부탄 캔 파열로 인한 화구의 피해에 관한 연구

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A Study on the Damage of Fireball by the Butane-Can Explosion

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Abstract : There have been 3E problems of energy, economy and environment since the earth has its history. Especially, as the industrial society is highly developing, human need in daily life has also changed drastically. With the introduction of 40 hour working week system, more households enjoy picnics on weekends. More gas accidents take place on Saturdays and on Sundays than any other days of week. Consequently, this study tries to find out the influence of flame caused by the explosion of butane canister on the adjacent combustibles and people by simulating relevant quantity of TNT. In addition, the damage estimation was conducted by using API regulations. If the scale of the radiation heat is known by calculating the distance of flame influence from the explosion site, the damage from the site can be easily estimated. And the accident damage was estimated by applying the influence on the adjacent structures and people into the PROBIT model. According to the probit analyze, the spot which is 50cm away from the flame has 97% of the damage probability by the first-degree burn, 8% of the damage probability by the second-degree burn and 4% of the death probability by the fire.

초록 : 지구상에 역사가 시작된 이후로 에너지, 경제, 환경 등 3E 문제가 존재해 왔다. 특히, 산업사회의 발전과 더불어 인간의 삶에 대한 욕구도 날로 급속하게 변하고 있다. 주 40시간제가 시행되면서 야외활동을 즐기는 사람들이 많아지고 있다. 가스에 의한 사고도 토요일과 일요일에 가장 많이 발생하고 있다. 따라서 본 논문에서는 부탄 캔의 파열에 따른 화염의 영향으로 인간에게 미치는 영향을 알아보고자 한다. 이를 위하여 API에서 규정한 피해예측을 통하여 평가를 실시하였다. 폭발장소에서의 화염에 의해 미치는 영향 거리를 산출하여 거리별 복사열의 크기를 알게 되면 그 지점에서의 피해는 간단하게 예측할 수 있다. 또한 폭발장소 주변에 위치한 인간에게 미치는 영향을 PROBIT 모델에 적용하여 사고피해예측을 평가하였다. 프로빗 분석에 의하면 화염에서 50cm 이격된 곳은 1도 화상에 의한 손상확률이 97%, 2도 화상에 의한 손상확률은 8%, 화재로 인한 사망확률은 4%로 나타났다.
Key Words : damage estimate, gas explosion, fireball

1. Introduction

The use of gas has dramatically increased in industry and in the home because the gas is an eco-friendly energy source, so it plays a pivotal role in industry as Table 1 shows[1]). With the development of the industry, the desire for safety of humans has increased.

However, gas accidents occur with various causes and types. Also, the potential dangerous factors always exist in industry and in the home, and the same types of accidents occur repeatedly.

Especially, the gas explosion accidents cause a severe loss in our society. For the last five years, accident status of the Korea, Japan and England is as below in Table 2, type is in Table 3[2-8]).

The accidents of portable butane burners and butane cans happened 58 times for the last 5 years. The main accident was poor setting of butane cans

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Table 1. Consumption of energy (Units : 1000ton)

	2005	2004	2003	2002	2001
Energy consumption	229,333	220,238	215,066	208,636	198,409
LNG	29,989	28,351	24,194	23,099	20,787
Oil (LPG)	101,553 (12,240)	100,638 (11,937)	102,380 (11,912)	102,414 (12,272)	100,385 (11,390)
Hydraulic	1,297	1,465	1,722	1,327	1,038
Nuclear	36,695	32,679	32,415	29,776	28,033
Coal	54,791	53,127	51,116	49,096	45,711
Other	5,007	3,977	3,241	2,925	2,456

Table 2. The present state of LPG accident (Units : Ea)

	2005	2004	2003	2002	2001
Korea	88	82	92	84	92
Japan	99	105	120	90	87
England	161	130	116	153	174

* The England data is the addition of LPG and NG.

Table 3. Accident by explosion and fire (Units : Ea)

	2005	2004	2003	2002	2001
Korea	62(13)	65(10)	84(7)	78(11)	86(11)
Japan	98(16)	129(26)	169(29)	125(22)	101(24)
England	36(117)	34(91)	30(86)	43(110)	38(136)

( ) : CO toxication

and using oversize cooking utensils of 38cases(68%). Then 20cases(34.5%) were because of careless keeping and handling of butane cans.

