NEW SAFE REACTOR, BUT NOT FIRST OF A KIND ENGINEERING

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Abstract

NEW SAFE REACTOR BUT NOT A FIRST OF A KIND ENGINEERING is a new reactor concept to fulfil the need on Small Reactor for power generation, both for electricity and for co-generation.

Nuclear reactor system of this concept in certain degree has similar design compared to the established and successful reactor systems now in operation; so the material used for the same function and purpose is not the same.

The strategy or choice adopted in achieving this concept will be automatically shown by the inspiration or philosophy of "not to re-invent the wheel."

Based on the above mentioned strategy, a certain degree of experimental verification and justification are of course needed/necessary to know better the deviations and the differences from the existing nuclear reactor concepts and further to anticipate of course precisely engineering behaviour of the proposed concept.

Physical and engineering discussion on the proposed concept are main objectives of this paper in which most of the scope and objectives of this IAEA TCM on Small Reactors with Minimized Staffing and/or Remote Monitoring are elaborated. They are discussed in such a way to give the technical and economical background of the proposed concept.

I. INTRODUCTION

Indonesia has taken its second 25 years development plan since 1994, now is looking forward to improve its energy situation and its economy.

As can be seen in Figure 1., Indonesia is an archipelagic country consisting more than 13 thousand islands and having almost 200 million population.

Due to geographic distribution of resources of energy and lack of uniformity of population concentration in the country, the demand for electricity leads Indonesia to consider that the nuclear energy is the energy for the future.

For the most populated and developed island, the size of the nuclear power station is beginning from 600MWe, but for the other small islands and for some isolated areas, small power reactors are compatible.

To fulfil such demands, since 1991, Indonesia has carried out the complete Feasibility Study and Site Investigation for its first nuclear power plant and beginning from 1994, Bid Invitation Specification has also been undertaken. Both studies will be completed next year, and in Figure 2., time schedule for the first studies are illustrated.

