

JAERI-M  
9389

PIC-CONTAINER FOR CONTAINMENT AND  
DISPOSAL OF LOW AND INTERMEDIATE  
LEVEL RADIOACTIVE WASTES

March 1981

Kunio ARAKI, Yasuro MAKI\*, Yoshimasa SHINJI  
Kanjiro ISHIZAKI\*\*, Keiichi MINEGISHI\*\* and  
Giichi SUDOH\*\*

この報告書は、日本原子力研究所が JAERI-M レポートとして、不定期に刊行している研究報告書です。入手、複製などのお問い合わせは、日本原子力研究所技術情報部（茨城県那珂郡東海村）あて、お申しこしてください。

JAERI-M reports, issued irregularly, describe the results of research works carried out in JAERI. Inquiries about the availability of reports and their reproduction should be addressed to Division of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, Japan.

PIC-Container for Containment and Disposal of Low and Intermediate  
Level Radioactive Wastes

Kunio ARAKI, Yasuro MAKI\*, Yoshimasa SHINJI<sup>+</sup>, Kanjiro ISHIZAKI\*\*,  
Keiichi MINEGISHI\*\* and Giiohi SUDOH\*\*

Division of Environmental Safety Research, Tokai Research  
Establishment, JAERI

(Received February 4, 1981)

Steel fiber reinforced polymer-impregnated concrete (SFPIG) has been investigated for low and intermediate level radioactive waste containers. The present study has been carried out by the following stages. A) Preliminary evaluation: 60 L size container for cold and hot tests. B) Evaluation of size effect: 200 L size container for cold tests.

The 60 L and 200 L containers were designed as pressure-container (without equalizer) for 500 kg/cm<sup>2</sup> and 700 kg/cm<sup>2</sup>. Polymerization of impregnated methylmethacrylate monomer for stage-A and B were performed by <sup>60</sup>Co-γ ray radiation and thermal catalytic polymerization, respectively.

Under the loading of 500 kg/cm<sup>2</sup> and 700 kg/cm<sup>2</sup>-outside hydraulic pressure, these containers were kept in their good condition. The observed maximum strains were about  $1380 \times 10^{-6}$  and  $3950 \times 10^{-6}$  at the outside central position of container body for circumferential direction of the 60 L and 200 L container, respectively. An accelerated leaching test was performed by charging the concentrate of the liquid radioactive waste from JMTR in JAERI into the container. Although they were immersed in deionized water for 400 days, nuclides were not leached from the container. From results of various tests, it was evaluated that the SFPIG-container was suitable for containment and disposal of low and intermediate level radioactive wastes. There was not any great difference between the two size containers for the physical and chemical properties except in their preparation process.

Keywords: SFPIG, PIC, Plain Concrete, Low and Intermediate, Radioactive Waste, Disposal, Container, Containment, Outside Hydraulic Pressure, Drop Impact, Leaching, Durability, Corrosion, Stress-Strain, Sea Water, Fire.

---

+ Division of Health Physics, Tokai Research Establishment, JAERI.

\* Central Research Institute of Electric Power Industry.

\*\* Chichibu Cement Co. Ltd.

低・中レベル放射性廃棄物の処理・処分用 P I C 容器

日本原子力研究所東海研究所環境安全研究部

荒木 邦夫・満木 泰郎\*・進士 義正<sup>+</sup>・石崎寛治郎\*\*  
峯岸 敬一\*\*・須藤 儀一\*\*

(1981年2月4日受理)

低・中レベル放射性廃棄物の処理処分容器として鋼繊維補強ポリマー含浸コンクリートを用いて研究してきた。本報告は次の2段階で実施した結果をまとめた速報である。(1) 60ℓ(200ℓドラム缶の $\frac{2}{3}$ 寸法モデル)容器を用いたコールドおよびホット試験による予備評価, (2) 200ℓ(実寸法)容器を用いたコールド試験による容器の寸法効果。

60ℓ容器と200ℓ容器はそれぞれ $500\text{ kg/cm}^2$ と $700\text{ kg/cm}^2$ の耐圧容器として設計した。(1), (2)段階の含浸したメタクリル酸メチルモノマーは、各々 $^{60}\text{Co}$ - $\gamma$ 線と熱触媒法により重合硬化させた。

