

# **低線量率放射線被ばくの健康影響**

--インド・中国の高自然放射線被ばく地域住民の  
調査結果を中心として--

**低線量率放射線被ばくの健康影響の定量的評価**

秋葉 澄伯(主任研究者)

**高自然放射線地域における線量評価に関する研究**

床次 真司(分担研究者)

**本研究の目的:**

低線量率放射線の外部被ばくによる疾病リスクが中・高線量率と異ならないか(どの程度異なるか)を明らかにする。

**これまでの調査結果:**

インド・中国の高自然放射線地域での外部被ばくの健康影響評価に、内部被ばくは殆ど影響していないと考えられる。十分な統計学的検出力を得るために、さらに追跡が必要。内部被ばくの影響や線量推定の不確実性などを評価することも重要。

本研究の成果は、福島第一原発の事故で、主に低線量率の放射線被ばくを受けた可能性がある緊急作業者や住民の健康影響を考える上でも重要である。

### **三年間の計画**

**初年度：追跡期間を延長して、悪性腫瘍リスクの検討、**

1. インドケララ州カルナガパリでのがん罹患率調査(Nair et al. Health Phys. 2009)を3年間延長し、2008年末までのがん罹患率を検討。

2. 中国広東省陽江地域の死亡率調査(Tao et al. Health Phys. 2012)を5年間延長し、2003年までのがん死亡率を検討。

3. 他の調査結果(原爆被爆生存者、Techa 川流域・台湾のコバルト60汚染鉄筋使用ビル住民、原子力作業者の追跡調査結果)と比較。

**次年度：追跡期間を延長して、非がん疾患リスクの検討、**

### **最終年度：**

**インドでは、追跡期間をさらに延長し、2010年までとして、悪性腫瘍罹患率・非がん疾患死亡率を検討。**

(このデータは、線量当たりのがん罹患率が原爆被爆者がん罹患率より有意に低いかを検討する十分な統計学的検出力を有する)

**悪性腫瘍・非がん疾患を対象に総合的検討**

(内部被ばくの影響・線量推定の不確実性の問題も考慮)

必要に応じてメタ分析を行う。

### **高自然放射線地域における線量評価に関する研究**

(分担研究者：床次真司)

### **平成24年度：**

ラドン・トロンとその壊変核種による内部被ばく、食物の摂取による内部被ばくの調査を開始。

空間線量率の詳細マップ作成・行動調査などを行う。

### **平成25年度：**

前年度に実施した予備調査の結果に基づき本調査を展開する。

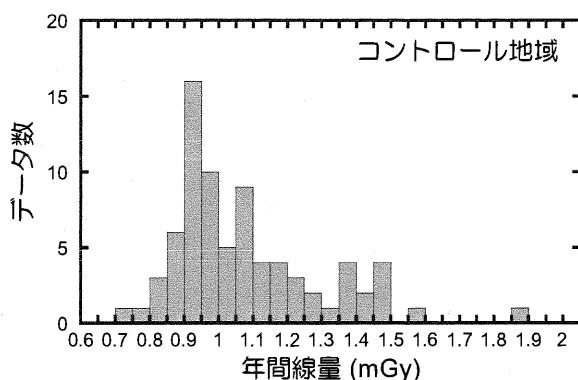
(調査対象家屋数：200軒以上、食物試料数：50サンプル以上)

### **平成26年度：**

ラドン・トロンとその壊変核種による内部被ばく、食物の摂取による内部被ばくを評価

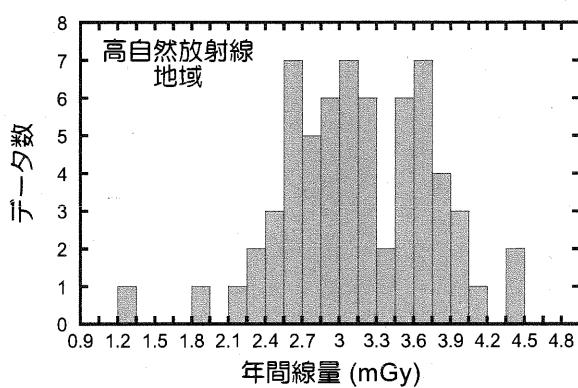
4月～9月に環境調査を主体とした測定や試料採取を実施し、10月～3月にデータ解析と取り纏めを行う。

## インド・ケララー走行サーベイによる外部被ばく線量の予備調査



### □ コントロール地域

集落名：Oachira  
面積： $12.86 \text{ km}^2$   
人口：23,267人  
データ数：62データ  
最大値：1.9 mGy/y  
最小値：0.71 mGy/y  
幾何平均値：1.0 mGy/y



### □ 高自然放射線地域

集落名：Alappad  
面積： $7.38 \text{ km}^2$   
人口：22,778人  
データ数：49データ  
最大値：4.4 mGy/y  
最小値：1.3 mGy/y  
幾何平均値：3.0 mGy/y

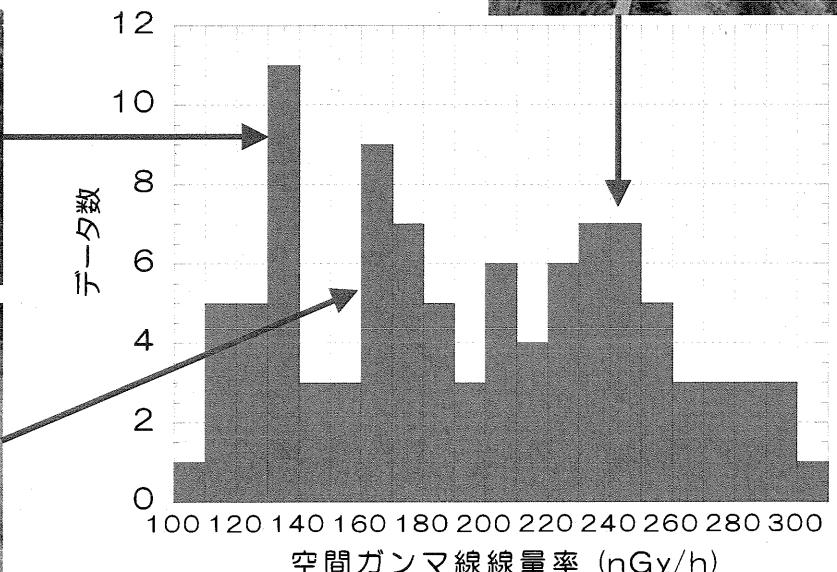
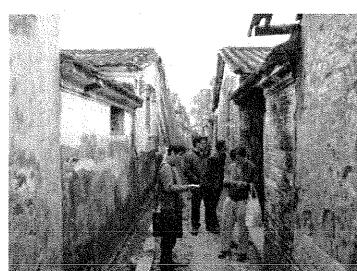
## 中国・陽江ー外部被ばく線量の予備調査

