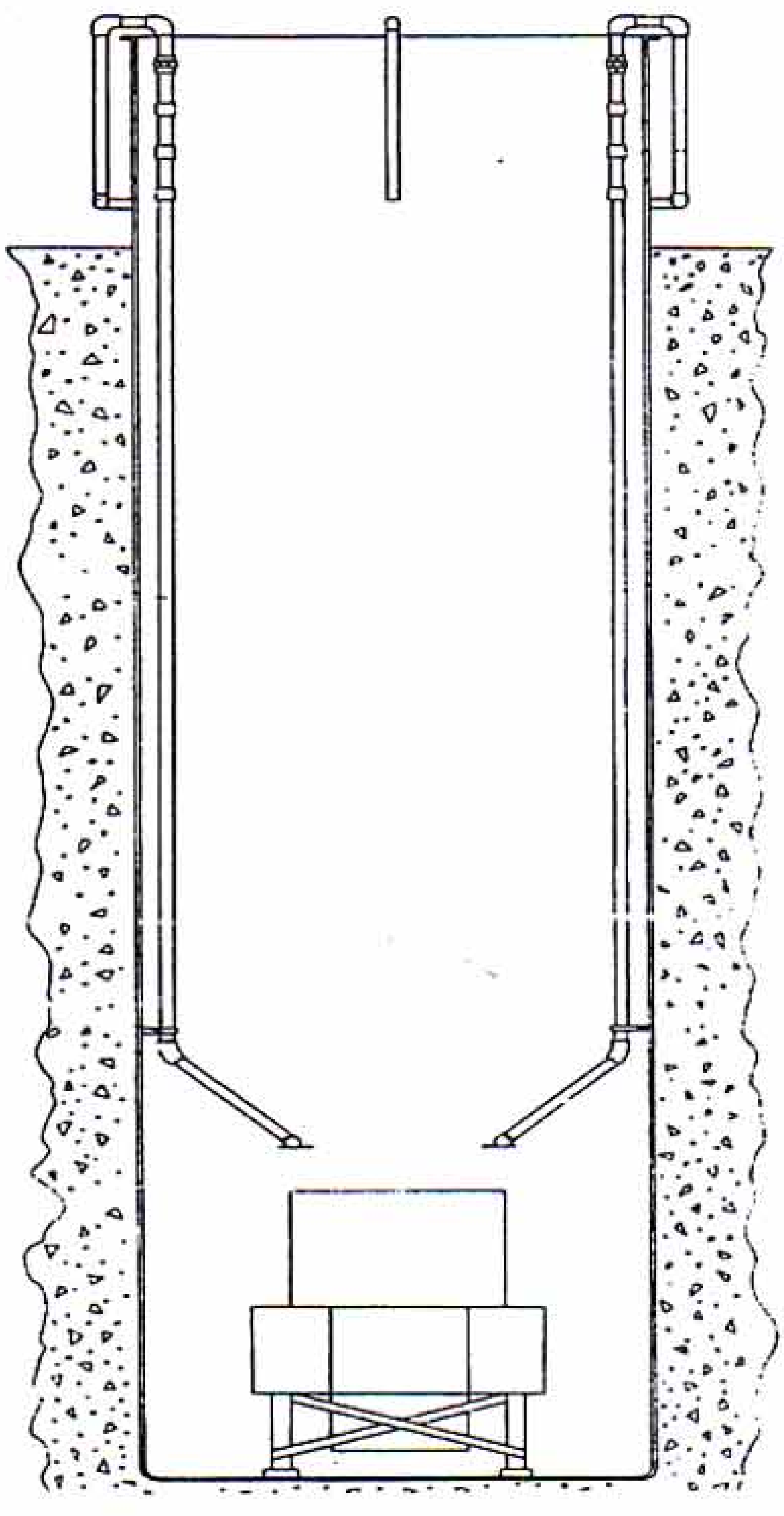

Figure 3. The piping component of the primary cooling system in the pool tank

Figure 4 shows schematically the pipe diagram of the diffuser system. In the process, the water is pumped from the upper side of the reactor pool through the piping system. After passing the piping system, the water is dispersed above the core by two flat water nozzles.

