

PIANOFORTE CITISTRA - Results of thyroid measurements with CzechRad detector

Pavol Ragan

Slovak Medical University (SMU)

Bratislava, Slovak Republic

NERIS workshop, Fontenay-aux-Roses, 28.-30. April 2026



Co-funded by
the European Union



Major nuclear emergencies

Release of radioactive I-131

- 1957 Windscale – 740 TBq
- 1948 - 1972 Mayak – 37 000 TBq
- 1979 Three Miles Island – 0,6 TBq
- 1986 Chernobyl – RBMK – 1 760 000 TBq
- 2011 Fukushima – 160 000 TBq

- Nuclear weapons tests 4 625 TBq/kT
- 1951-62 Nevada test site – 119 atm. tests – 5 550 000 TBq

(Sources: wikipedia, AI Gemini)

Chernobyl - Radionuclide release and deposition

- Major releases from unit 4 of the Chernobyl nuclear power plant continued for ten days
- They included
 - radioactive gases,
 - condensed aerosols and
 - a large amount of fuel particles.

Chernobyl - Radionuclide release and deposition

- The total release of radioactive substances was about 14 EBq
 - which included
 - 1.8 EBq of ^{131}I (50 – 60 % of the core inventory)
 - 0.085 EBq of ^{137}Cs and other cesium radioisotopes,
 - 0.01 EBq of ^{90}Sr and
 - 0.003 EBq of plutonium radioisotopes.
 - The noble gases contributed about 50% of the total release of radioactivity.
 - Sr and Pu were deposited close to the release source
-
- $1 \text{ EBq} = 10^{18} \text{ Bq}$

Iodine

- Much of the release comprised radionuclides with short physical half-lives
- The releases of radioactive iodines caused concern immediately after the accident.
- radioactive iodine was dispersed in various physical and chemical forms, which determined how far it traveled and how easily it was absorbed by the human body.
- few reliable measurements were made of the spatial distribution of deposited radioiodine (which is important in determining doses to the thyroid).
- Current measurements of ^{129}I may assist in estimating ^{131}I deposition better and thereby improve thyroid dose reconstruction

Isotopes

- Iodine-131 : The most critical isotope for short-term health risks due to its 8-day half-life and rapid accumulation in the thyroid gland.
- Short-lived isotopes ^{132}Te (2,3 d) $\rightarrow$ ^{132}I (2.3 h), ^{133}I (20.8 h), ^{135}I (6.6 h): These contribute to high radiation doses in the immediate days following the explosion but will decay within weeks.
- Iodine-129: A long-lived isotope with a half-life of roughly 16 million years, used primarily for long-term environmental tracking.

Physico-chemical forms in the atmosphere

- Gaseous Form: This included molecular iodine I_2 and other inorganic gases. Gaseous iodine is highly mobile and is difficult to capture with standard filters.
- Aerosols (Particulate): Iodine attached to fine solid particles or "dust." These particles typically range from 0.3 to 1.5 μm in size, allowing them to remain suspended in the air for long periods and travel across borders.
- Organic Compounds: Organically bound iodine, such as methyl iodide (CH_3I)

REPORT OF THE
UNITED NATIONS
SCIENTIFIC COMMITTEE
ON THE
EFFECTS OF ATOMIC RADIATION

1958, Annex D

TABLE XX. MISCELLANEOUS DATA ON FALL-OUT

Country	Belgium	Brazil	Denmark	France	India	Italy	Japan	Netherlands	Norway	Sweden	United Arab Republic (Egypt)	United Kingdom
Period of measurement of air concentrations of fission products.....	1957	May to July 1956	1956	1957	Feb. to Aug. 1956	Nov. 1956 to Jan. 1958	a) 1955 b) 1956 c) 1957	May 1956 to Dec. 1957	Mar. 1956 to Oct. 1957			April 1952 to Jan. 1956
Maximum concentration of fission products in air at ground level (10^{-16}Ci/l).....	14.8 ^a		21.9 ^b	87 ^b	17.9 ^b	33.2 ^a	a) 14.7 ^a b) 177.3 ^a c) 153.6 ^a	120 ^b	18 ^b			113 ^a
Mean concentration of fission products in air at ground level (10^{-16}Ci/l)	7.5	0.5	2.8	10	5.6	12.6	a) 5.9 b) 37.1 c) 54.1	9	7			2.3
Content of I^{131} in thyroids of cattle ($\mu\mu\text{Ci/g}$).....	Thyroid activity									Sept. 1956 100-800	May to Sept. 1956 11 (0-129) Oct. 1956 344 (3-1290)	
I^{131} in milk ($\mu\mu\text{Ci/l}$).....	Activity in milk									1957 82 (0-1350)	3 Bq/l (0 - 50 Bq/l)	

^a Average over 1 month.

^b Average over 24 hours.

87. Results of measurements of the I^{131} content in cattle thyroids from various laboratories show a large spread of values. Neglecting high values from areas near test sites, average results for cattle from different geographical locations are comparable, and are of the order of 1 to 100 $\mu\mu\text{C/g}$ thyroid for the period May 1955 to the end of 1956.^{76,78} On account of the short half-life, I^{131} concentrations in thyroids vary with time as related to weapon tests.^{79,80}

- Cattle thyroids

- High values near test sites only
- 0,04 – 3,7 Bq/g

88. I^{131} activities in human thyroids are lower than in those of cattle from the same area and show less spread in the values. Considering only the I^{131} activities from a group of barn-fed cattle and correcting for different respiratory volumes, values similar to those of human thyroids are obtained.⁸⁰ This supports the idea that the human I^{131} intake is through inhalation. In some areas of the United States away from test sites, the I^{131} concentrations in human thyroids averaged about 4 $\mu\mu\text{C/g}$ thyroid during May 1955.⁸⁰ The human thyroids measured were mostly from adults (more than 50 years old), but a few samples from persons of different ages