建材からのガンマ線が寄与している  
ことが示唆された

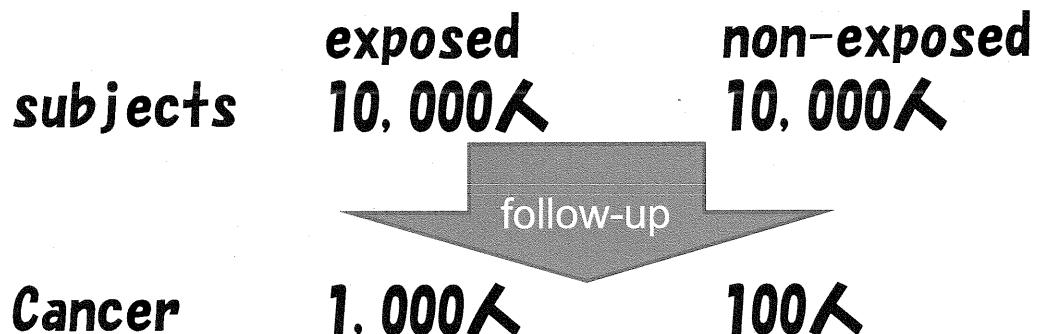
(右下：屋外100点のガンマ線線量率分布)

集落の外周 (130 nGy/h程度、写真上)と  
集落内の広い路地 (170 nGy/h程度、写真下)

集落内の狭い路地  
(240 nGy/h程度)



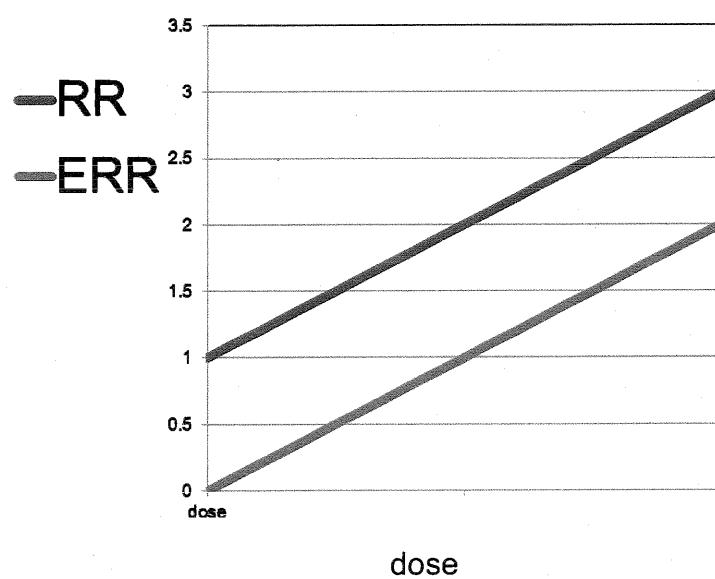
# Relative risk



## Relative risk

$$= (1000/10,000) / (100/10,000) = 10$$

Relative risk = risk ratio  
Excess RR = RR-1



RR is not proportional to radiation dose.  
ERR is proportional to radiation dose.

## Leukemia ERR / dose acute vs protracted

ERR(%)/10mGy

### Acute exposure (high dose rates) :

medium-high doses      **3.1** (95%CI=1.8, 4.3)

low doses :                **1.5** (95%CI=-0.01, 3.1)

Atomic bomb survivors (Ozasa et al. 2012)

### Protracted exposure (low dose rates)

low-medium doses      **1.9** (95%CI=<0, 8.5)

IARC 15-country study of nuclear workers, BMJ 2005

mean cumulative dose=19.4mSv

**1.9** (95%CI=0.7,3.2)

A meta-analysis by Daniels & Schubauer-Berigan

**0.9** (95%CI=-1.7, 6.5)

pooled case-control study of US nuclear workers

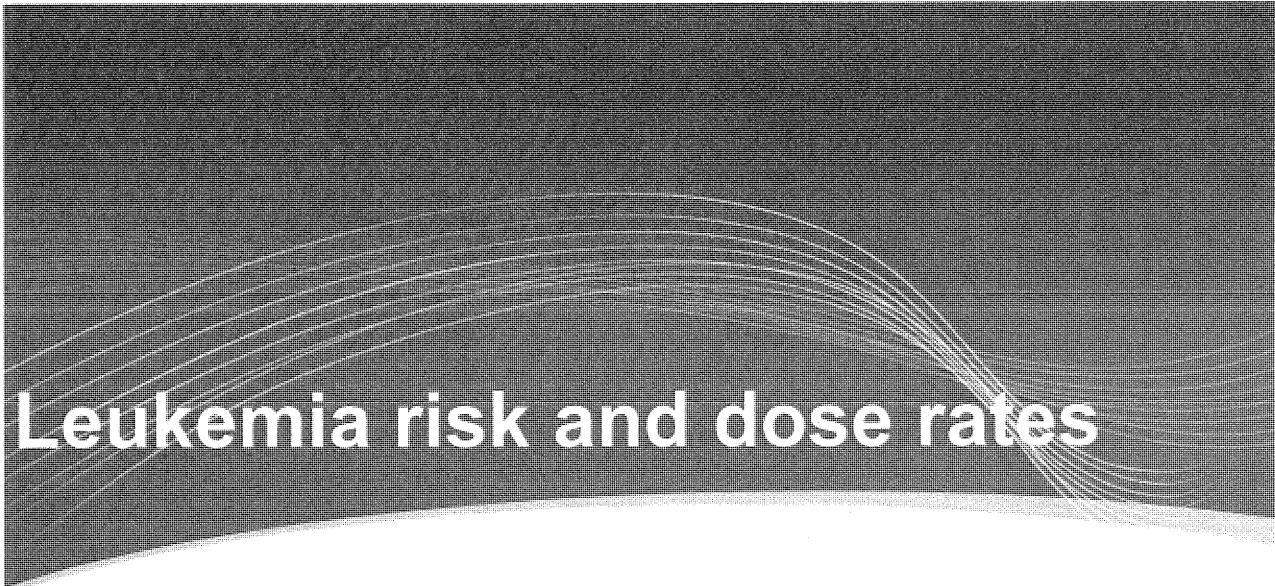
In the case of acute exposure,  
ERR at 1 Gy(%)/10mGy is known to be about 4.  
→ A dose of 1Gy gives an ERR of 4.

In the case of protracted exposure,  
ERR(%)/10mGy =2.0,

Then,  
0.1Gy is expected to give an ERR of 0.2; and  
0.1x 10 =1Gy, an ERR of 2.0,

which is half of that of acute exposure.

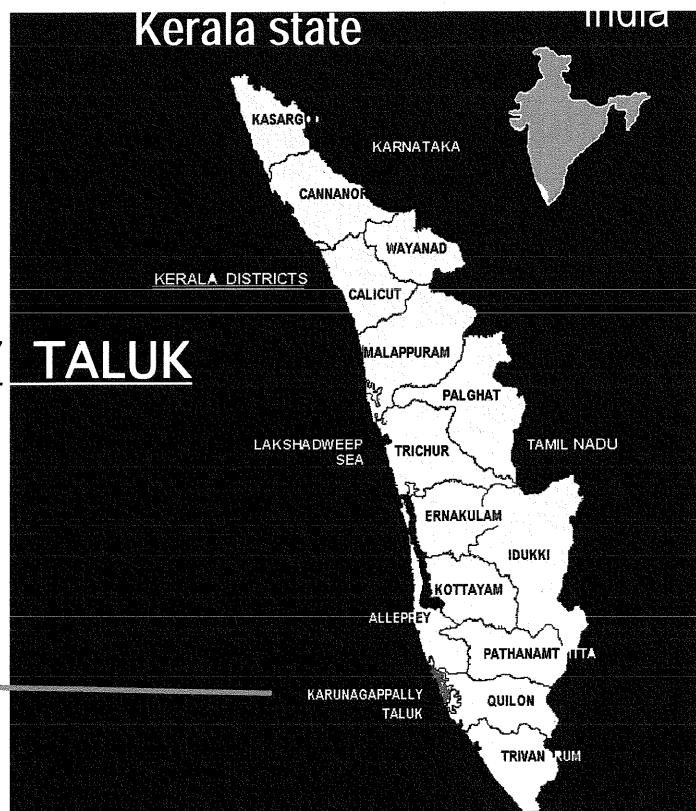
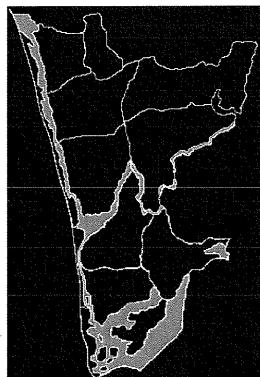
→ Dose fractionation decreases risk per dose.