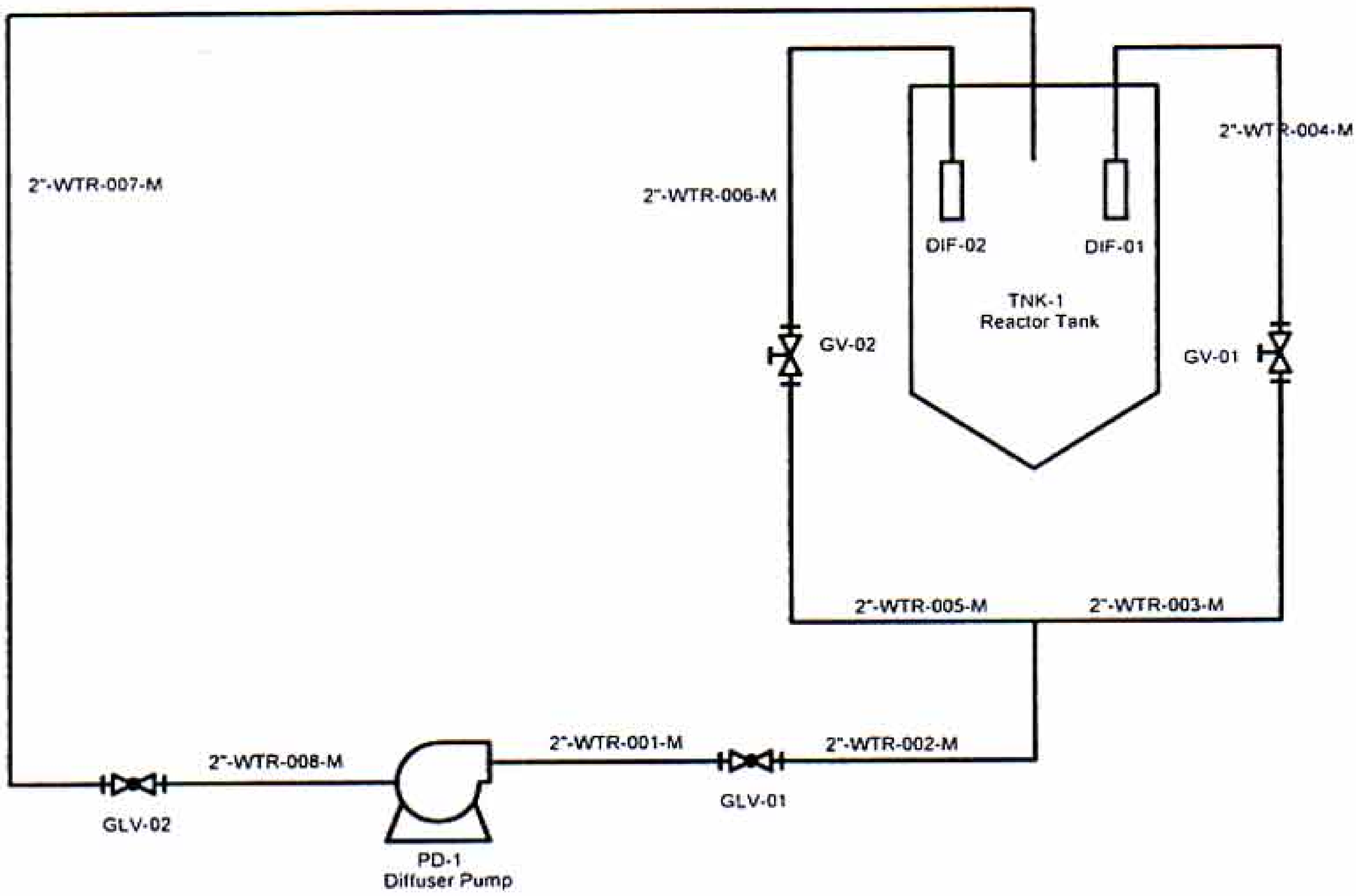

Figure 4. Pipe and instrumentation diagram of TRIGA 2000 diffuser system [7]

Results of design analysis have also given the data about a loss coefficient, and system head loss in piping system. The detail calculations of the loss coefficient of the diffuser system are listed in Table 2. As indicated in Table 2, the minor losses are higher than the losses due to pipe friction because the diffuser system has many components (as elbows, valves, nozzle and reducer). The detail calculations of the system head loss and the dispersal velocities of the diffuser system are shown in Table 3.

By using the volumetric flow rate, it is possible to develop a curve of system head loss of the diffuser system versus volumetric flow rate. The system head loss curve for the diffuser piping system is shown in Figure 5.