$500\text{ kg/cm}^2$ と $700\text{ kg/cm}^2$ の外水圧力の载荷によって、P I C容器は良好な状態を保持し、実測された最大ひずみはそれぞれ60ℓ容器と200ℓ容器の外側胴中央部円周方向でおよそ $1380 \times 10^{-6}$ と $3950 \times 10^{-6}$ を示した。R Iの促進浸出試験を原研大洗研の材料試験炉から排出した濃縮廃液を容器中に直接入れて実施した。この容器を400日間イオン交換水中に浸漬したが、放射性核種の浸出は認められなかった。その他の各種試験結果を含めて、鋼繊維補強ポリマー含浸コンクリート容器は低・中レベル放射性廃棄物の処理処分に適していると評価された。

また、2種類の容器について検討した結果、容器の製造工程における多少の相異を除いて物理的、化学的性質に大きな差はなかった。

---

+ 保健物理部

\* 電力中央研究所

\*\* 秩父セメント株式会社

## Contents

1. Introduction .....	1
2. Method .....	2
3. Results and Discussion .....	2
3.1 Resistance to Outside Hydraulic Pressure .....	2
3.2 Resistance to Drop Impact .....	3
3.3 Resistance to Leaching of Radioactive Materials .....	4
3.4 Resistance to Sea Water .....	4
3.5 Resistance to Fire .....	4
Acknowledgment .....	6
References .....	6

## 目 次

1. 緒 言 .....	1
2. 実験方法 .....	2
3. 結果と考案 .....	2
3.1 耐外水圧性 .....	2
3.2 耐落下衝撃性 .....	3
3.3 放射性廃棄物を使用した耐浸出性 .....	4
3.4 耐海水性 .....	4
3.5 耐炎性 .....	4
諸 辞 .....	6
引用文献 .....	6

## 1. INTRODUCTION

In recent years, low and intermediate level radioactive waste generated at nuclear power plants and other atomic energy facilities has been increasing and it is, therefore, an urgent problem to establish a safe disposal and containment system for radioactive waste. The Japanese government will confirm safety and establish sea dumping and ground burial techniques on its own responsibility with the cooperation of the agencies concerned both at home and abroad. For example, "the guideline for sea dumping packages\*" is indicated by IAEA (1). It is also said that the container for ground burial is necessary to have a long-term durability over 50 years.

Thus a container for disposal and containment of radioactive waste requires that it must have complete impermeability to radioactive materials and durability under the various conditions for management and it must be resistant to corrosion, resistant to impact and resistant to fire.

Research and development of polymer-impregnated concrete abbreviated as PIC was performed by M. Steinberg, J.T. Dikeou et al in the USA (2). PIC has high strength, excellent impermeability excellent durability and so on. Therefore, we have been examined an application on the PIC-container for radioactive waste since 1973 year. Also, PIC application to the cement solidification of radioactive waste is reported by A. Donato (3) and P. Colombo et al (4).

The PIC-container was designed as a pressure-resistance container without pressure equalizer. However, it was clear that defects of PIC-container were short of impact strength and fire-resistance. We have carried out the fundamental studies on improvement of the defects with fibers reinforced PIC (5), (6), (7). Consequently, the requirements for such the container have been satisfied by newly applying steel fiber reinforced PIC abbreviated as SFPIC.

The present study has been carried out by the following stages. A) Preliminary evaluation is a 60 L size (a 2/3 size model of 200 L drum) container for cold and hot tests. B) Evaluation of size effect is a 200 L size (a full size) container for cold tests.

---

\* ; It is packaged solid or solidified radioactive waste in a container.

## 2. METHOD

The design and preparation of containers and the cross section of PIC-containers are shown in Table 1 and Fig.1, respectively. Evaluation tests were mainly carried out by 5 items and their methods are shown in Table 2.

## 3. RESULTS AND DISCUSSION

3.1 Resistance to Outside Hydraulic Pressure

A stress-calculation for 60 L size PIC-container under  $500 \text{ kg/cm}^2$ -outside hydraulic pressure loading was carried out by a finite element method. The lines of equivalent stress are illustrated in Fig.2. The maximum compressive stress of  $1500 \text{ kg/cm}^2$  was expected at inside central position in circumferential direction. Therefore, if the container is imploded by high hydraulic pressure, the implosion will be occurred at this position.

The comparison of the stress-strain curves and the deformation figures calculated from the observed strain for various containers under outside hydraulic pressure loading are shown in Fig.3 and Fig.4, respectively.