THE MAP OF INDONESIA

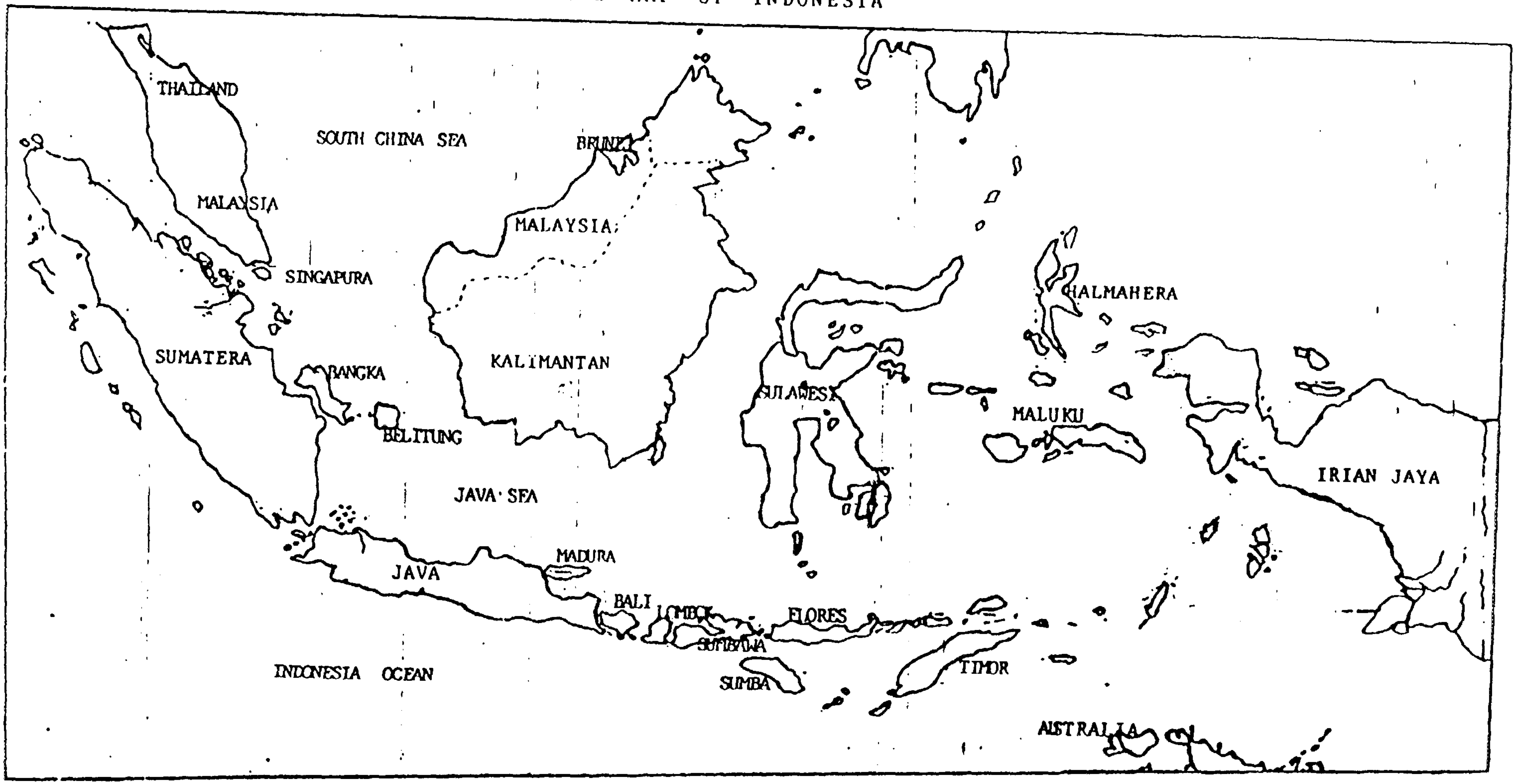
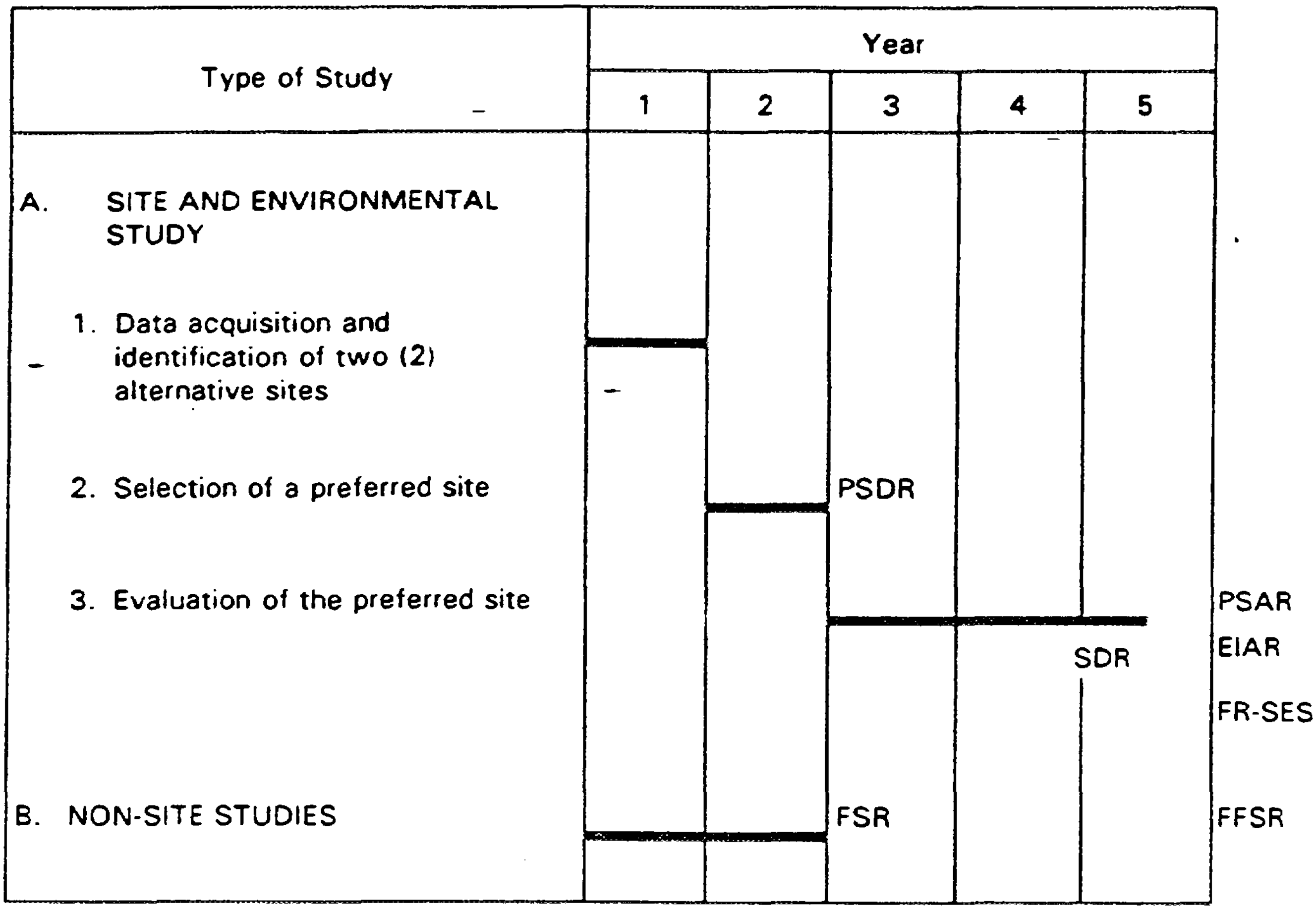