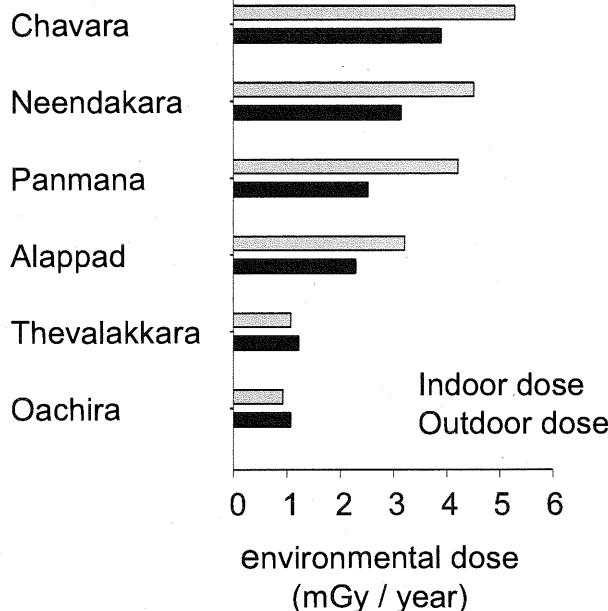
In low-medium doses, ERRs of leukemia per dose after protracted/fractionated are similar to those of exposure after acute exposure.

Kerala state is located in the southern end of Indian subcontinent. HBRA is located in Karunagappally taluk.

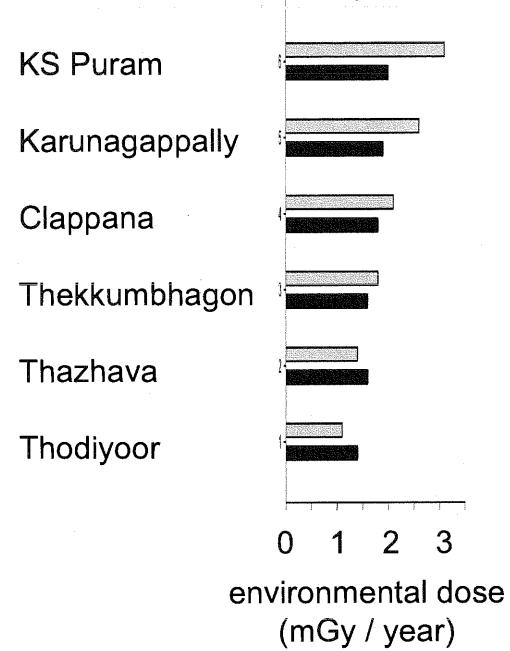
## KARUNAGAPPALLY TALUK



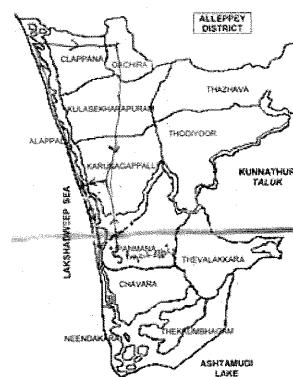
**Panchayats used  
in the present analysis**