- Human thyroids
- Avg 0,15 Bq/g

REPORT OF THE
UNITED NATIONS
SCIENTIFIC COMMITTEE
ON THE
EFFECTS OF ATOMIC RADIATION

UNITED NATIONS
New York, 1964

TABLE XXIX. I^{131} IN THYROIDS
In vivo counting technique
(Number of subjects in parentheses)

<i>Location and age</i>	<i>Period of measurements</i>	<i>Average milk consumption in litres per day</i>	<i>I^{131} in thyroids pCi</i>	<i>Reference</i>
UNITED STATES				
New York City, N. Y.				
Adults.....	November 1961	0.25-1.0	57 ± 33 (6)	248
New York City, N. Y.				
Adults.....	November 1961	Very low	4.3 ± 4.9 (3)	248
New York City, N. Y.				
Below 18 years.....	November 1961	~ 1.0	83 ± 29 (16)	248
UNITED KINGDOM				
London, Sutton				
Adults.....	November 1961	~ 0.25	250^* (20)	254
UNITED STATES				
Utah				
Adults.....	1-6 August 1962	1.3	5,900 3,700-11,000 (14)	250
Utah				
Adults.....	22-31 August 1962	1.3	3,600 700-10,900 (12)	250

10 000 pCi =
370 Bq

Table 3-2—Change of I-131 activity in milk with time following Windscale reactor accident on October 10, 1957. (Data from Booker, ref. 3-4 p. 3 and 4.)

The Windscale accident released an estimated 20,000 curies of I^{131} , or 0.16 kt equivalent. Samples of milk measured in Harwell varied from less than 300 $\mu\mu\text{C } I^{131}/\text{liter}$ to over 1,000,000 $\mu\mu\text{C } I^{131}/\text{liter}$ close to the point of release.

A daily series of samples was obtained and analysed at Windscale to study the change in I^{131} activity in milk with time. Although the dissemination of I^{131} from the pile reached a peak in the early hours of October 11th, and ceased by about noon on that day, the activity did not appear in the milk of the local cows until the afternoon of the 11th. The maximum activity in milk was reached on the afternoon of the 12th or the morning of October 13th as shown below.

Time of Milking		Sellafield $\mu\text{C}/\text{l}$	Seascale $\mu\text{C}/\text{l}$
11/10/57	am	0.003	
	pm	0.47	0.4
12/10/57	am	0.48	0.85
	pm	1.32	0.6
13/10/57	am	0.39	0.94
	pm	1.12	0.63
14/10/57	am	0.54	0.51
	pm	0.72	0.67

1 $\mu\text{Ci}/\text{l} =$
37 kBq/l

IODINE-131 IN FRESH MILK AND HUMAN THYROIDS FOLLOWING A SINGLE DEPOSITION OF NUCLEAR TEST FALLOUT

H. A. KNAPP, Fallout Studies Branch, Division of Biology and Medicine, U. S. ATOMIC ENERGY COMMISSION report TID-19266, Washington 25, D. C., June 1, 1963

- Nevada test site
 - Test Small Boy, 14 July 1962
 - 1,7 kt
 - 270 kCi, 10 000 TBq of I-131 release/fallout
-
- The report warns of serious consequences resulting from radioiodine releases and contamination