Table 2. Head loss characteristics

Piping element	Loss coefficient
- straight main pipes (3.375 m)	1.148
- straight main pipes (7.695 m)	3.232
Valve and fittings in main pipes	
- foot valve	8.0
- 90 elbow	5.7
- tee	1.4
- globe valve	20.7
	Total loss : 35.8
Valve and fittings in branch pipes	
- nozzle	0.56
- 90 elbow	3.80
- 45 elbow	0.90
- reducer	0.22
- gate valve	0.16
	Total loss : 5.64

The diffuser system has also been tested and the volumetric flow rate in the main pipe is 60 gallons per minute (this result corresponds to the dispersal velocity of 2.56 m/s). By graphing a system characteristic curve and the pump characteristic on the same coordinate system, the point at which the pump operated can be identified. In Figure 6, the operating point for the diffuser pump in the original system is obtained by the intersection of the pump curve and the system curve. The total head loss and net positive suction head available (NPSH) of the diffuser system for the volumetric flow rate in main pipe of 60 gallon per minute (GPM) are 7.54 and 5.1 m, respectively. Based on the design analysis (see Table 3 and Figure 5), in order to provide the stagnant layer below the pool water surface, the minimum volumetric flow rate is needed of 50 GPM and this value corresponds to the head system of 5.34 m. It means, the volumetric flow rate in main pipe or the dispersal velocity is close to the minimum dispersal velocity required to create a sufficiently deep stagnant water layer below the pool top. However, the diffuser pump characteristic supplied by General Atomic is in the range of the pump specification around 106 % of the minimum pump capacity needed.

Table 3. System head loss and coolant velocity of the diffuser system

Volumetric flow rate (GPM)	Dispersal velocity (m/s)	Head loss (m)
0	0	0
10	0.22	0.22
20	0.86	0.86
30	1.92	1.92
50	2.12	5.35
60	2.54	7.60
70	2.97	10.36
80	3.39	13.55
90	3.82	17.32
100	4.24	21.38
110	4.66	25.87
120	5.09	30.79
130	5.51	36.13
140	5.94	41.91
150	6.36	48.10