FIG. 1.



PSDR	-	Preliminary Site Data Report
FSR	-	Feasibility Study Report
SDR	-	Site Data Report
PSAR	-	Preliminary Safety Analysis Report (Site Part)
EIAR	-	Environmental Impact Analysis Report
FR-SES	-	Final Report of Site and Environmental Study
FFSR	-	Final Feasibility Study Report

FIG. 2. Time schedule of the feasibility study for a nuclear

The study for small nuclear power reactor has been initiated since late eighties, using light water and helium gas as the coolant, and since 1990, BATAN (National Atomic Energy Agency) as a responsible agency in this matter has set up a team dedicated to study related aspects of a small (mini) nuclear power reactor using light water as the coolant.

A group studying High Temperature Gas Reactor for enhance oil recovery in 1987 has become a team dedicated for high temperature reactor since 1993.

Along the line of mini reactor, the study on liquid metal reactor (Pu-burner) has also been taken place. The activity of this group was firstly communicated at IAEA meeting in Djerba Zarzes, September 6-10, 1993. the philosophy "not re-inventing the wheel" is well adopted. Most of technical or engineering aspects used in this concept are coming from proven and experienced reactor systems, so that, due to time frame, it is expected that this concept challenges the needs for small reactor in many island and isolated areas in Indonesia.

Regarding to the philosophy adopted in exploring this concept, it enables us to consider that this concept does not belong to the first of a kind engineering. To realize the prototype or the first reactor of this concept, Indonesia recommends an international cooperation under the IAEA frame work.

II. ENGINEERING CONCEPT OF THE REACTOR

From thermodynamic point of view, the higher enthalpy will give higher efficiency; and to do so, normally the thermodynamic conditions of the working fluid is translated directly to the operating condition of the primary loop of heat transport system.

High temperature and pressure steam in the Pressurized Water Reactor's (PWR) system are below the temperature and pressure of the primary coolant, on another word, to have better efficiency, we are obliged to increase the temperature and pressure of the primary system. This is the origin of the problem, where to handle complication come up, as a result of reactor operating conditions, the system becomes sophisticated, and in the same time, safety and safety related items increase and the choice of material used becomes more and more difficult.

The most recent examples is the phenomena of stress corrosion cracking found at the vessel head of some PWRs. The remedy was made by replacing material around the penetration, from inconnel 600 (T600) to inconnel 690 (T690) and the same change was also proposed-envisaged for Steam Generator piping.

The system envisaged for small islands and for isolated areas taking into account the conditions suggested by International Atomic Energy Agency (IAEA) Technical Committee Meeting (TCM), the system must be simple, be easy to operate and be easy to maintain and repair. To obtain this goal, the system has to have minimum safety and safety related items, but it does not mean that the plant safety is not adequate, compared to the existing reactors in operation.