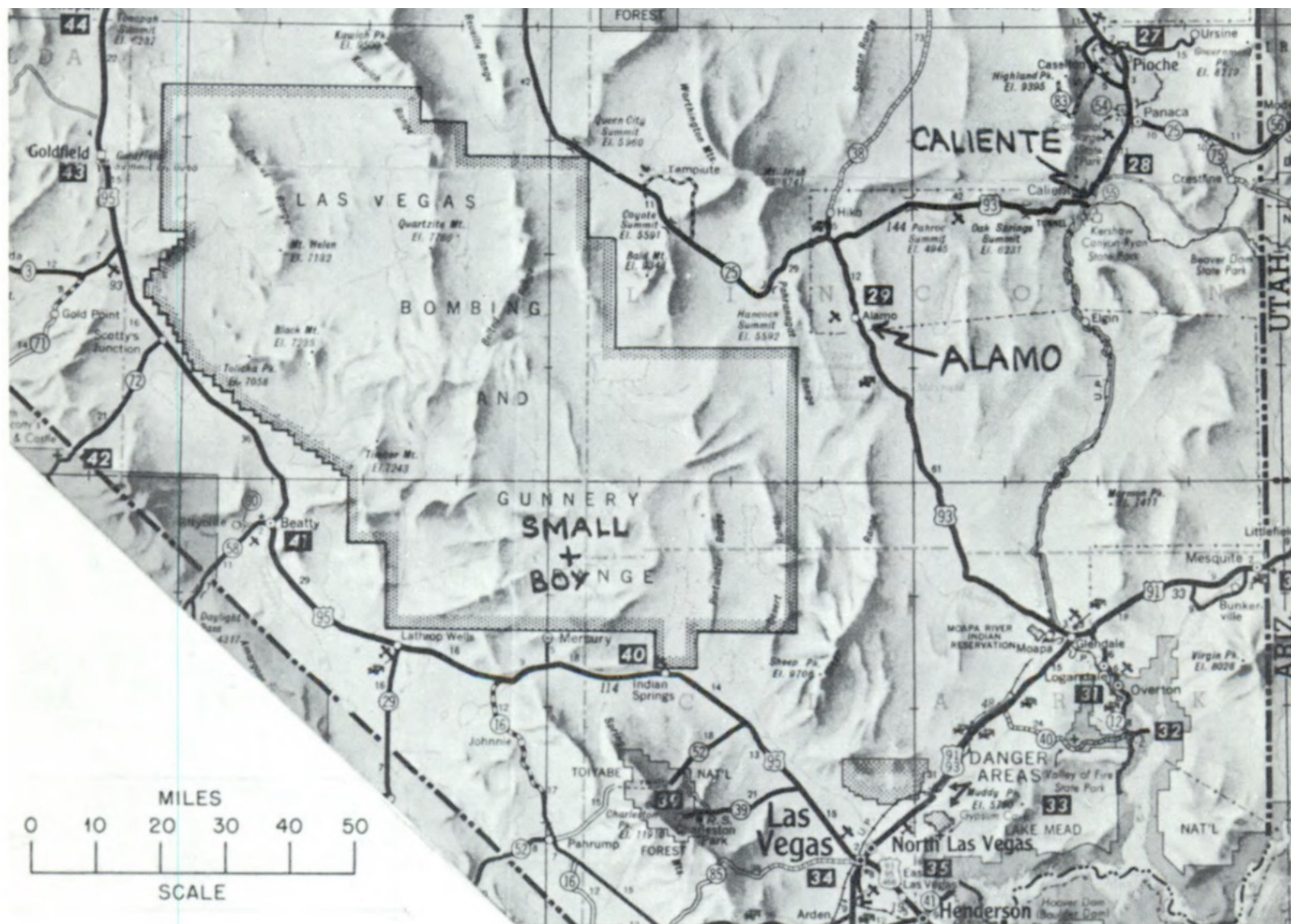


Fig. 3—Area surrounding Nevada Test Site.

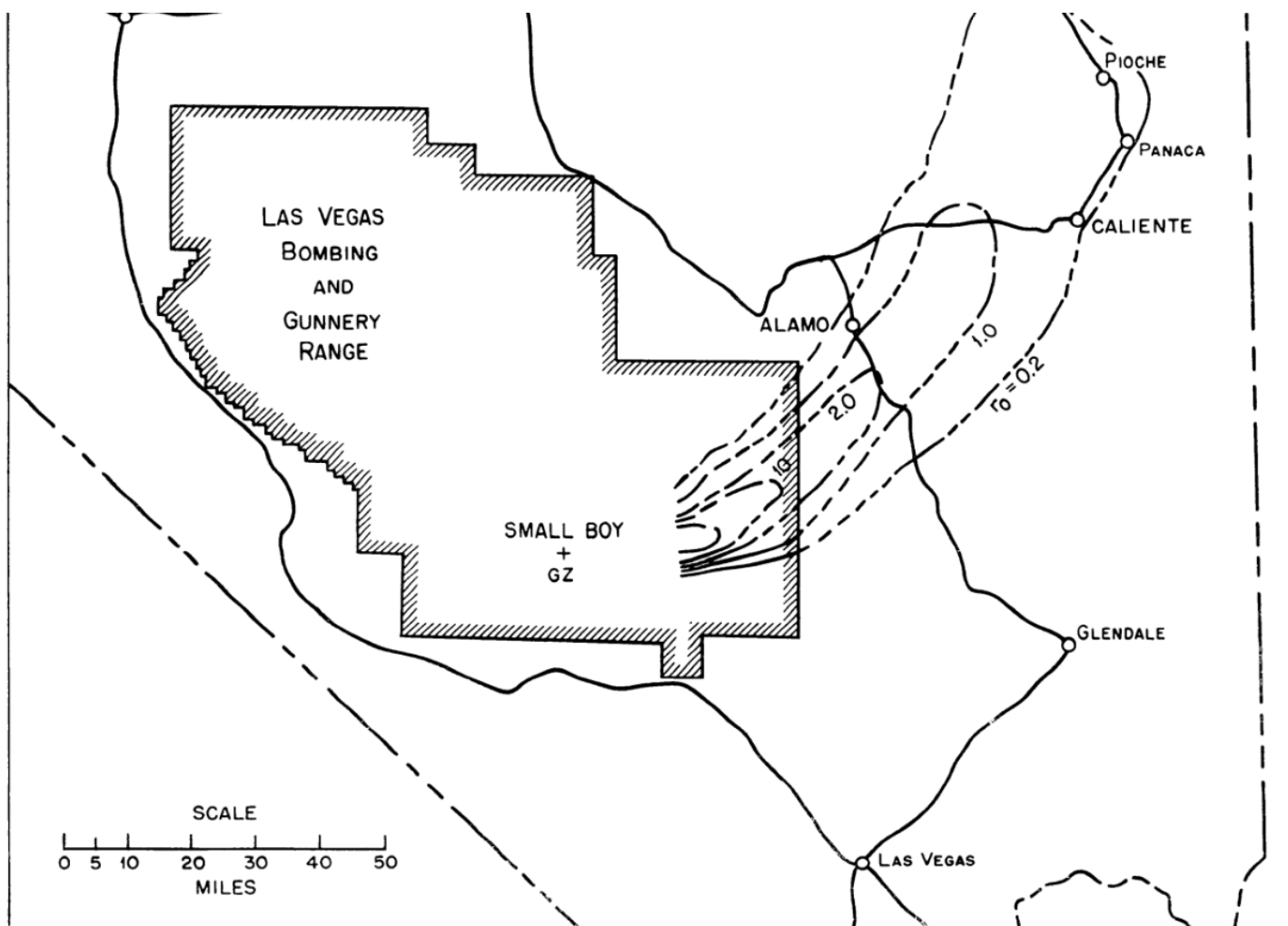


Fig. 4—Estimated 24 hour dose rate contours in Alamo-Caliente area following fallout from Small Boy (mr/hr). Based on aerial surveys on 7/16 and 7/17, 1962 by ARMS II, EG&G. Contours in mr/hr at H + 24 hours based on $t^{-1.2}$ decay correction and a conversion factor of 50,000 counts/sec at 500 ft alt. = 1 mr/hr 3 ft above ground. Project Officer R. B. Gullou, EG&G.

Hot spot

A hot spot occurred southeast of Salt Lake City,

300-400 miles from the point of detonation following the passage of the SMALL BOY cloud.