Also, 10cases(26.3%) were explosion and fire resulted from gas escape by poor setting of butane cans. 16cases(80%) of careless keeping and handling were explosion by rising of pressure proof, which were occurred by heating container to use the gas left with neglecting the butane cans placed around fires including keeping butane cans in portable butane burners[8].

The study on the damage range by the gas explosion such as flame behavior and safety of the gas fire was preceded[9-12], but it is insufficient to calculate the damage distance for provision of the accident which can be occurred by unsuitable treat of butane cans. Therefore, this study is to provide the damage distance of gas explosion against the accidents happened by improper handling of butane cans and to be used as a basic data for setting up the boundary range of collecting place of butane cans.

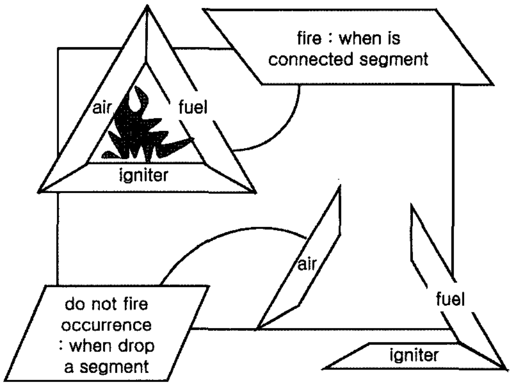

Fig. 1. 3 elements of fire.

2. Theory and Computation Method

The gas explosion can be divided into the explosion in a sealed space and the explosion in an open space, and the pressure which is made by the gas explosion can cause the damage to humans and structures. Also, the explosion can be advanced to a fire and an accident such as BLEVE[13-17].

The gas explosion is seriously influenced by the explosion pressure, and the variables are fuel, kinds of oxidizer, the concentration and size of vapor cloud, the ignition spot, the strength of ignition source, the size, place, and type of vent, the surrounding obstacles, the method to make the smallest damage and so on[18-20].

Also, the gas explosion accident turns into a fire, and the damage by this flame is very serious[21].

Like Fig. 1, a fire cannot occur although one of three elements is excluded as a triangle cannot be made without one side.

Classification of fire is very important for extinguishment. The level of fire is set based on the kind and nature of flammable materials of the elements that makes fire. Korea divides the level of fire into A, B, C, D and E like America and Japan. However it is classified roughly into A, B and C by the frequency of fire generation, and it is generally used. Table 4 is the classification of fire of Korea, America, Japan and German based on the flammable materials which make combustion at fire.

Korea usually follows the regulations of America. Proper extinguishing method should be chosen accor-

Table 4. Classification of country fire

Grade of fire	Korea/Japan	America	Germany
A (General fire)	General combustibles of wood, paper, textile etc.	Such as left	Such as left
B (Oil fire)	Oil (combustibility liquid inclusion)	Such as left	Such as left
C (Electric fire)	Electric	Such as left	Gas (compression, liquid)
D (Metal fire)	Metal	-	Such as left
E (Gas fire)	Gas (compression, liquid)	Such as left	Electric

ding to the above classification of fire. If it is not followed, more dangerous accident can be happened.

The damage of radiant heat by the fire is serious, and the formula of the radiant heat is as follows[22-25].

2.1. Calculating the size of fireball

$$D_{fireball} = 5.8 \times M_{fireball}^{1/3} \tag{1}$$

$D_{fireball}$: The largest diameter of fireball(m)
$M_{fireball}$: Early leaking amount of flammable liquid(kg)

2.2. Calculating the continuance time of a flame

$$t_{fireball} = 0.45 \times M_{fireball}^{1/3} \tag{2}$$

$t_{fireball}$ = Continuance time of a flame(second)

2.3. Calculating the height of the center of fireball

$$H_{fireball} = 0.75 \times D_{fireball} \tag{3}$$

$H_{fireball}$: The height of the center of fireball(m)