From the considerations and criteria mentioned above, the system should always be capable of producing high temperature steam, it means that the primary coolant temperature is high and even higher than in PWRs. To minimize the pressure and to keep the function of the plant for energy production as economic as possible, lead us to use liquid metal as a coolant. Since the boiling temperature of the liquid metal is relatively high, the reasonable modification can be carried out, i.e. that the primary coolant pressure is atmospheric pressure and the temperature can be adjusted according to the type of the coolant, fuel element used, steam quality recommended and the objectives of the installation as a whole.

Another important factor is the capability of the reactor to accommodate the transient. Whatever it is the cause of the transient, the core will not produce any unstable of any power excursion. To enhance the leakage of neutron during increase of the power, both at normal or abnormal condition, the core design must have the annular part. This annular part must be able to absorb the excess neutron coming in, and if the reactor becomes bigger and bigger, this part can be used to facilitate the heat sink, in case of emergency.

The primary circuit is isolated from the secondary ones by using an intermediate heat exchanger, so the heat (energy) is transferred from liquid metal to the same liquid metal at another side. Intermediate loop is designed as such, if there is a leakage, the primary liquid metal will never come to the intermediate loop, so that the contamination of the intermediate liquid metal is expected not to occur.

III. CHOICE OF COOLANT, MODERATOR AND FUEL ELEMENT

1. **Reactor Coolant:**

To have high temperature at atmospheric pressure conditions, unitization of liquid metal as the reactor coolant is inevitable and represent a proper solution.

So far, liquid metal used as the reactor coolant is liquid sodium; it's use is well known internationally. It's chemical, physical and engineering properties are recognized in detail, in which, those properties impose many restrictions.

Considering the problems imposed by the unitization of liquid sodium, another liquid metal having physical, chemical and engineering properties affordable in technical point of view, should be introduced.

In this case, liquid metal lead having no reaction with the air, transparent and from neutronic point of view has very low neutron absorption (isotope Pb 208) is interesting, to be used as the reactor coolant. It's melting point is around 320C and it's boiling temperature is about 1500C.

Using the inlet coolant temperature of 360C, according to the design, the outlet coolant temperature can range between 400C and 750C. It depends on the objective and on fuel element used, the outlet temperature of the liquid lead can be adjusted. In this case, desalination does not belong to the objective; and the high pressure and temperature steam can be used for electricity generation and for enhancing oil recovery.

Assuming that in many islands and isolated areas in Indonesia, the main objectives are only in the need for electricity and potable water; the reactor inlet temperature must be adjusted to enable us to use the steam produced by the installation. In this case, mix of lead and bismuth is inevitable, making the alloy of Pb-Bi, the melting point will reduce. Lead bismuth entectic melts at 125C and various tritectics have melting point in the mid ninety Celsius range.

With inlet coolant temperature around 150C, it can produced the outlet coolant temperature beginning from 250C to 450C.

The second scenario is much more realistic compared to the first one, if the reactor is intended to supply electricity and to produce desalted water.

Dealing with the material that will be used in the reactor core, it's pure concentration on the degree of impurity must be well verified, in order the possibility of contamination can be reduced as much as possible.

2. **Reactor Moderator:**

There are two types of moderators, the first type is liquid moderator like light water, heavy water and another type is the solid one like graphite.

According to the operating conditions derived from the possible objectives elaborated above, utilization of liquid moderator is impossible, and it is automatically that the more relevant one for these objectives is graphite.

Graphite material is an effective moderator and can be used in high temperature environment. The compatibility between graphite and liquid lead is very amazing, where the solubility of lead in graphite is very low.

Graphite block having the hole in the centre, as the annulator part, will of course contain many holes (smaller than annular part) to accommodate fuel channel, control rods, instrumentations, etc. Since temperature maximum of the operating condition is much less than 1000C, it is not necessary to be cooled.

The core structure is similar to the CANDU core structure, but for this reactor system, the core is vertical, where the absorber material can be inserted by gravity force and passive safety features can be explored as much as possible.