At  $425 \text{ kg/cm}^2$ , the maximum strain of plain concrete-container of 60 L was about  $6050 \times 10^{-6}$  and its maximum average deformation to radius direction reached about 0.50 mm, and immediately after it was imploded at  $427 \text{ kg/cm}^2$ . The imploded position was approximately central part of container body.

The SFPIC and PIC-containers of 60 L did not loose integrity by the loading of  $500 \text{ kg/cm}^2$  - 3 min. The increased weight of SFPIC and PIC-containers were 1.6 kg and 0.5 kg, respectively. Both water absorption of the containers were below 0.5 %. The maximum strains at inside and outside central part of the SFPIC-container were about  $2880 \times 10^{-6}$  and  $1380 \times 10^{-6}$ , and those of the PIC-container were  $3980 \times 10^{-6}$  and  $1720 \times 10^{-6}$ , respectively. The deformation was estimated from the each strain as the each part of container was equally deformed by the pressure loading. Although the average in deformation to radius direction reached about 0.33 mm and 0.34 mm, these deformation were below 0.50 mm of implosion limit. Therefore, the integrity of the containers is reasonable.

The SFPIC-container of 200 L did not loose integrity by the loading

of  $700 \text{ kg/cm}^2$ -1 min. The increased weight of container after test was 1.6 kg and its water absorption was 0.2 %. The maximum strain at outside central part was about  $3950 \times 10^{-6}$  and the average deformation to radius direction reached about 0.92 mm. This value was close to 1.10 mm of the implosion limit which was measured in other container. Therefore, it may be designed by considering a safety rate in the actual use.

From these results, it is clear that a pressure container made of SFPIC or PIC can withstand outside hydraulic pressure of  $700 \text{ kg/cm}^2$  corresponding to 7000 m depths in the sea floor, which is more deep than the depth of the expected dumping site in Japan.

### 3.2 Resistance to Drop Impact

The tests were mainly performed from horizontal position which gave the severest drop impact. The results of drop impact test for 60 L container are illustrated in Table 3. Here, dropping from 0.6 m height corresponds to the dropping speed of the container in the sea and 1.2 m height corresponds to criterion for transport of A-type container indicated by IAEA. 2.0 m height considers dropping accident under the transport.

As regards the plain concrete and PIC-container, cracks were observed on the container body by the dropping from 0.6 m and 1.2 m height. The SFPIC-container kept integrity by the dropping from 0.6 m height. By the dropping from 1.2 m height, a few hairline cracks occurred in resinous adhesive but no change in the container body. And this container equipped with simple shock absorbers could withstand the impact of dropping from 2.0 m height.

The dropping behavior of the container was observed by high speed camera. The G value of deceleration or acceleration was measured at three positions of container with acceleration sensors. Fig.5 shows a typical behavior and deceleration-acceleration waves for container at landing in drop impact.

Acceleration sensor gave G value of minus or plus and they were defined as acceleration or deceleration, respectively. An evaluation of drop impact was discussed by the deceleration value. In general, the G value of second landing was higher than that of first landing.

The variation of maximum G value of deceleration with drop impact is shown in Fig.6. The maximum G values by dropping from 0.6 m and 1.2 m height were approximately 1000 G and 1400 G, respectively. The maximum



G values were extremely lowered by the using of two rubber belts. As a result, it is clear that the SFPIC-container can withstand to impact of 1000 G and can almost withstand up to 1400 G. Therefore, if the maximum G value generated with drop impact is lower than the G value which may be destructed or it is lowered than the limit value by using some shock absorbers, the containers keep integrity.

Also, when the SFPIC-containers of 200 L were dropped from 1.2 m height, a few hairline cracks occurred on the surface of container but no change in the interior of container. The damage of the cement solidified-container was lower than that of the empty container.

From these results, it is clear that the SFPIC-container is not disintegrated by the dropping from 1.2 m height corresponding to IAEA criterion and the size effect of container is not great.

### 3.3 Resistance to Leaching of Radioactive Materials

The guideline for sea dumping(1) prevents disposal of the liquid radioactive waste which is not solidified by some methods. In the present study, an accelerated leaching test was performed by charging the concentrate of the liquid radioactive waste into the PIC-containers. They were immersed in deionized water for 400 days. Since the radioactivity of the sampling water was under the detectable limit;  $2.7 \times 10^{-8}$   $\mu$  Ci/ml, nuclides were not leached from the containers.