2.4. Calculating atmospheric transmissivity

$$\tau_a = 2.02(P_{P_{water}} \times X_S)^{-0.09} \tag{4}$$

$$P_{P_{water}} = RH \times P_{water} \tag{5}$$

$$P_{water} = 0.0060298 \times P_a \times \exp\left\{5407\left(\frac{1}{273.15} - \frac{1}{T_a}\right)\right\} \tag{6}$$

τ_a : Permeation degree(Dimensionless)
X_s : The distance from the surface of fireball to the damaged point(m)

$$X_S = \sqrt{(H_{fireball}^2 + L_{fireball}^2)} - \frac{D_{fireball}}{2} \tag{7}$$

P_{water} : Steam pressure of water(Pa)
T_a : Temperature of atmosphere(K)
RH : Relative humidity(%)
P_a : Pressure of atmosphere(Pa)
$L_{fireball}$: The horizontal distance from the center of fireball to the damaged point(m)

2.5. Calculating radiation energy of surface

$$E = \frac{R \times M_{fireball} \times H_C}{3.14 \times D_{fireball}^2 \times t_{fireball}} \tag{8}$$

E : Radiation energy of surface(kJ/m^2 · s)
R : Radiation ratio of combustion heat(Dimensionless) 0.4(The case that a container or a pipe breaks at over the set pressure of pressure radiation equipment)
H_c : Genuine combustion calory(kJ/kg)

2.6. Calculating view factor

$$F_V = \frac{L_{fireball} \times \left(\frac{D_{fireball}}{2}\right)^2}{(2L_{fireball} + 2H_{fireball})^{\frac{2}{3}}} \tag{9}$$

2.7. Calculating radiation

$$Q_{fireball} = \tau_a \times E \times F_V \tag{10}$$

$Q_{fireball}$: Radiation at a certain point(kW/m^2)

2.8. Probit analyze

The human injury degree by the heat radiation is calculated with the exposure time to the flame, the size of the radiant heat and the probit analyze model formula[26-28].

(1) In the case of first-degree burn

$$P_r = -39.83 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (11)$$

(2) In the case of second degree burn

$$P_r = -43.14 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (12)$$

(3) In case of death caused fire

$$P_r = -36.38 + 2.56\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (13)$$

P_r = Probability value(Probit value)
t = The time of exposure[sec]
Q = Intensity of radiant heat[W/m2]

3. Estimate of damage and Results

According to API521 and World bank, the criterion of the effect of radiant heat is as Table 5, 6.

Table 5. Time of feeling an ache(API521)

Intensity of radiant heat		Time that begin to sting (sec)
(Btu/ft²hr)	(kW/m²)	
500	1.6	60
740	2.3	40
920	2.9	30
1500	4.7	16
2200	6.9	9
3000	9.5	6
3700	11.7	4
6300	19.9	2

Table 6. The effect of radiant heat(Word bank)

Intensity of radiant heat		Effect
(Btu/ft²hr)	(kW/m²)	
11900	37.5	Equipment and facilities are damaged.
7900	25	If it is exposed for a long time, a wood is caught fire by the minimum energy.
4000	12.5	The minimum energy which is enough for ignition of a wood or a plastic tube.
3000	9.5	Feel a severe pain 8 seconds later and got burnt of the second degree 20 seconds later.
1300	4	If it is not protected in 20 seconds, an ache is felt and the skin is swollen.
500	1.6	If it is exposed for a long time, discomfort is felt.

Table 7. Related value of fireball

M(g)	D(m)	t(s)	H(m)
34g	1.879	0.146	1.409

Table 8. Related value of C_4H_{10}

C_4H_{10}	kcal/kg	kJ/kg
90%	12341.88	51656.94

To predict the damage to humans, the numerical value which comes out from the probit analyze formula is applied to the formula (1), (2) and (3) like Table 7.

For the calculation of the radiant heat of Table 9, the numerical value which comes out from the formula (1), (2) and (3) is applied to the formula (7), and then we can get the distance from the surface of the fuel intake to the damage spot.

At first, the temperature, air pressure and humidity of the time when the fire occurs are applied to the formula (6), and the result is applied to formula (5), and the final value is applied to the formula (7) and (4). Then, we can get the Permeation degree.

To get the surface radiant energy, the values of the formula (1), (2), (3) and of the Table 8 are applied to the formula (8).

