Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Regulatory Issues on the Safety Distance between HTGR and Hydrogen Production System

H. S. Kang,[a] S. B. Kim,[a] W. J. Lee,[a] H. C. No [b]

a Korea Atomic Energy Research Institute, P. O. Box 105,Yuseong,Taejon, Korea, 305-600, hskang3@kaeri.re.kr
b Korea Advanced Institute of Science and Technology, 373-1, Guseong,Yuseong,Taejon,Korea, 305-701,

1. Introduction

A High Temperature Gas-Cooled Reactor (HTGR), which would be connected to a hydrogen production system, has being developed at KAERI [1]. The HTGR and the hydrogen production system should be designed and constructed according to national regulations and technical standards, respectively. One of the regulations to be issued may be a safety distance between the HTGR and the hydrogen production system because this regulation definitely affects the necessary land site and the interfacial heat transfer system for the two plants. However, the specific regulation for the safety distance relating the HTGR has not been published as yet. The only available regulations are regarding to the safety distances defined as a distabce, which assure the integrity of a structure and people from a hypothetical gas explosion near to a storage facility containing highly combustible gases [2,3,4]. This distance was generally determined based on the maximum overpressure which could not damage a structure or people. Therefore, an investigation into the safety distance regulations including the overpressure is needed to establish a methodology for the determination of the safety distance between the HTGR and the hydrogen production system.

2. Regulations of Safety Distances

Most countries follow the regulation of America such as Code of Federal Regulations (CFR), National Fire Protect Association (NFPA), and U. S. Regulatory Guide (RG) as for their safety distance regulations. Germany uses its own regulation "Protection of Nuclear Power Plant with Respect to Their Stability and Induced Waves as well as by Safety Distances" [3]. The regulations showed the maximum overpressure to which a structure or a human is endurable under a hypothetical gas explosion (Table 1), and the safety distance from the center of the hypothetical explosion was usually calculated by the Trinitrotoluene (TNT) equivalent method based on the overpressure limit [3,5]. In U.S.A, the separation requirements for a hydrogen production and high temperature nuclear reactor were investigated in terms of a Probability Risk Assessment (PSA) based on RG 1.174 by Idaho National Laboratory (INL) [4]. INL suggested that the separation distance should be at least 110m, and using mitigating barriers may decrease this distance. Intensive research on the safety distances was performed in Japan because JAERI had a High Temperature Test Reactor (HTTR) and a hydrogen production system. JAERI set up the safety distance of 175m from by installing a barrier originally assigned distance of 1,900m to meet the overpressure requirement of 10 kPa on a reactor building [2].

Table 1 Safety Distance Regulations in Several Countries [2,3,4]

	Regulation	Overpressure / Object	Recommended Safety Distance	TNT
U.S.A [2,4]	RG 1.91 (RG : U.S. Regulatory Guide)	7 kPa / Structure	R [m] = k*$W^{1/3}$ -k [m/$kg^{1/3}$] : 18 -W [kg] : TNT equivalent mass	O
	RG 1.174 (Risk-informed)	10~30 kPa / Structure	> 110m [4] (may decrease with barrier)	X
Japan [2]	RG 1.91	10 kPa / Structure (Concrete Temp. ≤ 175℃)	175 m with Barrier [2]	O
	BMI	15 kPa / Human	205m for 400m^3 LNG Tank	O
Germany [3]	BMI, TRB 810 (BMI : German Federal Ministry of Interior)	15 kPa / Human	120m for 300 ton Liquid Gas Tank R =k*$W^{1/3}$ -k : 2.5~8 for Working building 8~22 for Neutral Building 22 for Residential Building 200 for No Damage	O
France [2]	CFR 29 NFPA 50A, 50B	14 kPa / Fireman	220m for 4 ton H_2 tank	O
		5 kPa / Human	550m for 4 ton H_2 tank	