**Panchayats  
to be included in analysis**

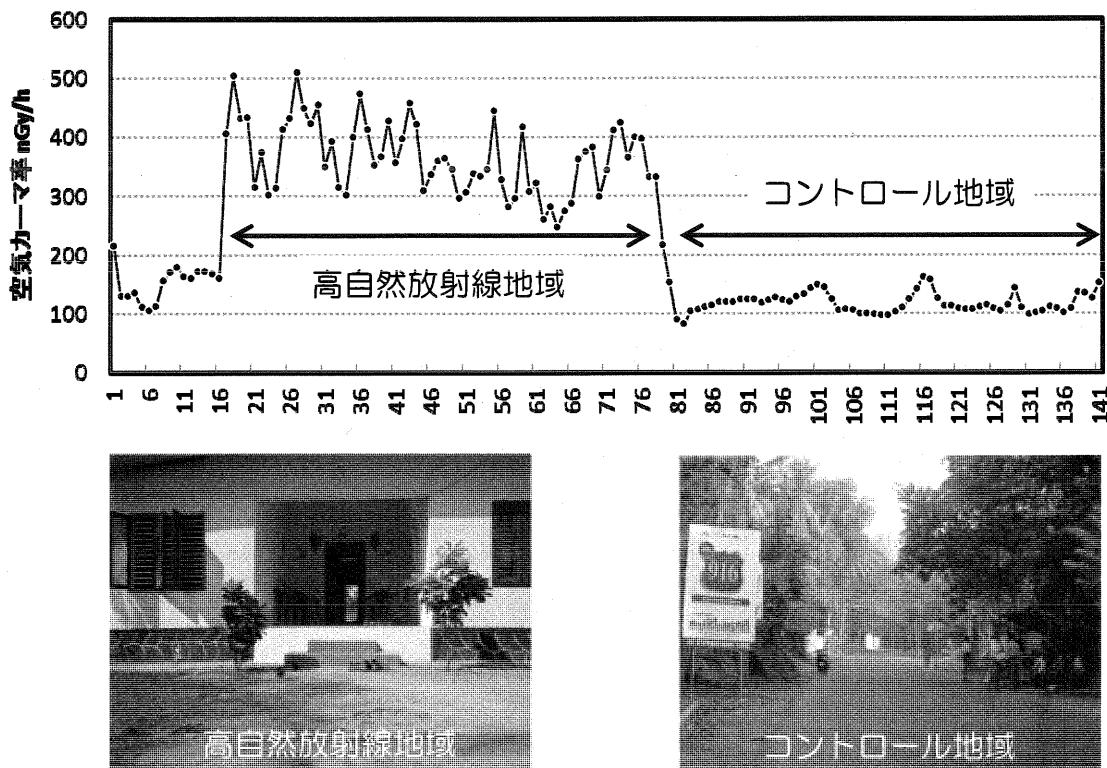


## 走行サーベイによる外部被ばく線量の評価

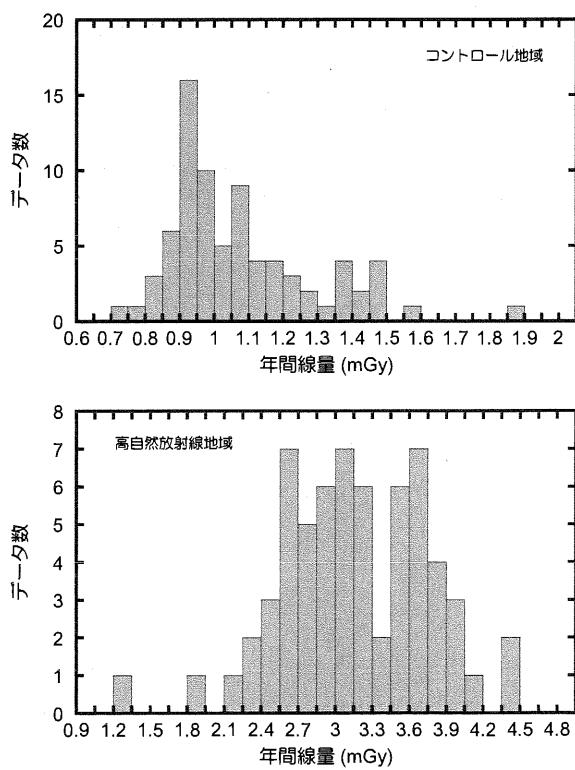


- 3-inch×3-inch NaI(Tl)シンチレーションスペクトロメータ(EMF-211)によって移動しながら車内線量率（空気カーマ率）を測定
- GPSによって移動しながら緯度・経度を測定
- 30秒間隔で線量率・GPSデータを取得
- 車内線量率から車外線量率への換算係数: 1.48  
→ 研究所内とホテルの駐車場において測定  
→ 測定点数を増やして換算係数の精度を上げる必要あり

## 走行サーベイによる外部被ばく線量の評価



## 走行サーベイによる外部被ばく線量の評価

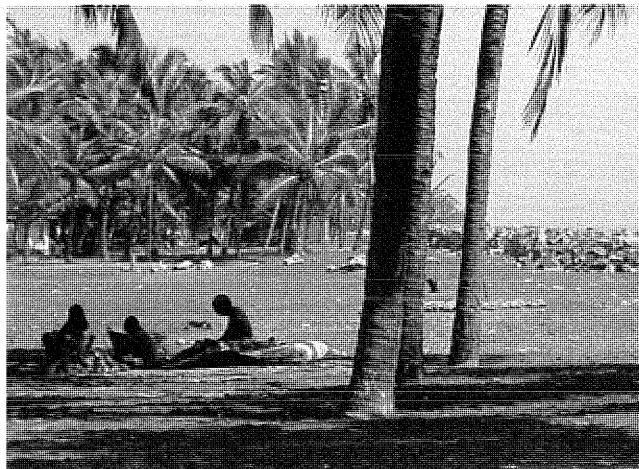


### □ コントロール地域

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### □ 高自然放射線地域

集落名 : Alappad  
面積 :  $7.38 \text{ km}^2$   
人口 : 22,778人  
データ数 : 49データ  
最大値 :  $4.1 \text{ mGy/y}$   
最小値 :  $1.3 \text{ mGy/y}$   
幾何平均値 :  $3.0 \text{ mGy/y}$



In this area,  
natural radiation levels  
are high  
due to black sand  
containing monazite.



The population size of Karunagappally : 385,103 in 12 panchayats )

→ A cohort of residents in 6 coastal panchayats was established in 1990: N=173,067

→ Age 30-84 : N=71,399

→ After excluding those who diagnosed as cancer, died, migrated into other areas before our base-line survey conducted in 1990-97, there were 69,958 subjects for statistical analysis

1. Cancer cases were identified by cancer registry
2. Indoor and outdoor doses were measured at every house.
3. Information on potential confounder is available for all the cohort members.

- i) monthly routine visits to the Regional Cancer Centre (RCC) in Trivandrum, which is the comprehensive cancer centre in the state of Kerala, and more than half of cancer cases registered in Karunagappally cancer cancer registry were those who sought medical treatment in RCC (unpublished data);
- ii) annual visits to Trivandrum Medical College Hospital in Trivandrum;
- iii) annual visits to major pathological laboratories in Karunagappally taluk and its neighboring areas, and in Trivandrum;
- iv) annual visits to all the hospitals and medical practitioners in Karunagappally taluk;
- v) 3-4 time visits to three primary health centers in the taluk, which have cancer screening facilities;

## **Dosimetry**

**It is impossible to measure cumulative HBR doses from birth.**

**→ dose estimation is necessary**

The approach used in the studies in China and India is as follows:

**Individual cumulative dose**

**=measured indoor dose x occupancy factor**

**+measured outdoor dose x (1-occupancy factor)**

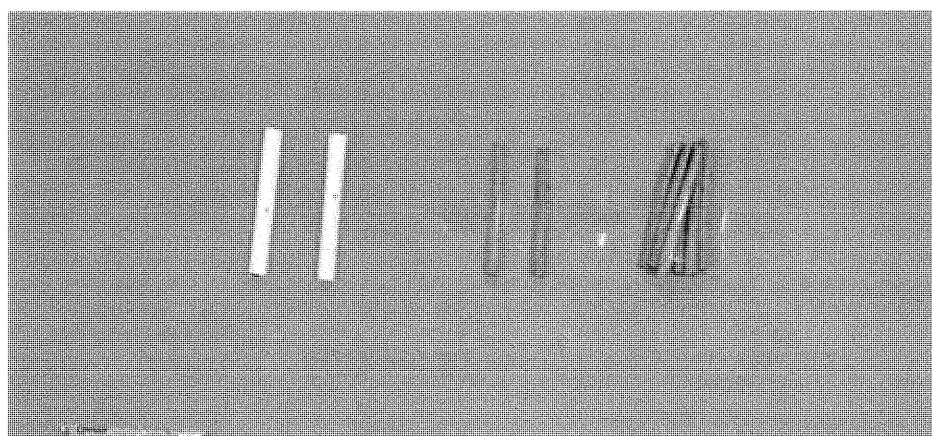
**Indoor and outdoor gamma radiation doses**

**were measured at every house**

**(N=71764 in the entire Karunagapally taluk)**

## Bidi (beedi)

is sun-dried flaked tobacco (0.15–0.25g) rolled into a conical shape in a dried rectangular piece of Temburni (*Diospyros melanoxylon*) leaf.



30

## 線量群別の白血病罹患率の比

All leukemia

P for trend = 0.288

Cumulative radiation dose (mGy)

	0-	50-	100-	200+
Case	5	6	13	6
RR	1	0.80	1.60	1.43
95%CI	reference	0.24 – 2.63	0.56 – 4.56	
	0.42 – 4.88			

Leukemia excluding  
chronic lymphocytic leukemia

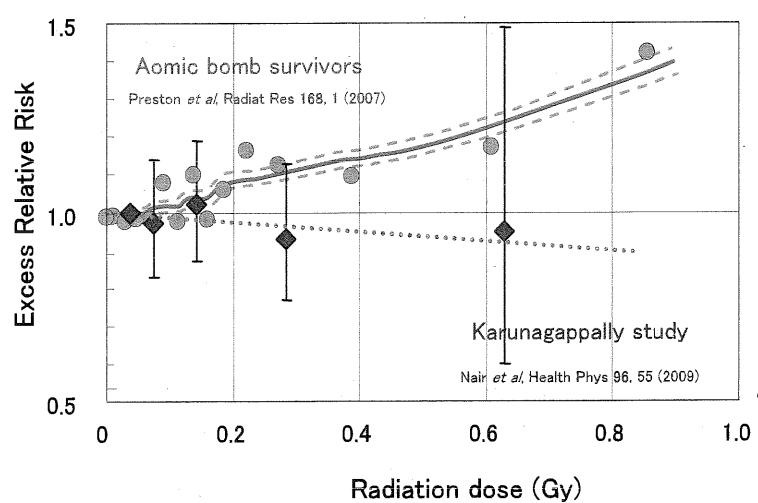
P for trend = 0.471

Case	4	4	7	5
RR	1	0.62	1.00	1.42
95%CI	reference	0.16 – 2.52	0.29 – 3.48	
	0.36 – 5.55			