The general location of this hot spot was first determined by an airborne radiological survey aircraft

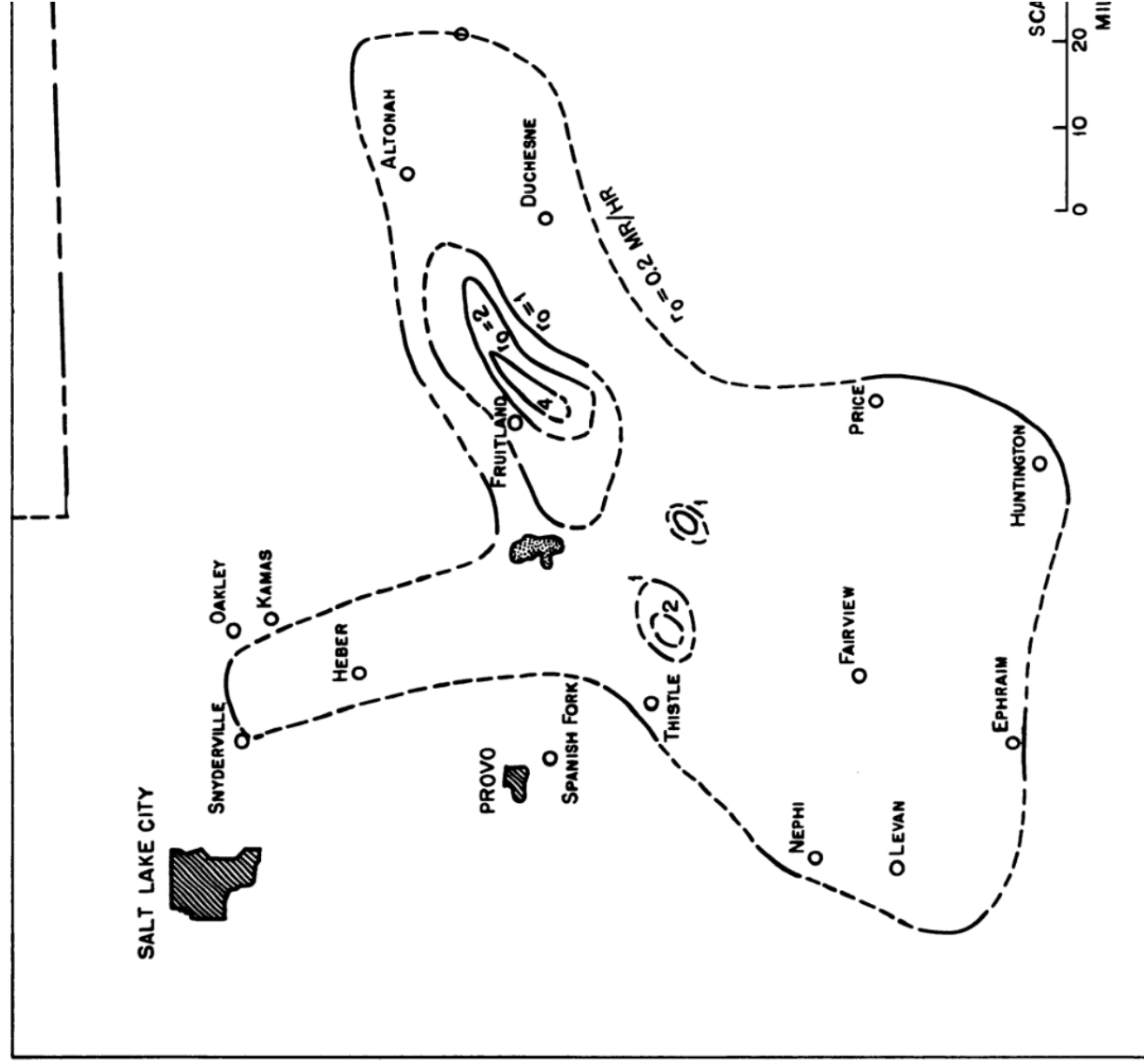


Fig. 6—Estimated 24 hour dose rate contours in NE Utah following fall of the SMALL BOY atomic bomb (mr/hr). Based on aerial surveys by ARMS I, USGS 7/16/62, ARMS II, E. Contours in mr/hr at H + 24 based on $t^{-1.2}$ decay correction and a conversion factor of 1 counts/sec at 500 ft alt. = 1 mr/hr at 3 ft above ground. Project Officer

Milk contamination following SMALL BOY

The Caliente milk was collected from a dairy 5 miles north of Caliente on Highway 93.

I-131 levels in the Alamo milk, $T = 5.2$ days, $I_{\max} = 2300 \mu\mu\text{c}$ I-131/liter, and $I_0 = 3000 \mu\mu\text{c}$ /liter.

I-131 levels in Caliente milk, $T = 4.7$ days, $I_{\max} = 7700 \mu\mu\text{c}$ I-131/liter, and $I_0 = 10,000 \mu\mu\text{c}$ I-131/liter.

Estimates

100 000 pc/l per 1 mr/h gives maximum 400 000 pc/l at hot spot in Utah

Measurements results - **370 Bq/l** and resulting **child thyroid dose 17 mGy (1,7 rad)**

Estimates (Knapp, 1963) **up to 15 kBq/l** – resulting in **ThAD 680 mGy - $4 \times (17 \text{ rad} / (100\,000 \text{ pc/l})$**

Assuming a 2 gram thyroid (the average for a 1 year old child), a daily milk consumption of 1 liter, 30% uptake of ingested iodine by the thyroid gland, a 5 day half reduction time of I-131 in milk T , and an $I_{\max}$ or **100,000 pc** I-131/liter ($I_0 = 133000 \text{ pc} / \text{l}$) one may calculate (Eq. 1) **the thyroid dose to be 17 rads**, with essentially all of this dose delivered over a period of 6 weeks following fallout deposition. The corresponding dose to the 20 gram thyroid of an adult would be 2/20ths that of the infant, or 1.7 rads.