Therefore, the container made of PIC is suitable for the disposal and containment of radioactive waste.

### 3.4 Resistance to Sea Water

Although iron rust was observed around the cap nuts of plain concrete-containers, the change in appearance of the PIC-containers was not observed by the immersion in sea water for 400 days.

### 3.5 Resistance to Fire

A preliminary open fire test was performed by using plain concrete, PIC and SFPIC-caps. Many cracks on the surface of plain concrete and PIC-caps were observed and they were disintegrated around the reinforcing bars by striking them with a hammer. However, the SFPIC-cap was not disintegrated by striking.

Fig.7 shows SFPIC-container of 60 L exposed in flame. Kerosene of 50 L was burnt for 30 min, and then it was quenched rapidly by a fire pump.

Although the impregnated polymer and adhesive were baked or burned and some hairline cracks occurred on the surface of the container, the container itself was not disintegrated by striking them with a hammer and only the surface of the container suffered partial stripping. Furthermore, after the test this container was moved easily without any damage by a forklift.

Fig.8 shows the change of temperature at individual positions for a cement solidified 200 L SFPIC-container on closed fire test in furnace. The container was exposed at 800 °C for 30 min in a flame which burnt propane gas. The maximum temperature at the inside wall and solidification itself in container were approximately 100 °C which was lower than the expected temperature. Many hairline cracks and a few cracks were observed on the container surface but no change in the interior of container. The container was also moved easily without any damage by a forklift.

In general, when a concrete container is exposed to high temperature, internal stress develops(7) because of the volatilization of gas and the difference in coefficient of thermal expansion between the materials of which it is constructed, thus causing cracks. The fire-resistance of the SFPIC-container is much higher. The improved reason may be that the growth of microcracks is prevented by the reinforced steel fibers in the concrete. For the reasons stated above, this container is also practicable for use as a storage container used on land.

#### CONCLUSION

It is well known that concrete structures have long-term durability, however, the concrete structures are apt to deteriorate by freezing - thawing action, chemical attack or in special circumstances.

The PIC-containers indicated excellent resistance to outside hydraulic pressure, impermeability to water, resistance to leaching of radioactive materials and resistance to sea water because of the many cavities in concrete are filled with non-corrosive polymer. Furthermore, the defects of PIC-container such as resistance to fire, high temperature and drop impact were improved by reinforcing of steel fibers. It was also confirmed that there was not any great difference between the two size containers for physical and chemical properties.

Thus the SFPIC-container for low and intermediate level radioactive waste may be available to a pressure container for a sea dumping and a

long-term storage container for on land or ground burial. Consequently, it should be expected that the package of SFPIC-container can remarkably decrease the diffusion of radioactive waste compared with the package solidified in the conventional steel drum.

#### ACKNOWLEDGMENT

The authors thank Dr. H. Amano, Director, Reactor Safety Research Center, JAERI, for many helpful suggestions.

We are grateful to Mr. Y. Kasahara and Mr. N. Kasai of JAERI, Mr. A. Azami of Chichibu Cement Co. Ltd., for co-workers from beginning to end.

Also, the evaluation of the container was carried out in cooperation with the Takasaki, Tokai and Oharai Institute of JAERI, the Mechanical Engineering Laboratory of the Agency for Industrial Science and Technology and the Central Research Institute of Electric Power Industry. We thank the researchers concerned.

#### REFERENCES

1. A NEA Group of Experts, "Guide Lines for Sea Dumping Packages of Radio-active Waste." NEA organization for OECD, 1979.
2. Steinberg, M., Dikeou, J. T., et al, "Concrete Polymer materials." First topical report. BNL 50134, 1968.
3. Donato, A., "Incorporation of Radioactive Wastes in Polymer Impregnated Cement." Proceedings of a Symposium on the Management of Radioactive Wastes from the Nuclear Fuel Cycle, IAEA and OECD Nuclear Energy Agency, Vienna, V. 2, 1976, PP. 143-153.
4. Colombo, P. and Neilson, R. M., "Some Techniques for the Solidification of Radioactive Wastes in Concrete." Nuclear Technology, V. 2, 1977, P. 30.
5. Ohgishi, S., Araki, K. and Ono, H., "Mechanical Properties of Fiber Reinforced Polymer Impregnated Concrete" Proceedings of the 1974 Symposium on Mechanical Behavior of Materials, The Society of Material Science, Japan, Kyoto, V. 2, PP.443-451.
6. Araki, K., Sudoh, G., Ishizaki, K. and Azami, A., "Mechanical Properties