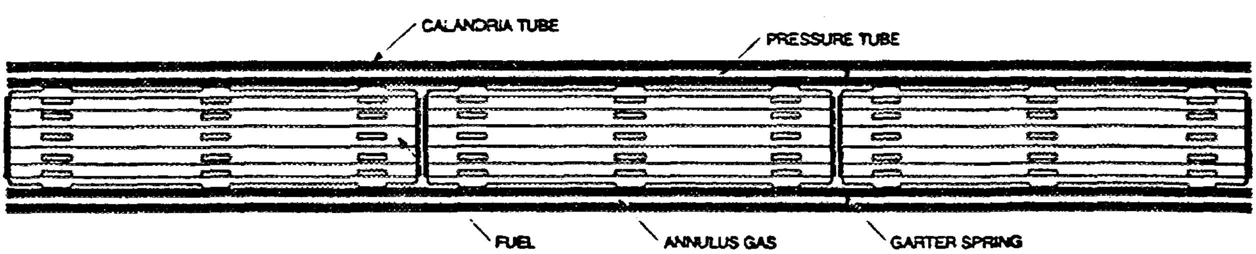
3- **Reactor Fuel:**

As explained in the above paragraph, fuel element should be introduced into the fuel channel, and this can be carried out through the upper part of the reactor core.

The pitch of the fuel may be the same or greater that in CANDU, but the length of fuel bundle is the same. The fuel assembly design adopted is coming from CANDU6 fuel design; where in one bundle exists 37 rods of fuel, and each rod has the same outer dimensions. It is worth to mention here that the cladding thickness may be different.

The number of fuel bundle per each fuel channel is the same, but they are surely less than 12 bundles as used in CANDU; and they are not subject to daily refuelling methods. Fuel management patterns will be defined through burn up calculation. One third of the fuel channel will be unloaded and loaded at the end of a cycle and due to the fuel management pattern defined before, out-in shuffling is undertaken. The fuel bundles in the fuel channel will look like as follows:

FUEL CHANNEL DETAIL WITHIN CALANDRIA



In this concept, there is no annulus gas, garter spring and calandria tube unifies with pressure tube. The main reason for this simplification is that the operating pressure of this system is atmospheric pressure and it has graphite moderator, which in case of leakage, there in no negative effect in the neutronic point of view and besides that the solubility of lead in the graphite is very low.

The choice of the fuel meat is determined by the conditions imposed to the system in the aspect of reactor operation, maintenance and safety. These conditions oblige the fuel element to have the following features:

- excellent prompt negative coefficien.
- good performance record.
- largely used and good availability.

Triga reactors have been used worldwide, both in developed and in developing countries, so they have been operated in more than a dozen countries. Indonesia has operated Triga reactor since 1964 at Bandung Reactor Centre.

Triga is a research reactor, operate at low temperature and at atmospheric pressure, and so far, they have developed-exported 5 types of fuel elements, namely:

- F 104 using 8.5% uranium content
- F 106 using 12.0% uranium content
- F 20/20 using 20.0$ uranium content
- F 20/30 using 30.0% uranium content
- F 20/40 using 45.0% uranium content