## 累積線量群別のがん(白血病を除く)罹患率比

	Cumulative radiation dose (mGy)					P for trend
	0-	50-	100-	200-	500-	
Mean dose (mGy)	36	74	141	283	628	
SD	6	9	17	49	118	
Total Case	282	371	463	211	22	
RR*	1	0.97	1.02	0.93	0.95	>0.5
Male Case	149	196	254	135	13	
RR	1	0.97	0.97	0.98	0.81	>0.5
Female	Case	133	175	209	76	9
RR	1	0.98	1.08	0.86	1.25	>0.5
Cases with pathological diagnosis						
Case	204	284	348	134	17	
RR	1	1.07	1.16	0.93	1.21	>0.5

## Solid cancer risk Atomic bomb survivors vs Karunagappally study



In both studies, ERRs/Gy were estimated assuming a Linear-Non-Threshold model. The ERR/Gy obtained from the Kerala study was significantly smaller than that from the Atomic bomb survivor study.

## ERR/Gy, 1990-2005

	Cases	ERR / Gy	95%CI	P value
<b>All cancer excluding leukemia</b>				
all subjects	1349	<b>-0.13</b>	-0.58 – 0.46	>0.5
60 <= attained age	784	<b>-0.19</b>	-0.69 – 0.49	>0.5
Male	747	<b>-0.16</b>	-0.70 – 0.62	>0.5
Female	602	<b>-0.09</b>	-0.76 – 0.92	>0.5
Cases with pathological verification	987	<b>-0.03</b>	-0.57 – 0.71	>0.5
Lung cancer, all subjects	189	<b>-0.07</b>	ND – 1.94	>0.5
Breast cancer, female	125	<b>-0.60</b>	ND – 0.85	>0.5

Assuming linear dose-response, the following model used:

$H_0(\text{sex, attained age, follow-up interval, bidi smoking, education, occupation}) [1 + \beta D]$

## ERR/Gy, 1990-2010

	Cases	ERR/Gy (95%CI)	P value
<b>All cancer excluding leukemia</b>			
All subjects	2120	-0.08 (-0.44 – 0.38)	>0.5
Male	1153	-0.27 (-0.64 – 0.26)	0.276
Female	967	0.29 (-0.38 – 1.19)	0.463
Cases with pathological verification	1650	-0.05 (-0.60 – 0.39)	>0.5
Oropharyngeal cancer	326	0.17 (ND – 1.61)	>0.5
Digestive tract cancer	424	-0.039 (ND – 0.53)	>0.5
Lung cancer	267	-0.073 (ND – 1.75)	>0.5
Breast cancer (female)	188	-0.83 (-2.05 – 0.40)	>0.5

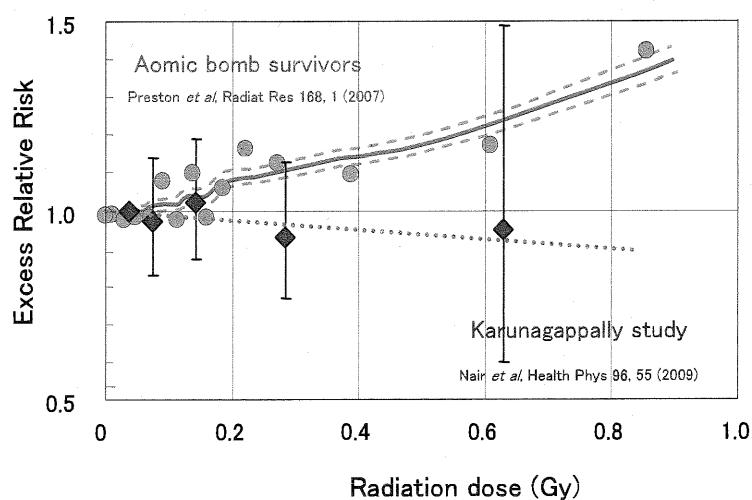
Risk of all cancers excluding leukemia  
according to cumulative radiation dose, lagged by 10 years,  
1990-2010

Cumulative radiation dose (mGy)

	0-	50-	100-	150-	200-	250-	500+
Case	485	585	432	267	136	187	28
RR*	1	0.96	0.98	1.03	0.95	1.00	0.91
95%CI	-	0.85 -1.08	0.85 -1.12	0.88 -1.21	0.78 -1.16	0.84 -1.20	0.61 -1.35

\*RRs were obtained from the following model, using colon dose lagged by 10 years: H0(sex, attained age, follow-up interval, radiation cohort or not, education, the numbers of bidis smoked a day, tobacco chewing and alcohol drinking) [ $\exp(\beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4)$ ]. The estimates of  $\beta_1$ ,  $\beta_2$ ,  $\beta_3$ , and  $\beta_4$  correspond to log RRs for dose categories, 0-, 50-, 100-, 150-, 200-, 250- and 500+ mGy, respectively.

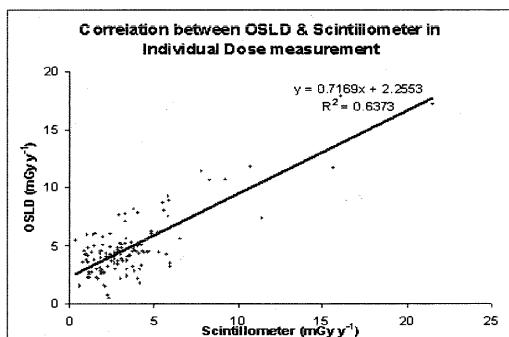
**Solid cancer risk**  
**Atomic bomb survivors vs Karunagappally study**



In both studies, ERRs/Gy were estimated assuming a Linear-Non-Threshold model. The ERR/Gy obtained from the Kerala study was significantly smaller than that from the Atomic bomb survivor study.

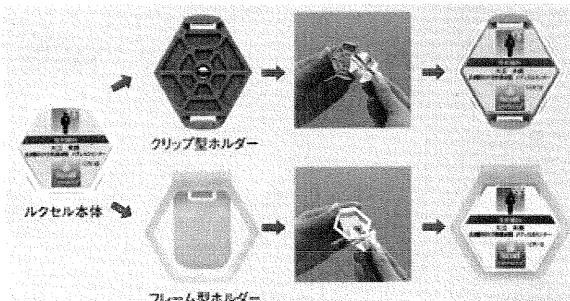
## Estimated doses had a high correlation with individual doses measured using luxell badges

Individual cumulative dose  
=Indoor dose x occupancy factor  
+outdoor dose x (1-occupancy factor)