Table 9. Calculated value of radiant heat

L(m)	Xs(m)	P_{water}	Pp_{water}	τ_a	E (kJ/m² · s)	Fv	Q (kW/m²)
1	0.788	3319.46	253.61	1.25	434.04	0.171126	94.14
2	1.507	3319.46	253.61	1.18	434.04	0.120558	61.90
3	2.375	3319.46	253.61	1.14	434.04	0.072727	35.84
4	3.301	3319.46	253.61	1.10	434.04	0.046289	22.15
5	4.255	3319.46	253.61	1.08	434.04	0.031483	14.72
6	5.224	3319.46	253.61	1.06	434.04	0.022622	10.39
7	6.201	3319.46	253.61	1.04	434.04	0.016972	7.67
8	7.184	3319.46	253.61	1.03	434.04	0.013174	5.88
9	8.170	3319.46	253.61	1.02	434.04	0.010508	4.63
10	9.159	3319.46	253.61	1.01	434.04	0.008570	3.74
15	14.127	3319.46	253.61	0.98	434.04	0.003872	1.63
20	19.110	3319.46	253.61	0.94	434.04	0.002190	0.89
25	24.100	3319.46	253.61	0.92	434.04	0.001406	0.56
30	29.094	3319.46	253.61	0.91	434.04	0.000977	0.38
40	39.085	3319.46	253.61	0.88	434.04	0.000551	0.21

* temperature: 25.7, humidity: 76.4%, atmosphere: 752.6

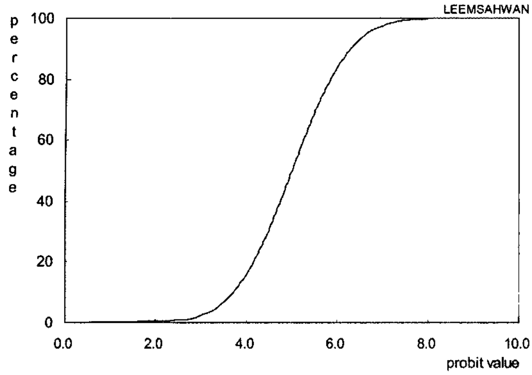

Fig. 2. Relation with probability value(probit) and percent.

Also, the value of visual factor is calculated by applying the formula (1), (2) and (3) to the formula (9).

Finally, the human injury degree by the heat radiation can get by applying the Permeation degree, the radiant energy and the visual factor which come out from the above to the formula (10) like Table 9.

The relationship between the probability value and the percentage of the human injury degree by the heat radiation is like Fig. 2[29], and the calculated values by using the formula (12), (13) and (14) to apply to that are like Table 10.

Table 10. Probit value about distance of butane can weight 34g(ingredient of 10% propane and 90% butane)

Z(m)	Possibility with a first degree burn	Possibility with second degree burn	Possibility with burnt to death
0.5	6.88457	3.57457	3.237472
1	0.412828	-2.89717	-2.25105
2	-1.23165	-4.54165	-3.64569
3	-3.4306	-6.7406	-5.51057
4	-5.36838	-8.67838	-7.15395
5	-7.01173	-10.3217	-8.54763
6	-8.41636	-11.7264	-9.73887
7	-9.63503	-12.945	-10.7724
8	-10.7078	-14.0178	-11.6822
9	-11.6643	-14.9743	-12.4934
10	-12.5263	-15.8363	-13.2244
15	-15.8815	-19.1915	-16.0698
20	-18.2835	-21.5935	-18.1069
25	-20.153	-23.463	-19.6924
30	-21.683	-24.993	-20.99
40	-24.0998	-27.4098	-23.0396

If the values of Table 10 are applied to Fig. 2, we can get the damage type by the radiant heat. This study researched the damage by the probit analyze formula, but the value which we got from the probit analyze formula was so small like Table 10 that we judged the burned degree by the explosion of butane cans would be little.

The probit analyze formula in about 50cm of the distance length between the portable gas range which is used to make food easily at restaurants and in the field and the user was calculated with the interpolation, and then we applied the result to Fig. 2, so the damage probability by the first-degree burn was 97%, by the second-degree burn was 8% and the death probability by the fire was 4%.