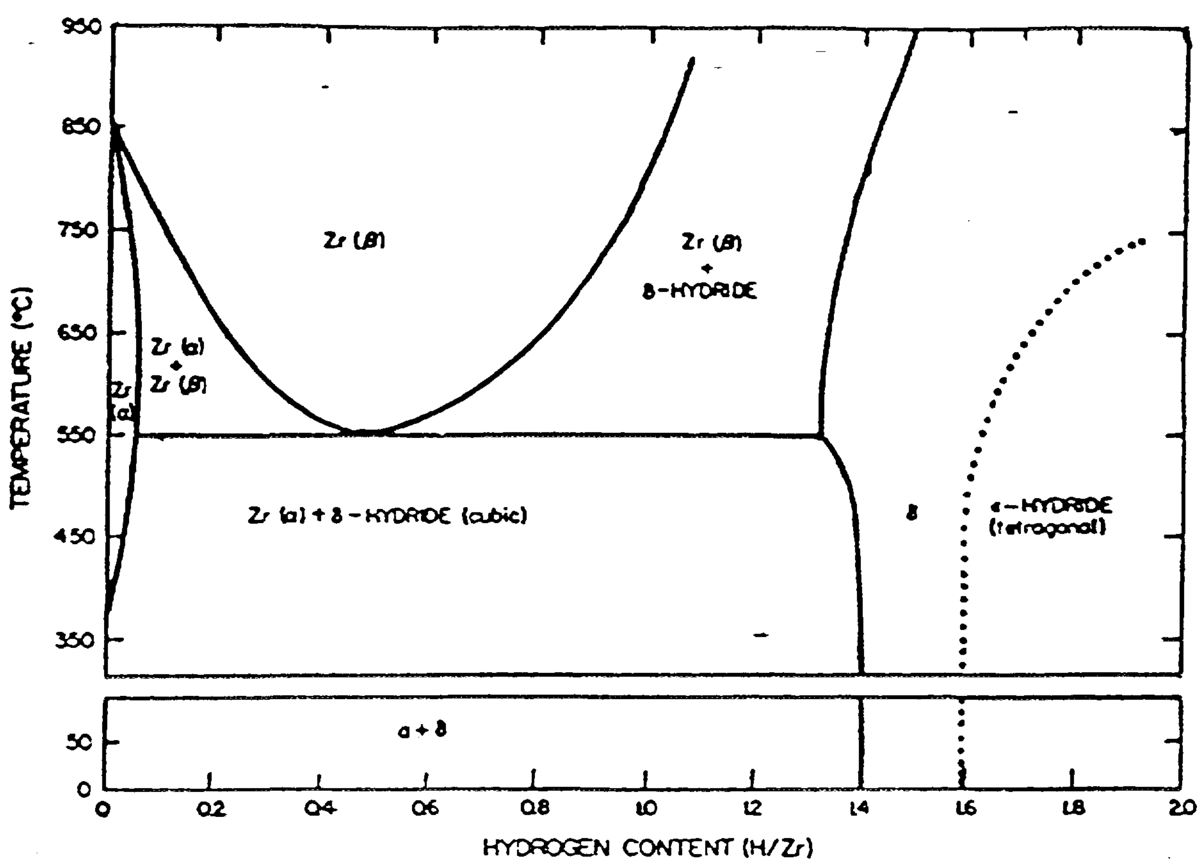
The first 4 types are in the form of fuel rod, and the last one is in the form of cluster, consisting of 16, 25 and 36 fuel rods. The dimensions of a cluster is more or less the same with outer dimension of MTR plate type fuel.

Triga fuel use UZrH as the fuel meat, the hydrogen bound in the atom Zirconium oscillate, and when epithermic neutron comes into head on collision with that hydrogen atom, the neutron will lose its energy and become thermal neutron and can enhance the fission reaction.

When the power increases, the hydrogen oscillates faster, at that situation if a neutron come and head on collision takes place, the neutron gets some more energy, so it becomes faster and faster. This fast neutron will lower the probability to have fission reaction, and so, the power decrease.

Prompt negative coefficient of Triga fuel is well known, and for fuel having higher uranium content, they use Erbium as the burnable poison to compensate excess reactivity.

Potential application of Triga fuel for power reactor (at high temperature) can be justified through the phase diagram of the fuel, as below:



From the phase diagram illustrated above, at around 1000C, Triga fuel having hydrogen to zirconium ratio equal 1.6, the fuel still stable; and mechanical properties at high and low temperatures are still coherence.

IV. CONCLUSION

1. As seen in this study, almost all sub-systems have been utilized in the other reactors that have already been in operation since many years.

2. Utilization of lead liquid metal and lead bismuth liquid alloy is still limited, verification is necessary.

3. Since the condition of reactor operation is determined by the objectives, choice of the coolant between lead liquid metal and lead bismuth liquid alloy can be derived according to the objectives taken into action.

4. Configuration of the whole system can also be obtained from many exercises and with the references to the existing or to the proposed concepts already discussed in many meetings and seminars.

5.. International cooperation will enable the realization of the project, share on the risks and on the market available can facilitate the task.

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