### Luxell badge

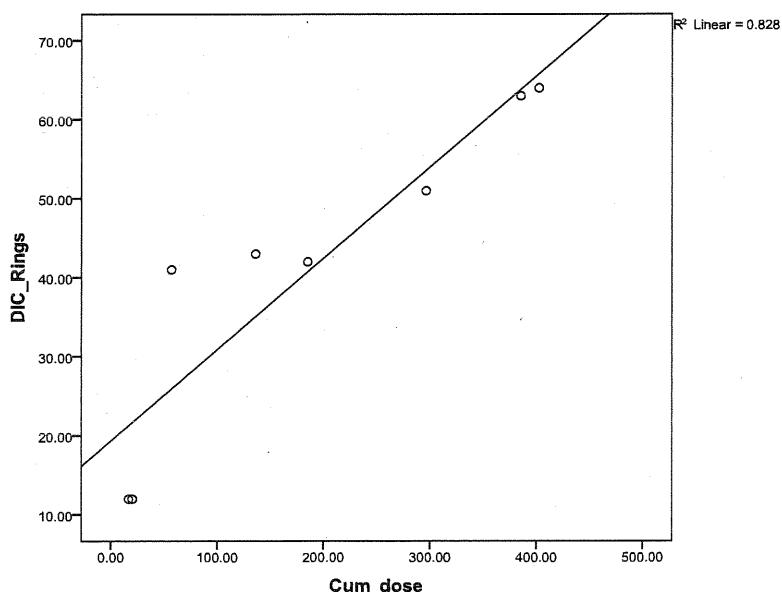
,based on optically stimulated luminescence  
from element of aluminum oxide,  $\text{Al}_2\text{O}_3:\text{C}$



A luxell badge was carried by each individual for 2 months.

29

## The frequency of Dic+Rings increases with cumulative radiation dose



30

# internal exposure

食品中の放射性物質の濃度は高くない  
空気中のラドンとその壊変核種の濃度もあまり高くない。

Sampling Points	Sample	K-40 1460.7keV	Pb-212 (Th) 238.6keV	Tl-208 (Th) 583.2keV
Thevalakkara (CA)	1 Cooked Rice	126.9 ± 0.92	1.80 ± 0.031	1.44 ± 0.057
Oachira(CA)	2 Colocasia (English ?)	14.6 ± 0.077	0.192 ± 0.0027	0.163 ± 0.0048
Oachira(CA)	3 Yam (Kachil)	14.6 ± 0.041	0.026 ± 0.00096	0.0227 ± 0.0018
Oachira(CA)	4 Tapioka	9.62 ± 0.067	0.114 ± 0.0020	0.0914 ± 0.0031
Oachira(CA)	6 Elephant Yam	19.9 ± 0.064	0.102 ± 0.0017	0.0861 ± 0.0031
Mean (CA) (±) *		37.1 ± 50.3	0.45 ± 0.76	0.36 ± 0.61
Range (CA)		9.62 ~ 126.9	0.026 ~ 1.80	0.023 ~ 1.44
Alappad	5 Coconut	12.7 ± 0.063	0.421 ± 0.0029	0.355 ± 0.0051
Chavara	7 Black Clam	1.95 ± 0.023	0.129 ± 0.0015	0.104 ± <sup>32</sup> 0.002

# Cancer Rate Comparison

(cases per 100K)

	Japan		Karunagappally	
	Male	Female	Male	Female
All Solid	271	169	116	80
Oral	6.2	2	20.4	8.8
Stomach	61.8	23.8	6.1	2.6
Colon	31.2	18.5	2	2.1
Liver	23.5	7.5	3.9	0.8
Lung	37.6	11.8	21.3	2.3

## Natural Background China, Thyroid

	High Background	Control
Number examined	1,001	1,005
Thyroid dose (cGy)	14	5
Nodular disease	9.5%	9.3%
Single nodules	7.4%	6.6%
RR (95% CI)	1.13 (0.8-1.6)	

Wang et al. J Natl Cancer Inst, 82:478, 1990

# Natural Background China Mortality



	High Background	Control
Number (1979-86)	80,640	32,651
Doses		
Effective ( $\text{mSv y}^{-1}$ )	6.4	2.4
Radon ( $\text{WLM y}^{-1}$ )	0.38	0.16
Deaths (1979-95)		
Lung	62	32
Leukemia	33	11
All cancer	710	293
RR (95% CI)		
Lung	0.81 (0.53-1.24)	
Leukemia	1.12 (0.56-2.22)	
All	0.99 (0.87-1.14)	