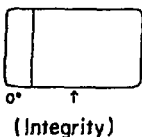
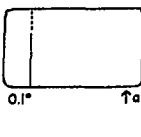
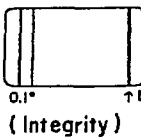
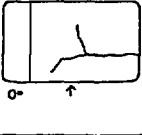
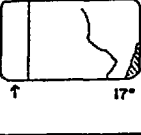

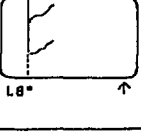
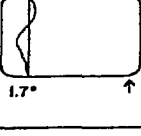

for "Steel Fiber Reinforced Partially Polymer-impregnated Concretes"  
Review of 31th General Meeting, The Cement Association of Japan, Tokyo,  
1977, PP.316-319.

7. Ishizaki, K., Asami, A., Sudoh, G., Kasahara, Y., et al, "A Few Considerations on Fire-Resistance and Heat-Resistance of Polymer-Impregnated Concretes." Review of 32th General Meeting, The Cement Association of Japan, Tokyo, 1978, PP.315-319.

Table 1 Design and preparation of containers

Items	60 L container	200 L container
a) Outer size of container	60 L size (2/3 scale model of 200 L drum)	200 L drum size
b) Type of container	A pressure container (without pressure equalizer)	A pressure container
c) Strength of pressure - resistance	500 kg/cm <sup>2</sup> (corresponding to 5000 m depths in sea)	700 kg/cm <sup>2</sup> (corresponding to 7000 m depths in sea)
d) Adhesion of cap and container	Epoxy resin and tightening with 4 bolts	Epoxy resin and tightening with 8 bolts
e) Material	PIC, Plain concrete, SFPIC	SFPIC
f) Polymerization method	Radiation method: <sup>60</sup> Co-γ ray, 8 Mrad	Thermal catalytic polymerization, 95 °C-2h
g) Impregnant	Methylmethacrylate monomer + polystyrene (5wt%)	Methylmethacrylate monomer, Catalyst: Azobisisobutyronitrile (1.5wt%)
h) Solidification	Empty (No solidification)	Cement solidification of simulated radioactive waste

Table 3 Results of drop impact test for 60L container.

Materials	Drop height ( m )		
	0.6	1.2	2.0
S F P I C	 0° ↑ (Integrity)	 0.1° ↑a)	 0.1° ↑b)
P I C	 0° ↑	 ↑ 17°	
Plain concrete	 1.8° ↑	 1.7° ↑	

Note

a). ↑ Shows the first landing part.

b). Two rubber belts of 17mm<sup>φ</sup> were used as shock absorber.

Table 2 Methods of evaluation test

Items	60 L container	200 L container
a) Resistance to outside hydraulic pressure	500 kg/cm <sup>2</sup> - 3 min	700 kg/cm <sup>2</sup> - 1 min
b) Resistance to drop impact	Containers were dropped on concrete plate of 25 cm thick putted on iron base. Dropping height was 0.6 m, 1.2 m and 2.0 m.	Containers were dropped on iron plate of 25 mm thick putted on concrete base. Dropping height was 1.2 m
c) Resistance to leaching of radioactive materials	Concentrate* of liquid radioactive waste from JMTR in JAERI was charged in container and immersed in deionized water for 400 days after sealing.	_____
d) Resistance to sea water	Immersion of container in sea water for 400 days.	_____
e) Resistance to fire	Open fire test in outdoor. Specimen was kept standing in a 50 L - kerosene flame for 30 min.	Closed fire test in furnace. Specimen was kept standing in propane gas flame at 800 °C for 30 min.

\* ; Physical properties of concentrate were the following, PH = 10.6, s.g. = 1.16, solid content = 19.8%, Activity; gross( $\beta$ ) =  $1.2 \times 10^{-2}$   $\mu$ Ci/ml, gross( $\gamma$ ) =  $1.1 \times 10^{-2}$   $\mu$ Ci/ml, Main nuclide;  $^{60}\text{Co}$  =  $2.6 \times 10^{-3}$   $\mu$ Ci/ml,  $^{137}\text{Cs}$  =  $5.6 \times 10^{-3}$   $\mu$ Ci/ml.