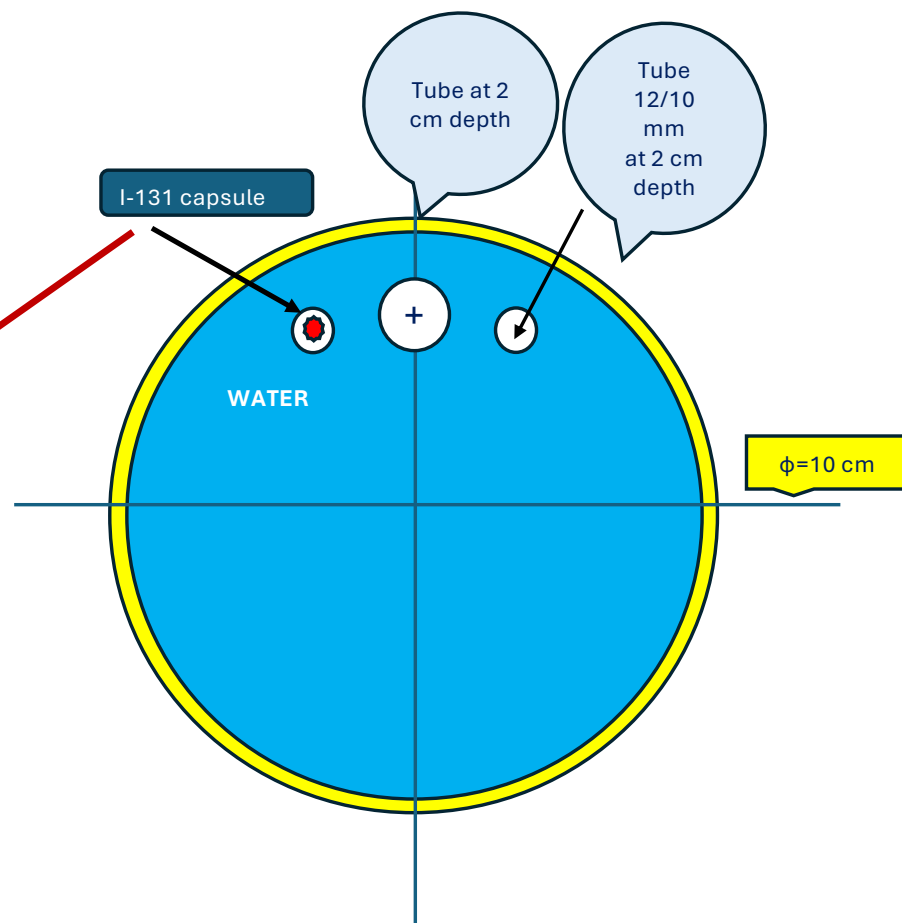
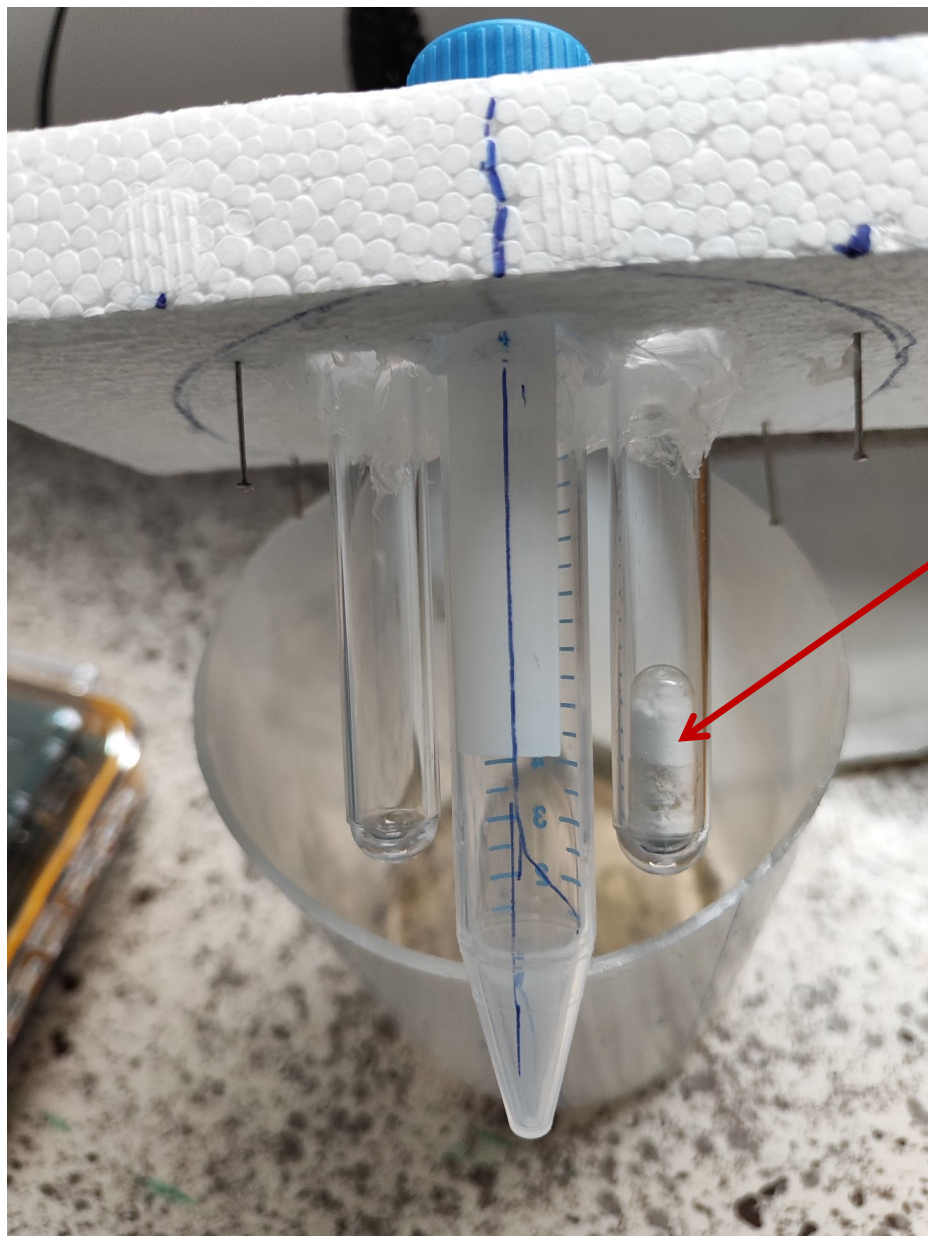
From H.A. Knapp letter to Mr. John T. Conway