We got the size of the fuel intake and the lasting hour of the flame by the explosion of butane cans by using the formula (1), (2) and (3), and the result is like Fig. 3. According to Fig. 3, every value goes up when the volume is increased.

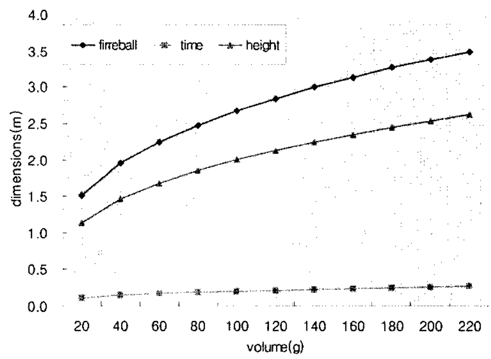

Fig. 3. Value for fireball.

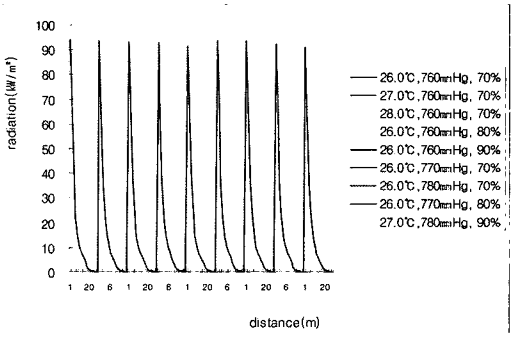

Fig. 4. State with temperature and humidity.

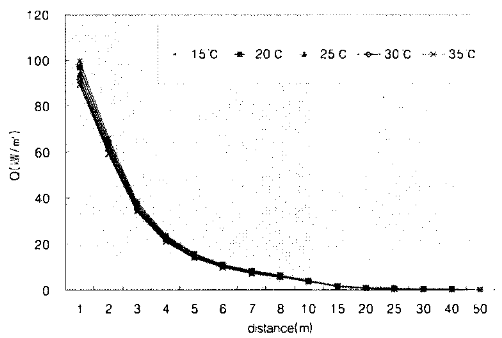

Fig. 5. Radiant heat by distance.

Fig. 4 is the amount of the heat radiation by the temperature and the humidity in the field of summer, and we can see there is little effect by the temperature and the humidity by Fig. 5.

4. Conclusions and discussion

This study calculated the accident occurrence probability for the damage by the radiant heat by using the probit analyze.

The following conclusion is come out through this study.

1) The hour when a human feels a pain is 0.15 seconds which cannot be reached to the regulated value of API521, so we judge it may be safe.

2) 9.5kW/m^2 which is the regulation of Word bank on the damage to the human body by the radiant heat is 6m from the heat of fire, but the lasting hour of the flame is so short that we judge it may be safe.

3) According to the probit analyze, the spot which is 50cm away from the flame has 97% of the damage probability by the first-degree burn, 8% of the damage probability by the second-degree burn and 4% of the death probability by the fire.

The case which got burned by the fire of the explosion of butane cans has appeared in succession during these five years. Therefore, we think the minimum distance length should be maintained to reduce the damage by the heat of fire through the result of this study. Also, we want to continue our research and find out the damage range of safety accident by the flame based on the gas concentration and by the splinters of the explosion through the experiments.