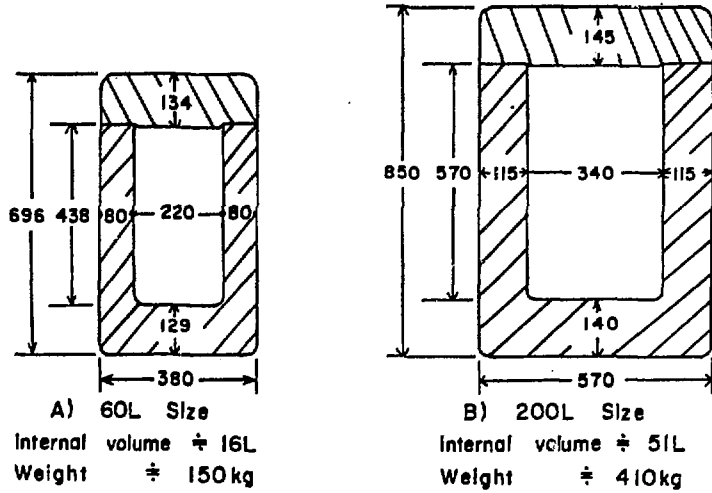


Fig.1 Cross section of containers

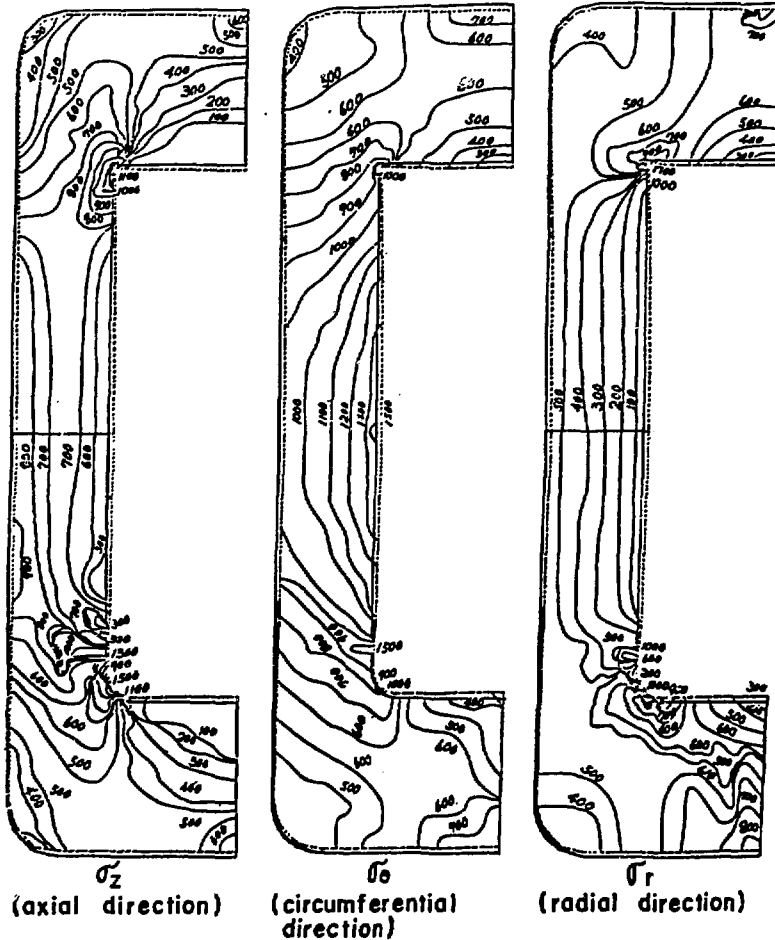


Fig.2 Lines for equivalent stress calculated as 500 kg/cm<sup>2</sup>—outside hydraulic pressure using finite element method for 60L size container.