Executive Director, Joint Committee on Atomic Energy, Congress of the United States, Washington, D. C., September 9, 1963

- The "potential significance" of this finding may be appreciated by an example.
- The relatively heavy fallout in the St. George, Utah area on May 19, 1953 resulted in a measured r_0 of **27 mr/hr**. If the relation were valid for this fallout, it would mean that milk levels reached values of from 700,000 to 2,600,000 ppc I-131/liter, and that the associated doses to the thyroid of an infant which drank 1 liter of this milk per day for three weeks following the test would lie in the range of **120 to 440 rads. (1,2 to 4,4 Gy)**
- In retrospect, the possibility of such high levels of I-131 in Nevada milk following the early tests is not surprising. The Windscale reactor accident in England in the fall of 1957, released an amount of I-131 equal to that generated in a fission explosion with one-sixth of a kiloton energy release, and led to milk levels as high as 1,300,000 ppc I-131/liter. In Nevada, about **1000 kilotons of fission energy were released before** there were reliable measurements for I-131 in milk in the off-site communities and ranches.

Experiments – with a simple neck phantom





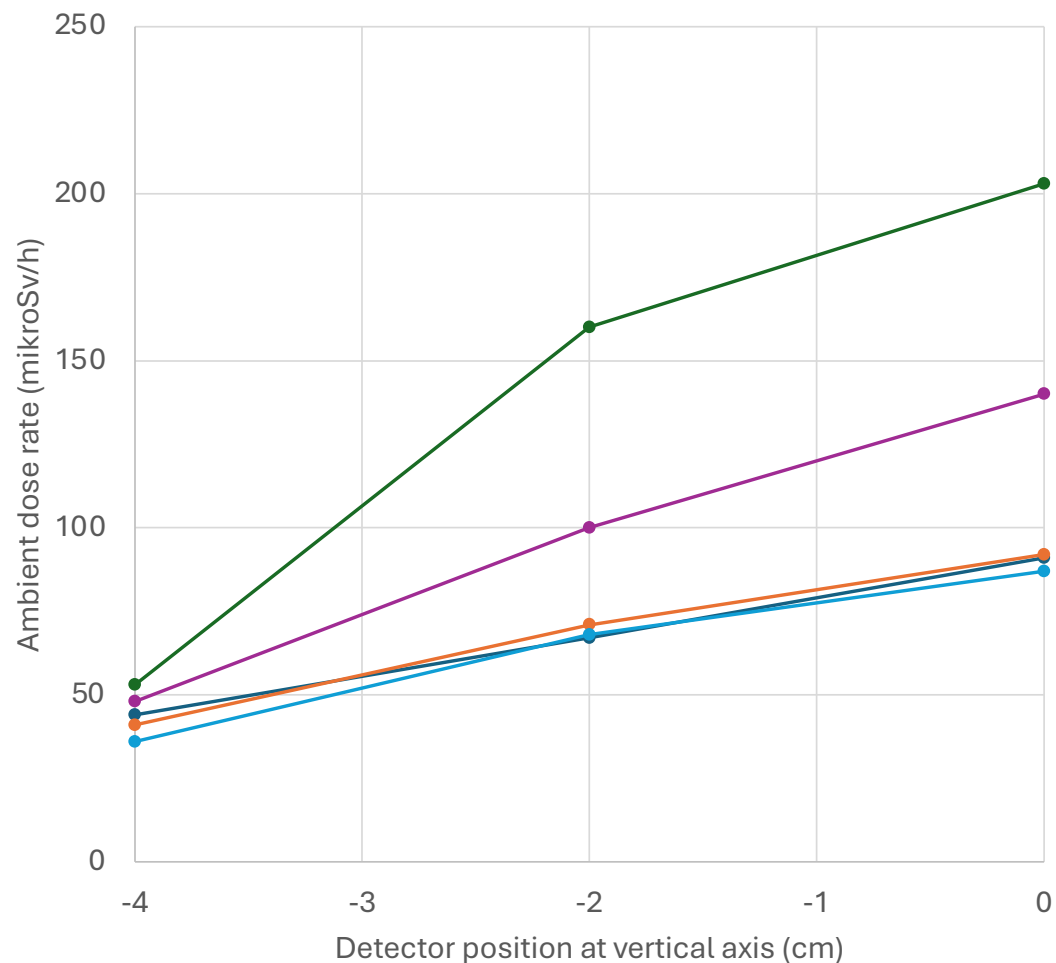
Experimental setup no. 1

Used instruments

- FH40G
- FH40GL10
- FH40F2
- RE B20 (Radeye)
- RE B20 ER
- Several Czechrad instruments