3. Prediction Method of a Safety Distance and Overpressure

3.1 TNT equivalent method

In the TNT equivalent method, which gives a bound calculation result for a safety distance, the conservative assumption was used that a detonation shock wave always occurred when a gas explosion happened [3,5]. In order to use the TNT equivalent method, the equivalent weight of TNT (W_{TNT}, Eq. 1) for the combustible gas used as the fuel of a gas explosion was calculated under the assumption that the combustion energy of a gas fuel was emitted at the stoichiometry condition. In general, the weight of a fuel in a gas cloud is obtained by assuming that all of the gas is quickly released from the storage tank. The equivalency factor was about 3~10%, and generally obtained based on experience [5]. The TNT method is expressed as follows:

$$W_{TNT} = \alpha \frac{W_F H_F}{H_{TNT}} \qquad (1)$$

W_{TNT} : Equivalent weight of TNT [kg]
W_F : Weight of fuel in the gas cloud [kg]
H_{TNT} : TNT blast energy [MJ/kg]
H_F : Heat of combustion of fuel [MJ/kg]
α : Equivalency Factor

The safety distance estimated by the TNT equivalent method may be over predicted because it assumes a detonation in the explosion phenomena with the use of conservative k and α factors (Table 1, Eq (1)). The Multi-Energy Method (MEM) was developed to simulate the deflagration phenomena of which a pressure wave was propagated below the shock condition [5].

3.2 Multi-Energy Method

In MEM, the overpressure around the gas cloud is predicted by an empirical correlation (Eq. 2) and classified into 10 classes (Fig. 1)[5]. And the overpressure at a certain location apart from the gas cloud may be different depending on the class. MEM has some drawbacks in that it does not correctly predict the overpressure at the center of a gas explosion, and also it does not do so in an air environment, and asymmetric conditions around the gas explosion. Therefore, the use of CFD has recently been started to accurately predict the overpressure in a gas explosion [5].

$$\Delta P_s = 0.84 \cdot \left(VBR \cdot \frac{L_P}{D} \right)^{2.75} \cdot S_L^{2.7} \cdot D^{0.7} \qquad (2)$$

VBR : Volume blockage method
L_p : Length of the flame path
D : Typical diameter
S_L : Laminar burning velocity

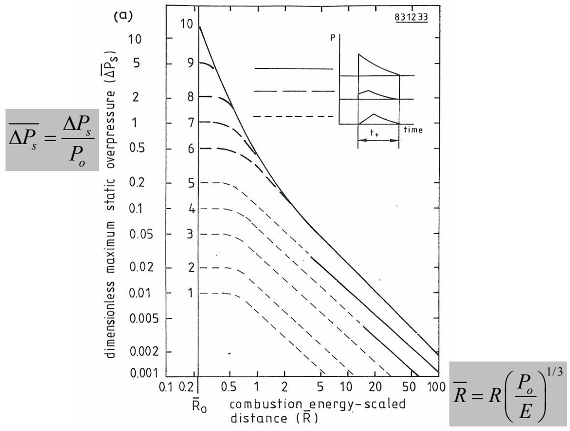

Figure 1. Blast wave overpressure dependent on the distance for a hemi-spherical fuel-air charge on the earth's surface (P_o : ambient pressure)

4. Conclusion and Further Research

As a result of a investigation into the safety distance regulations, it is found that the safety distance between the HTGR and the hydrogen production system may be varied from 10^2m to 10^3m depending on the regulation philosophy, the overpressure prediction method and the initial gas cloud volume. Therefore, an effective strategy should be prepared to set up a suitable safety distance. If the risk-informed regulation and MEM or CFD method with a barrier for a blast wave are applied, the safety distance may be decreased to less than 100m.

ACKNOWLEDGEMENTS

This work was financially supported for the nuclear R&D program from the Ministry of Science and Technology of Korea.

REFERENCES

1. J. H. Jang, et al, "Preliminary Conceptual Design and Development of Core Technology of Very High Temperature Gas-Cooled Reactor Hydrogen Production", Research Report, KAERI/RR-2666/2005, KAERI, 2005.
2. H. S. Kang, "Literature Survey for Safety Distance of Foreign Countries", Design Calculation Document, NHDD-KA04-RD-007, 2006.
3. IAEA, "Hydrogen as an Energy Carrier and its Production by Nuclear Power", Technical Document, IAEA-TECDOC-1085, 1999.
4. Curtis Smith, et al, Separation Requirement for a Hydrogen Production Plant and High Temperature Nuclear Reactor, Pro. of ICAPP'06, Reno, NV USA, June 4-8, 2006.
5. Dag Bjerketvedt, et al, Gas Explosion Handbook, J. Of Hazardous Materials, **52**, pp.1-150, 1997.