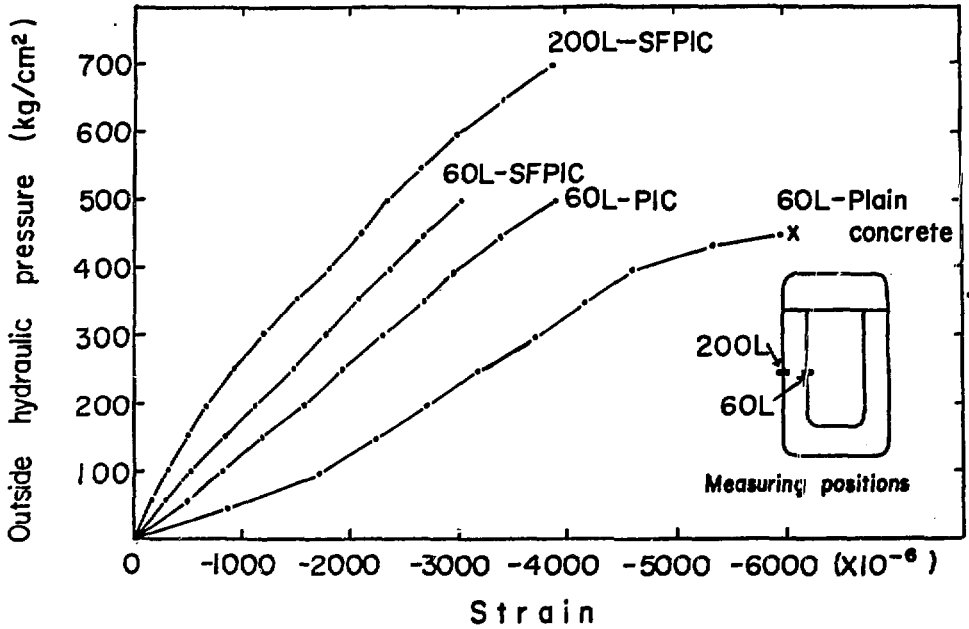


Fig.3 Comparison of stress-strain curves for various containers under outside hydraulic pressure loading.

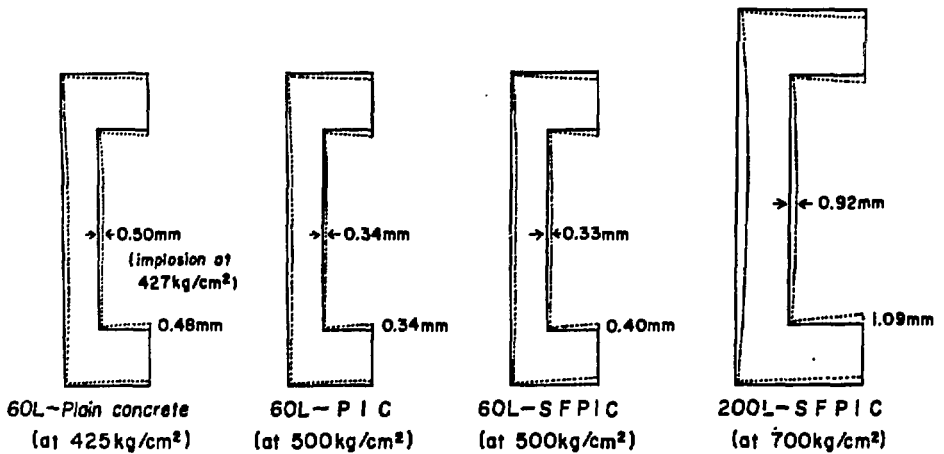


Fig.4 Comparison of deformation figures for various containers under outside hydraulic pressure loading.



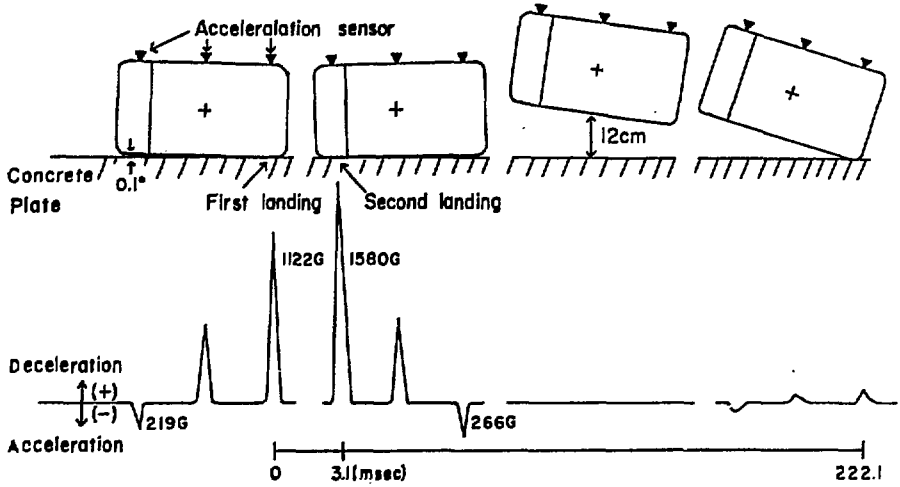


Fig5 Typical behavior and deceleration—acceleration waves for container at landing in drop impact. This figure shows a example of 60L SFPIC—container dropped from 1.2m height.