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References

1) Korea Statistical Information System Consumption data of Energy source. http://kosis.nso.go.kr
2) Japan's Ministry of Economy, Trade and Industry http://www.nisa.meti.go.jp/9_citygas/gas_accident_graph(rev1).pdf
3) Nuclear and Industrial Safety Agency, http://www.nisa.meti.go.jp/9_citygas/jiko.html
4) The High Pressure Gas Safety Institute of Gas, http://www.khk.or.jp/activities/incident_investigation/lpg_incident/statistics_material.html
5) Japan LPGas Association, http://www.j-lpgas.gr.jp
6) Agency for Natural Resources and Energy, http://www.enecho.meti.go.jp
7) British Petroleum, http://www.bp.com
8) Korea Gas Safety Corporation, "2005 Gas Accident Yearbook", Sun Jin company, pp. 87~172, 2006.
9) Sa-Hwan Leem and Yong-Jeong Huh, "A Development of Intelligent Decision System by Safety Distance of Gas Storage Tank", Journal of the Korea Academic Industrial Society, Vol. 7, No. 4, pp. 721~726, 2006.
10) Sa-Hwan Leem, "A Study on the Noise Near the Butane-can Explosion Location", Transaction of the Korean Society for Noise and Vibration Engineering, Vol. 14, No. 11, pp. 1166~1175, 2004.
11) Sa Hwan Leem, Ic Whoan Choi and Dong Yeon Lim, "A Study on Estimation of Overpressure Damage Caused by Rupture of Butane Can(volume : 34g)", Journal of the Korean Institute of Gas, Vol. 9, No. 2, pp. 8~15, 2005.
12) Kyu-Hyung Oh, Youn-Ok Kang and Sung-Eun Lee, "A Study on the Flame Behavior of Whirl Fire and Pool Fire", Journal of the Korean Society of Safety, Vol. 19, No. 3, pp. 45~50, 2004.

13) CCPS, "Guidelines for Evaluating the Characteristics of Vapor Cloud Explosion, Flash Fire, and BLEVEs", Center for Chemical Process Safety, AIChE, New York, USA, 1994.
14) Wiekema, B. J., "Vapour Cloud Explosion Model", J. of Hazardous Materials, Vol. 3, pp. 221~232, 1980.
15) Ven den Berg, A. C., "The Multi-Energy Method: a framework for vapour cloud explosion blast prediction", J. of Hazards Materials, Vol. 12, pp. 1~10, 1985.
16) Baker, Q. A., Tang, M. J., Scheier, E. A., and Silva, G. J., "Vapour Cloud Explosion Analysis", 28th Loss Prev. Symp., AIChE, April, 1994.
17) Dag Bjerketvedt, Kees Van Wingerden, Jan Roar Bakke, "Gas Explosion Handbook", Elsevier Science, pp. 40~65, 1997.
18) Kyu-hyung Oh, "A Study on the Explosion Relief Venting in the Gas Explosion", Journal of The Korean Society of Safety, Vol. 20, No. 3, pp. 71~77, 2005.
19) Crowl, D A. and J. F. Louvar, "Chemical Process Safety: Fundamentals with Applications", Prentice Hall, New Jersey. pp. 82~151, 1990.
20) Young-Soon Lee, Soo-Hyun Chae and Soo-Il Jung, "A Experimental Study on the Characteristics of Gas Explosion due to Vent Shape and Size", Journal of the Korean Society of Safety, Vol. 21, No. 3, pp. 38~44, 2006.
21) Kyu-Hyung Oh, Sung-Eun Lee and Kwang-Won Rhie, "A Study on the Transition of Hydrogen-Air and LPG-Air Explosion to Fire", Journal of the Korean Society of Safety, Vol. 19, No. 4, pp. 150~154, 2004.
22) M. Hattwing and H. Steen, "Handbook of Explosion Prevention and Protection", Wiley-VCH Verlag GmbH & Co. KGaA, 2004.
23) Van Dolah, R. W. and Burgess, D. S., "Explosion Problems in the Chemical Industry", The American Chemical Society, 1970.
24) Van Buijtenen, C. J. P., "Calculation of Amount of Gas in the Explosive Resion of a Vapour Cloud Released in the Atmosphere", J. Hazardous Materials, 3, pp. 201~220, 1980.
25) W. E. Baker, P. A. Cox, P. S. Westine, J. J. Kulesz and R. A. Strehlow, "Explosion Hazards and Evaluation", Elsevier, 1983.
26) W. K. Crowl, Structure to Resist the Effects of Accidental Explosion, Technical Manual TM 5-1300, U. S. Army, Navy and Air Force, U. S. Government Printing Office, Washington D.C., 1969.
27) R. J. Harris, M. R. Marshall and D. J. Moppett, "The Response of Glass Windows to Explosion Pressure", Symp. Series No. 49, ICJemE, 1977.
28) Frank P and Less, M. I. Ang, "Safety Cases", Butterworth & Co. Ltd., 1989.
29) Finney, D. J. "Probit Analysis", Cambridge, 1947.