Boice. J Radiat Prot. 22:102-4 2002

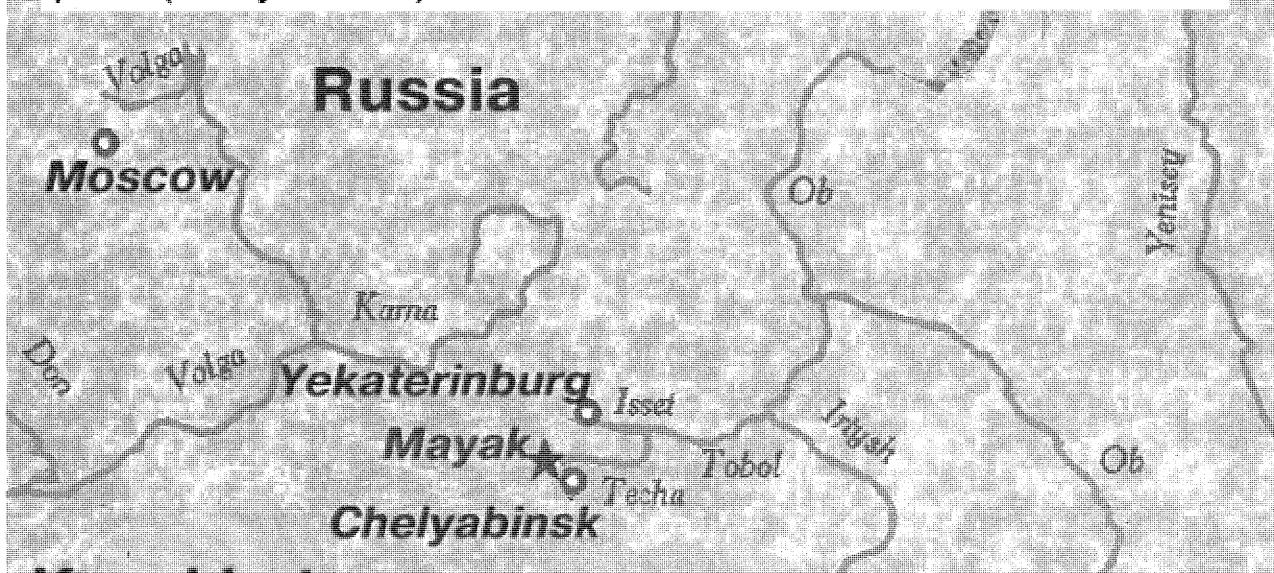
Wei, Sugahara J Radiat Res Suppl. 2000

## ERR/Gy for solid cancer

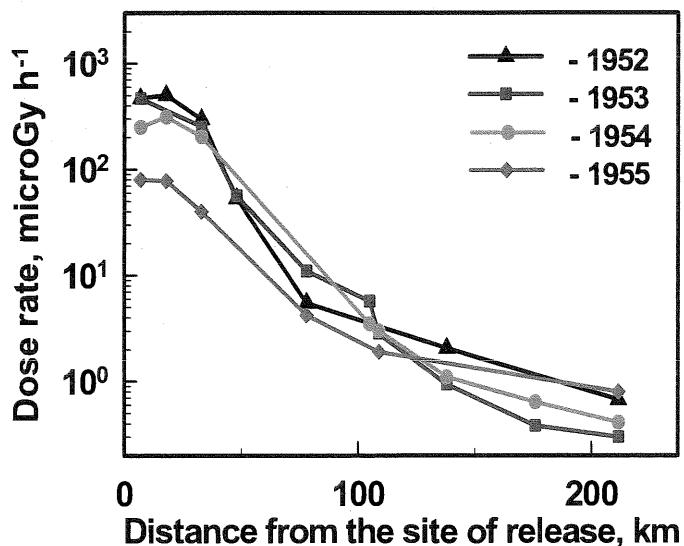
	ERR / Gy
Atomic bomb survivors	0.47 (90%CI: 0.40, 0.54)
Residents along Techa river	0.61 (95%CI: 0.04, 1.27)
Nuclear workers in 15 countries –pooled analysis of IARC (ca-leukemia mortality)	0.97 (90%CI: 0.27, 1.80)
Meta-analysis of nuclear workers in 4 countries (ca mortality)	0.14 (95%CI: -0.12, 0.41)
Residents in Karunagappally, India (ca-leukemia)	-0.13 (95%CI: -0.58, 0.46)
Residents in 陽江, China (ca-leukemia mortality)	0.19 (95%CI: 1.87, 3.04)
Residents in buildings with $^{60}\text{Co}$ -contaminated rebars in Taiwan (ca-leukemia)	0.2 (90%CI: -0.5, 0.8)



Mayak, a major plutonium plant in USSR, released a large amount of radioactive materials ( $10^{17}$  Bq) into Techa River in a relatively short time period (mainly 1948-51).



In definition, high dose rate is the dose rate higher than 6000 micro Gy/hr.  
The dose rate in highly contaminated areas along Techa rivers lower than was close to that value.



# Solid cancer

**High dose rates,**  
medium-high doses

ERR/Gy= 0.59 (95%CI=0.50, 0.70)  
age ATB=30, attained age=60

←Atomic bomb survivors

**“medium” dose rates**

low-medium doses ERR/Gy= 0.6 (Techa river)

**Low-dose rates**

low-medium doses ERR/Gy= 0.97 / ERR/Gy= 0.14  
(nuclear workers)

ERR/Gy= -0.08 (95%CI= -0.44, 0.38)

← Karunagapally residents

# Solid cancer

**High dose rates,**  
medium-high doses

ERR/Gy= 0.38 (95%CI=0.28, 0.51)  
male, age ATB=40, attained age=60

ERR/Gy= 0.61 (95%CI=0.45, 0.79)

male, age ATB=30, attained age=50

←Atomic bomb survivors

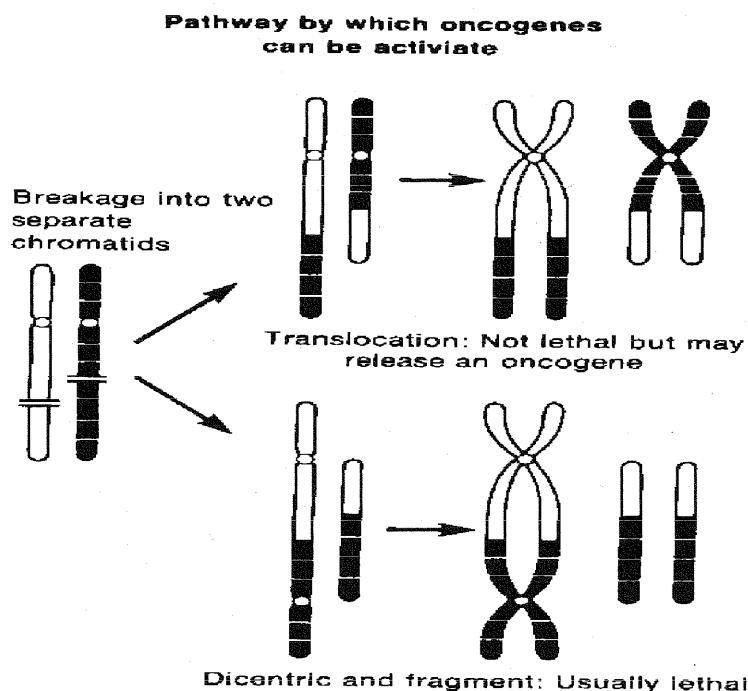
**Low-dose rates**

low-medium doses ERR/Gy= 0.97  
ERR/Gy= 0.14 (95%CI= -0.12, 0.41)  
(nuclear workers)

## Dose rates and cancer risk

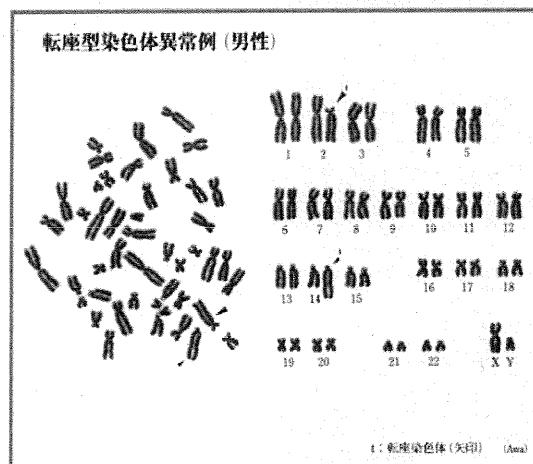
Solid cancer risk:  
acute exposure > protracted exposure

Ionizing radiation causes double stranded breaks of DNA, which lead to chromosomal aberrations.