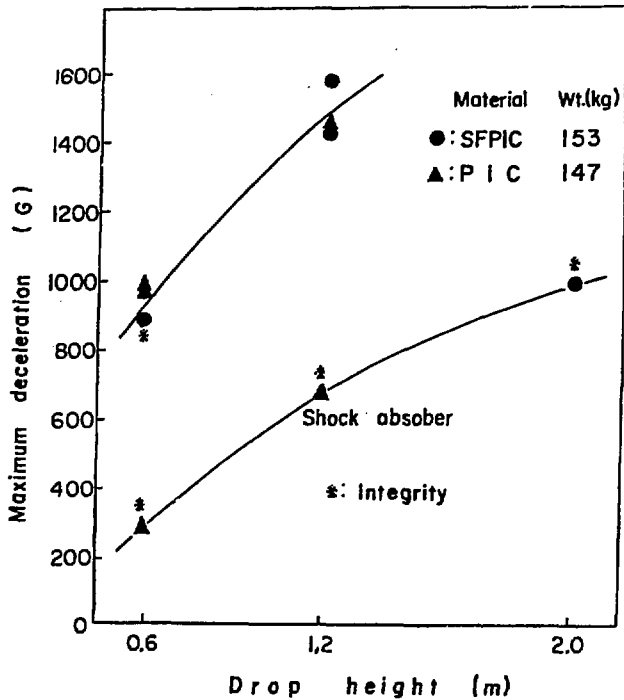


Fig.6 Variation of maximum deceleration with drop height.



Fig.7 Open fire test. 60 L SFPIC-container was exposed to a kerosene flame for 30 min.

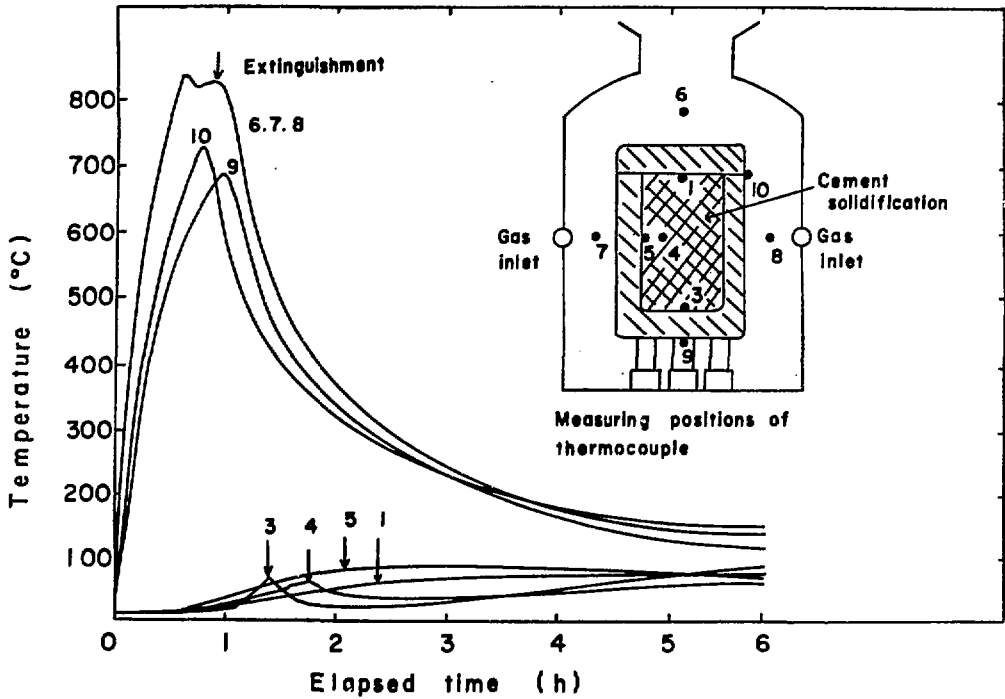


Fig.8 Change of temperature at individual positions for a cement solidified 200L SFPIC-container on closed fire test in furnace.