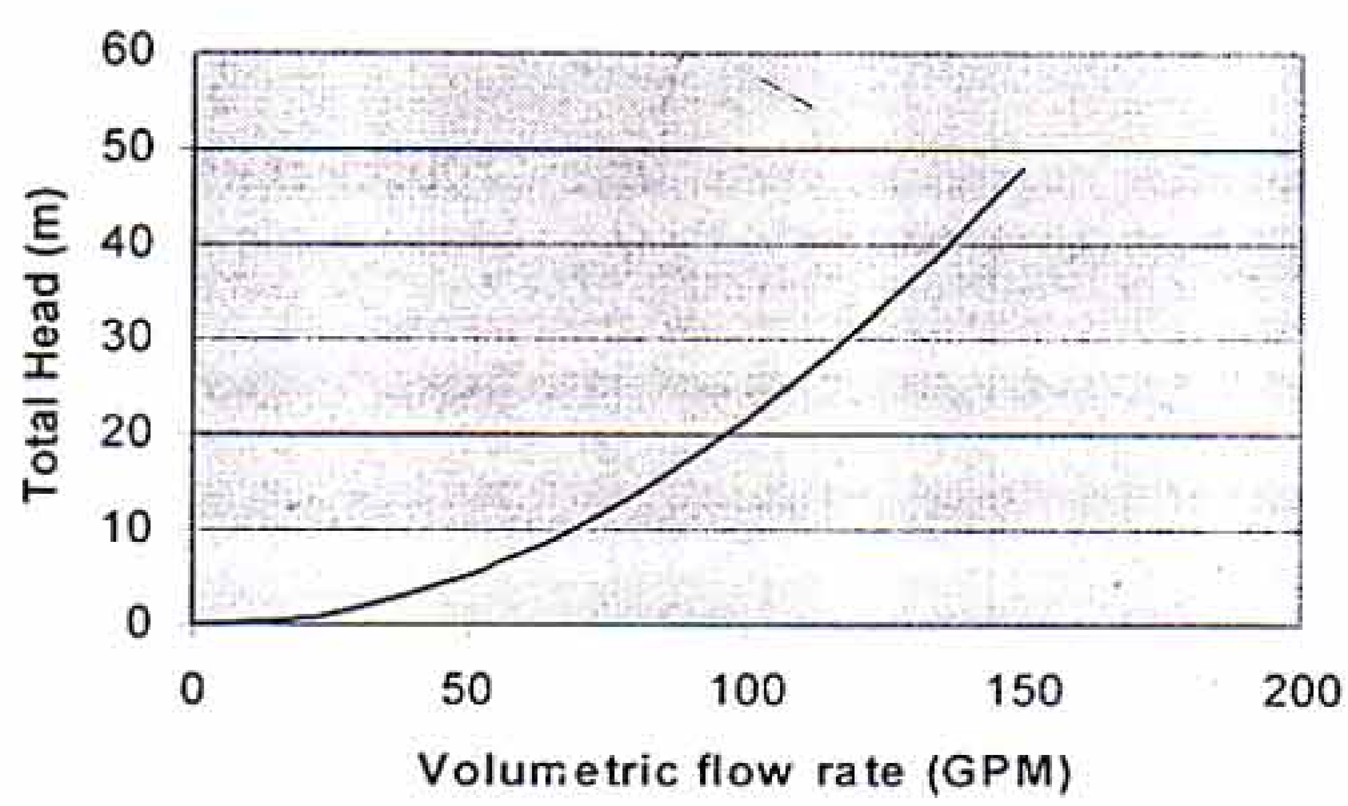

Figure 5. The system head loss curve for the diffuser

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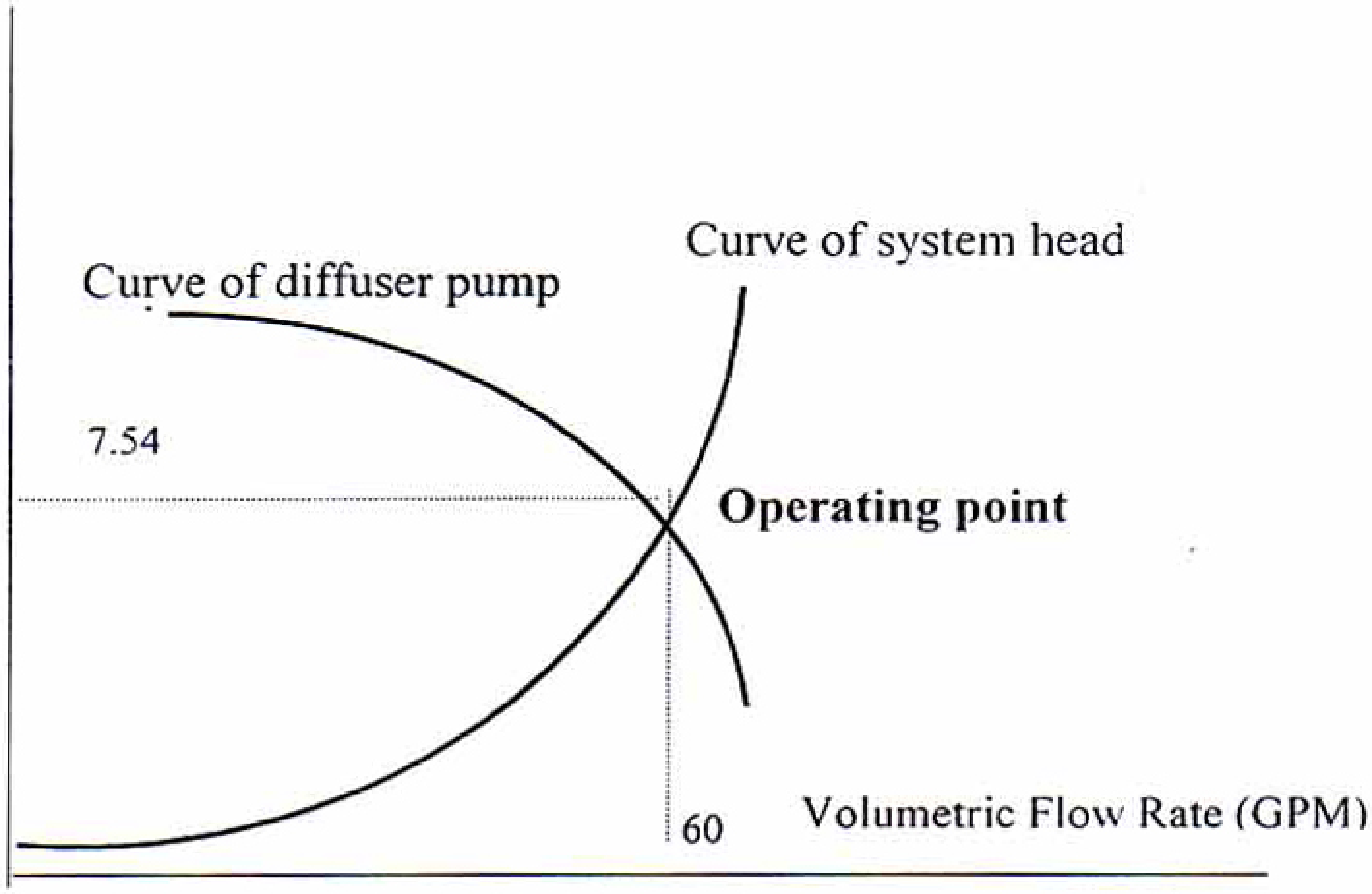