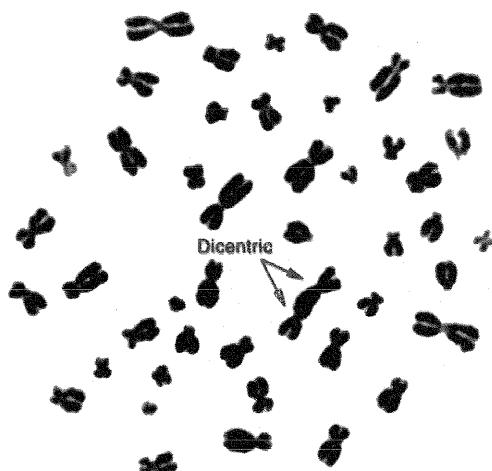
43

**Stable-type chromosome aberration**  
-- this type of chromosome aberration increase cancer risk

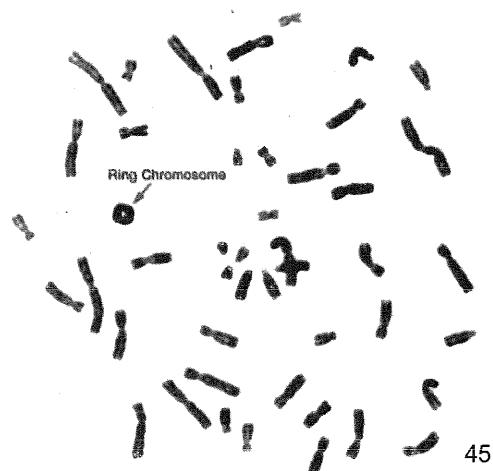


44

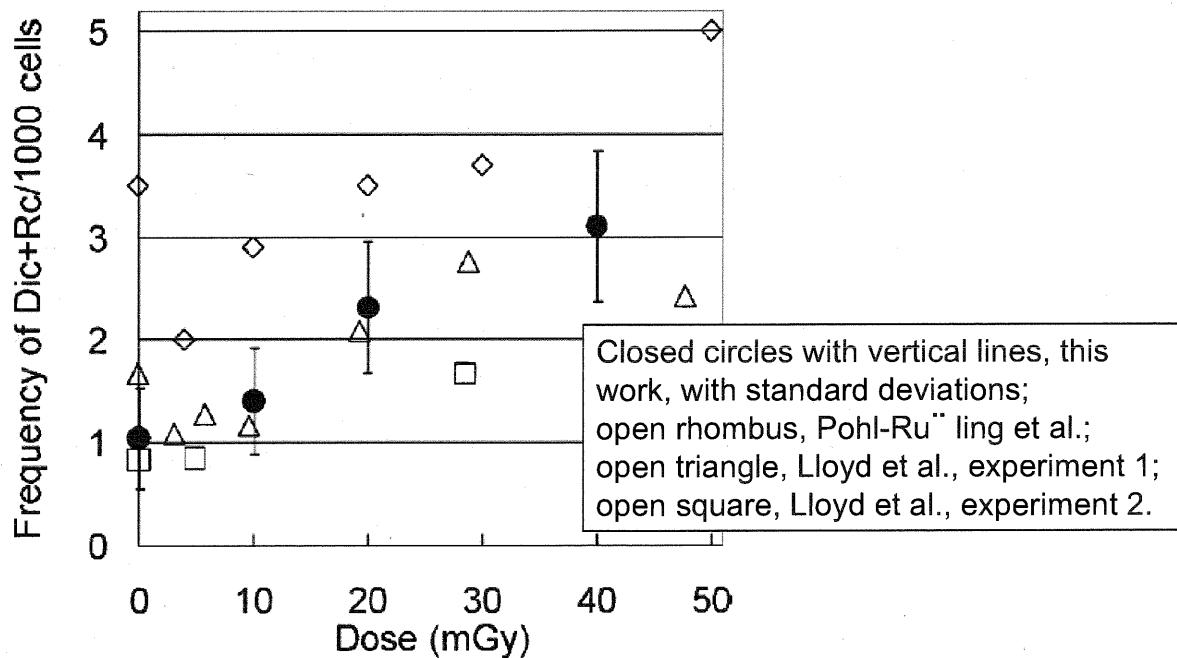
## Unstable type chromosome aberrations --mainly caused by ionizing radiation



画像の読み込みに失敗しました。



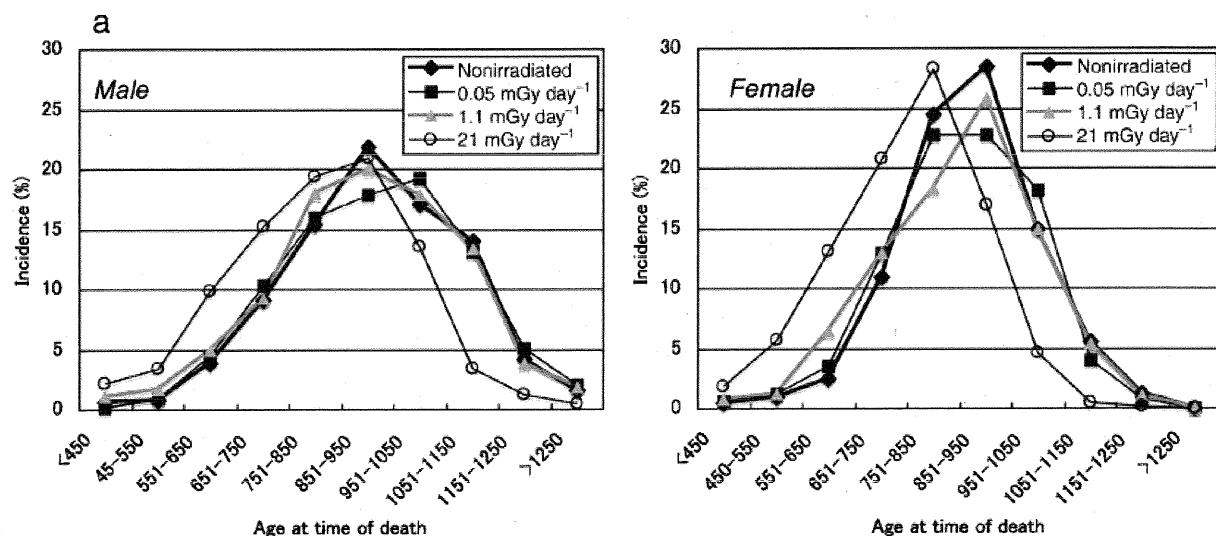
45



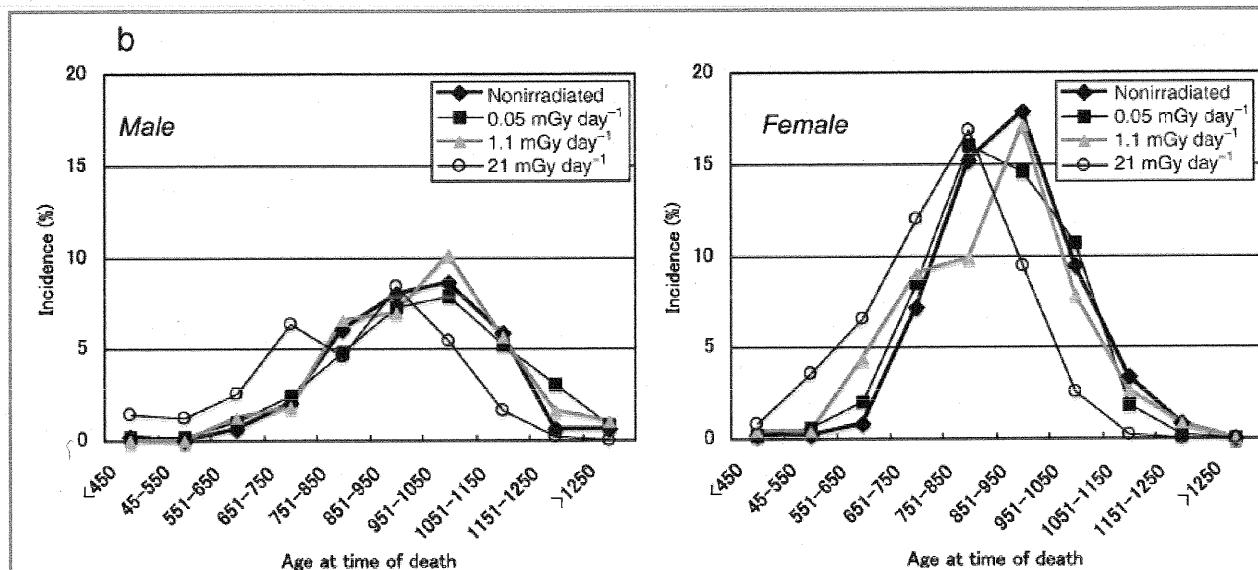
Radiation dose as low as 20mGy significantly increased the frequencies of unstable type aberrations.  
Note also that the dose response is linear.

46

## Animal experiments in Aomori: Tumor incidence was increased at 21 mGy/day



Temporal distribution of all neoplasms that caused in B6C3F1 mice irradiated with very low dose rates of rays for approximately 400 days.



Temporal distribution of malignant lymphomas that caused death in B6C3F1 mice irradiated with very low dose rates of rays for approximately 400 days.

49

B6C3F1 mice irradiated with very low dose rates of rays for approximately 400 days.

average body weights