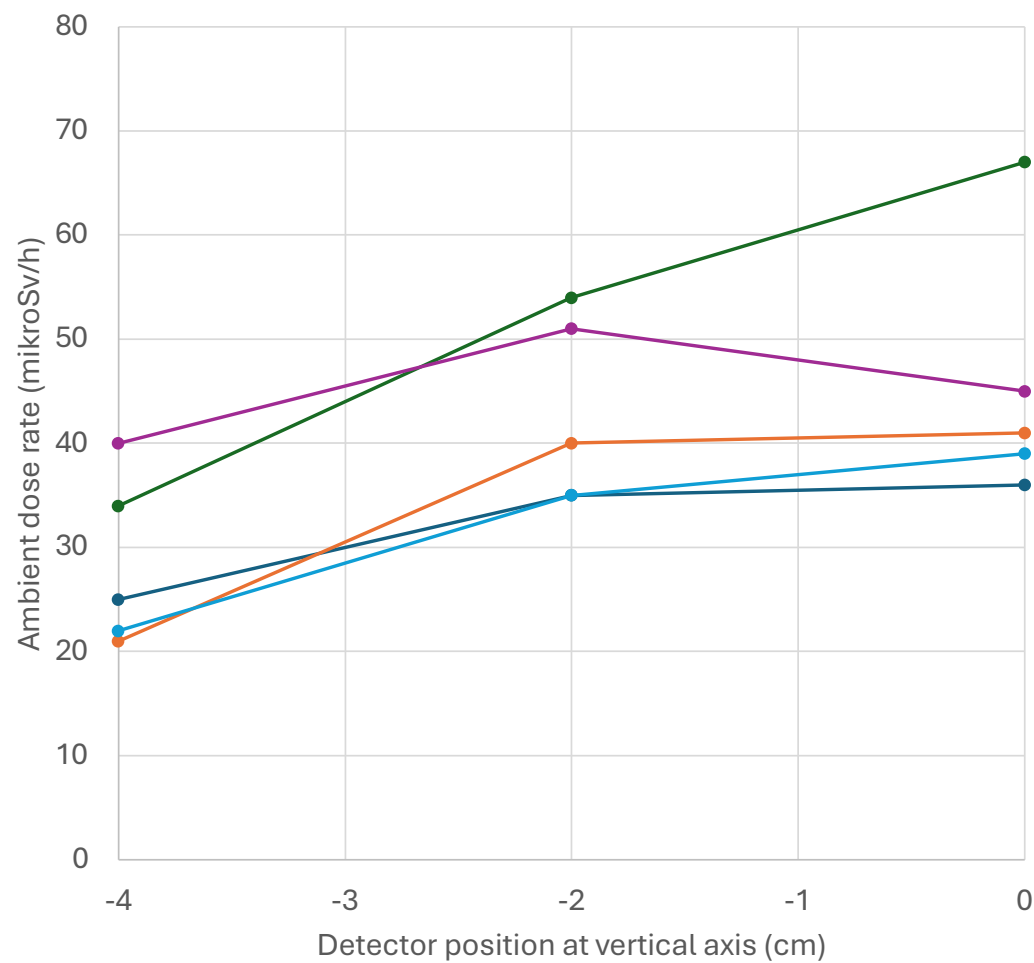
- PE phantom filled with water
- I-131 capsule
- $A = 99 \mu\text{Ci} = 3,67 \text{ MBq}$
- Capsule in one tube/th.lobe
- Measured
 - facing the tube with capsule
 - in the middle
 - Facing the empty tube
 - Detectors moved in vertical direction along the phantom
 - $z = 0, -2, -4 \text{ cm}$

Detector Centered at Left Lobe (with I131 capsule)