Figure 6. Operating point for the diffuser system

Commissioning step

In the commissioning activity of TRIGA 2000 reactor at 2000 kW power, the new diffuser system has been used to reduce the pool surface dose rate due to nitrogen-16. In the experiment, if the diffuser system off, the pool top dose rate varied between 110 – 200 mrad/hr. This value is lower than another 2000 kW TRIGA reactor where the value ranged between 600 - 1000 mrad/hr with no diffuser [1]. It means that an addition to the height of the new reactor tank can reduce the amount of nitrogen-16 that reached the tank surface. The height of the new reactor tank is higher about 1.5 m than TRIGA Mark II reactor before upgrading and a vertical shield is provided by 680 cm of water above the reactor core. Compared to the theoretical calculation [8], the equivalent dose in the pool surface was 9.8 mrem/h [8] and this value corresponds to the dose rate of 9.8 mrad/hr. In this calculation, the axial movement of cooling water was negligible so that the dose rate in the pool surface is lower than the experimental data. Based on this result, it is clear that the movement of nitrogen-16 to the pool surface is a contributor to increase of the radiation level at the pool surface. The experimental data also indicated that the pool top dose rate of TRIGA 2000 at 2000 kW was higher than the maximum value limit. The maximum value limit of dose rate in the pool surface was 80 mrad/hr [9].

If the diffuser system was on, the pool top dose rate varied between (30 – 50) mrad/hr. It means, with the diffuser, the quantity of nitrogen-16 at the pool surface can be greatly reduced (75 %). In the process, by using the diffuser system, interaction between the coolant water from the reactor core and the flat nozzles will cause the water-cyclone in reactor pool. The water-cyclone will increase the transit time of nitrogen-16 from core to the pool surface or reduce the rise velocity. With the smaller rise velocity, more radioactive decay will occur thus reducing the pool surface dose rate due to nitrogen-16. Further the use of the diffuser can decrease the nitrogen-16 dose rate at the surface of reactor tank. Based on the experimental data, if the diffuser system is on, the pool top dose rate of TRIGA 2000 at 2000 kW is lower than the maximum value limit [9]. Therefore, the diffuser system should be operated in the procedure of reactor operation of TRIGA 2000 reactor.

Compared to the experimental data of TRIGA Mark II reactor (before upgrading), the dose rate in the pool surface of TRIGA 2000 reactor at 2000 kW power is one half of the dose rate of TRIGA Mark II reactor (before upgrading) at 600 kW power. The pool top dose rate of TRIGA Mark II reactor at 600 kW reactor power varied between 75-90 mrad [10]. It means, the addition to the height of the reactor tank and the use of a new diffuser system can reduce the dose rate in the pool surface.

In the operation of TRIGA 2000 at 2000 kW power, bubbles appear in the reactor core and many of them collapse at the pool surface. Because of its lower density, the rise velocity of bubble is higher than the rise velocity of cooling water and it can also pass the stagnant layer, so that the quantity of nitrogen-16 reached the pool surface will increase. If the amount of bubble collapse in the pool surface increased, the dose rate in the pool surface will also increase. As indicated in the experiment, the variation of dose rate in the pool top is influenced by the amount of bubbles collapse in the pool surface. It means, the increase of dose rate in the pool surface depends not only on the rise velocity of cooling water in the reactor pool but also on the amount of bubbles collapse in the pool surface. In the experiment, it has also been observed, if the diffuser system is off, the amount of bubbles reached the pool surface also increased. Based on the experimental data, a function of the diffuser system of TRIGA 2000 reactor is not only to increase the transit time of nitrogen-16 but also to make the bubbles collapse in the reactor pool (not at the pool surface).

CONCLUSIONS

Based on the design analysis, construction and commissioning of the diffuser system of TRIGA 2000 reactor can be concluded:

1. Design and construction of the diffuser system for TRIGA 2000 reactor have been performed and the diffuser system has also been tested and operated successfully.
2. The total head and net positive suction head available (NPSH) of the diffuser system for the volumetric flow rate in main pipe of 60 gallons per second are 7.54 and 5.1m, respectively.
3. Operation at 2000 kW reactor power, the pool water surface dose rate varied between 30 - 50 mrad/hr. If the diffuser system is off, the pool water surface dose rate increased and the values varied between 110 - 200 mrad/hr.
4. The dose rate in the pool water surface of TRIGA 2000 reactor at 2000 kW is close to the dose rate of TRIGA Mark II reactor (before upgrading) at 600 kW power.