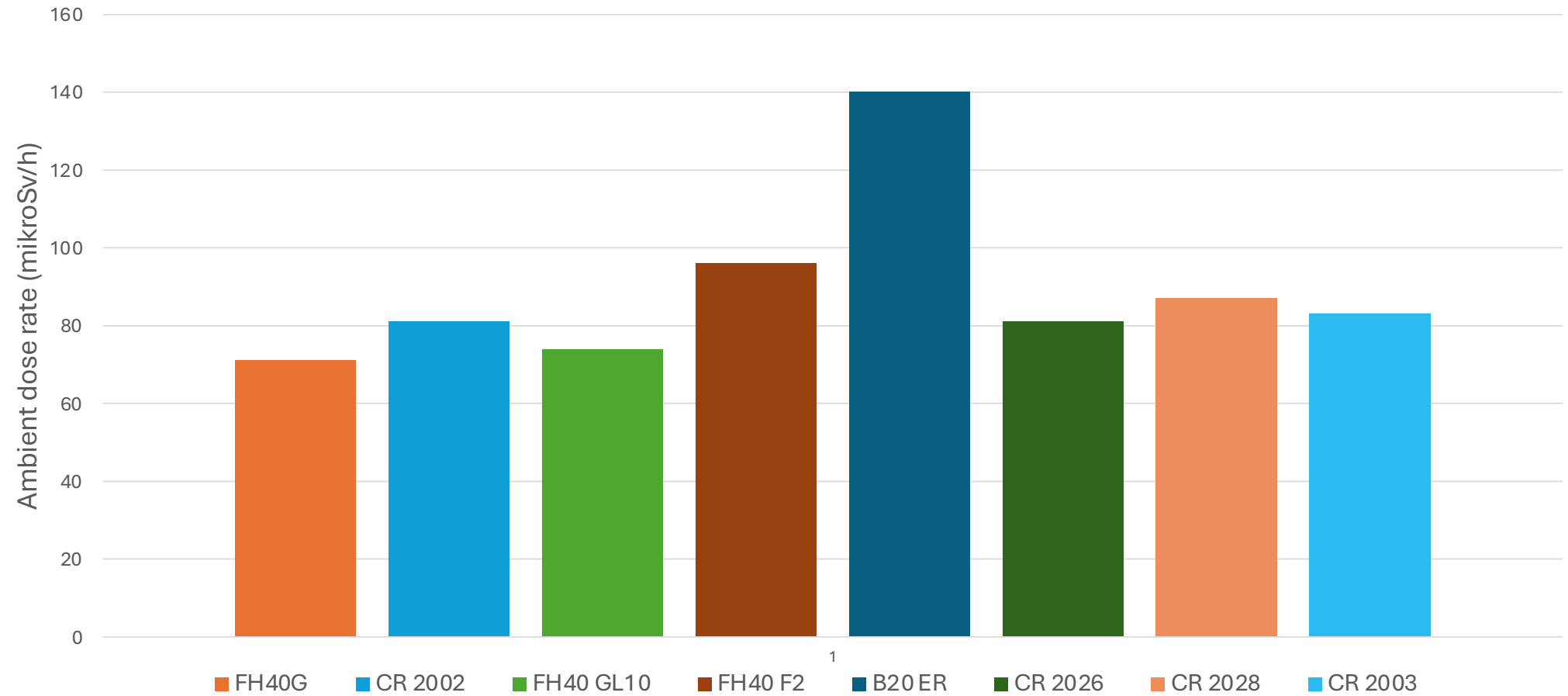
FH40G CR 2002 RE B20 FH40 GL10 FH40 F2

Detector Centered at Right Lobe



FH40G CR 2002 RE B20 FH40 GL10 FH40 F2

Detector position in the middle of the Neck, z = 0 cm

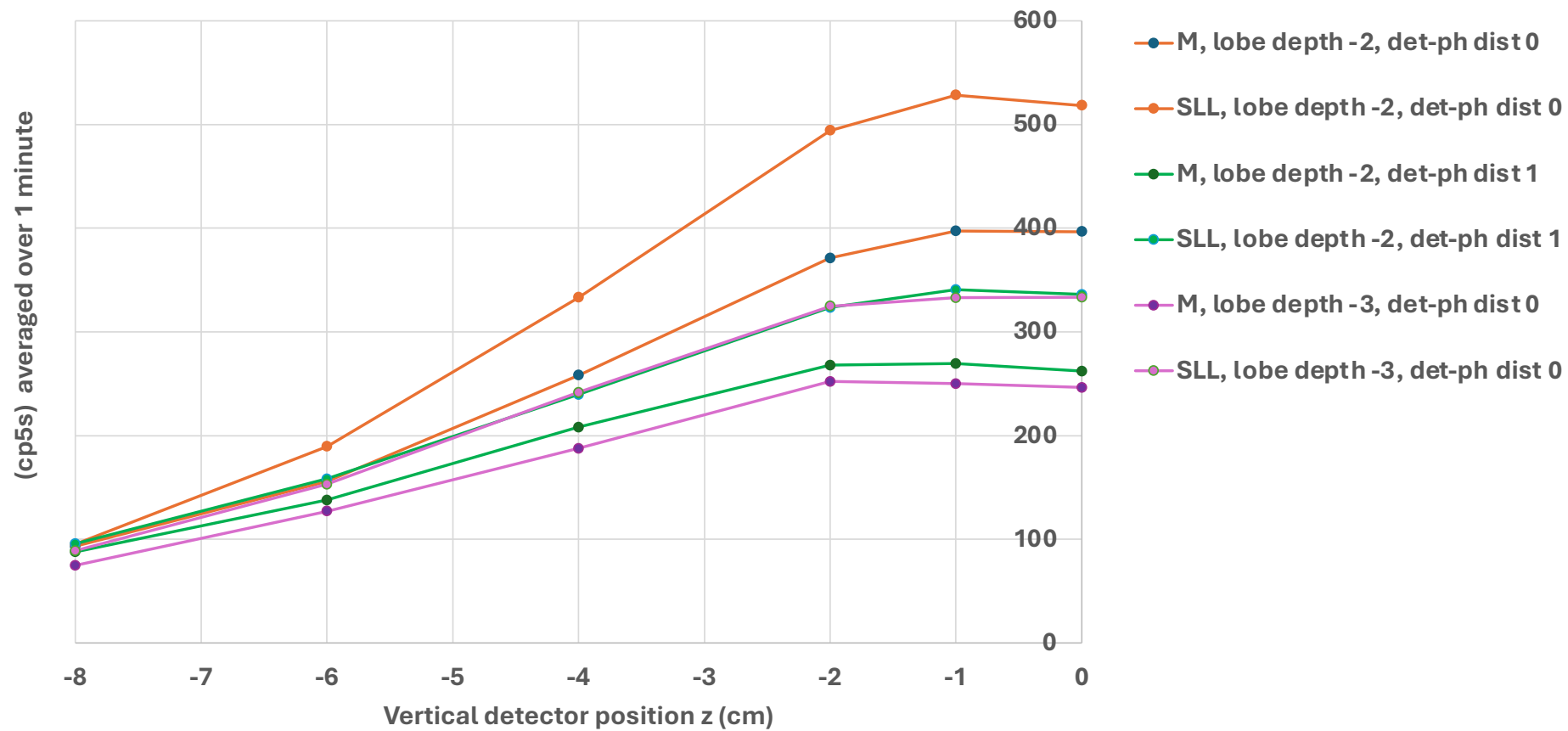


Experimental setup no. 2

Used instruments

- Czechrad instruments only

- PE phantom filled with water
- I-131 capsule
- $A = 16,13 \mu\text{Ci} = 0,582 \text{ MBq}$
- Capsule in one tube/th.lobe
- Measured
 - facing the tube with capsule
 - in the middle
 - Facing the empty tube
 - Detectors moved in vertical direction along the phantom
 - $z = 0, -1, -2, -4, -6, -8 \text{ cm}$



Uncertainties

The thyroid gland exhibits significant anatomical and physiological variability among individuals, commonly involving variations in size, lobe shape, and the presence of a pyramidal lobe (15%–75% of cases).

([Google Gemini](#))

- Statistical
- Relating to
 - Instrument type
 - Position
 - Thyroid gland
 - Volume, mass
 - Shape and size of ThG
 - Depth of ThG
 - Overlaying tissue thickness

Statistical influences

$$\alpha = \beta = 0,05$$

$$k = 1,645$$

95 % confidence interval

- $L_D = 2,71 + 4,65\sqrt{B}$

- $MDA = \frac{2,71 + 4,65\sqrt{B}}{\epsilon \cdot P_\gamma \cdot T}$

- $MDA = \frac{k^2 + 2k\sqrt{2 \cdot R_b \cdot T}}{\epsilon \cdot P_\gamma \cdot T}$

- Valid for $T_s = T_b$

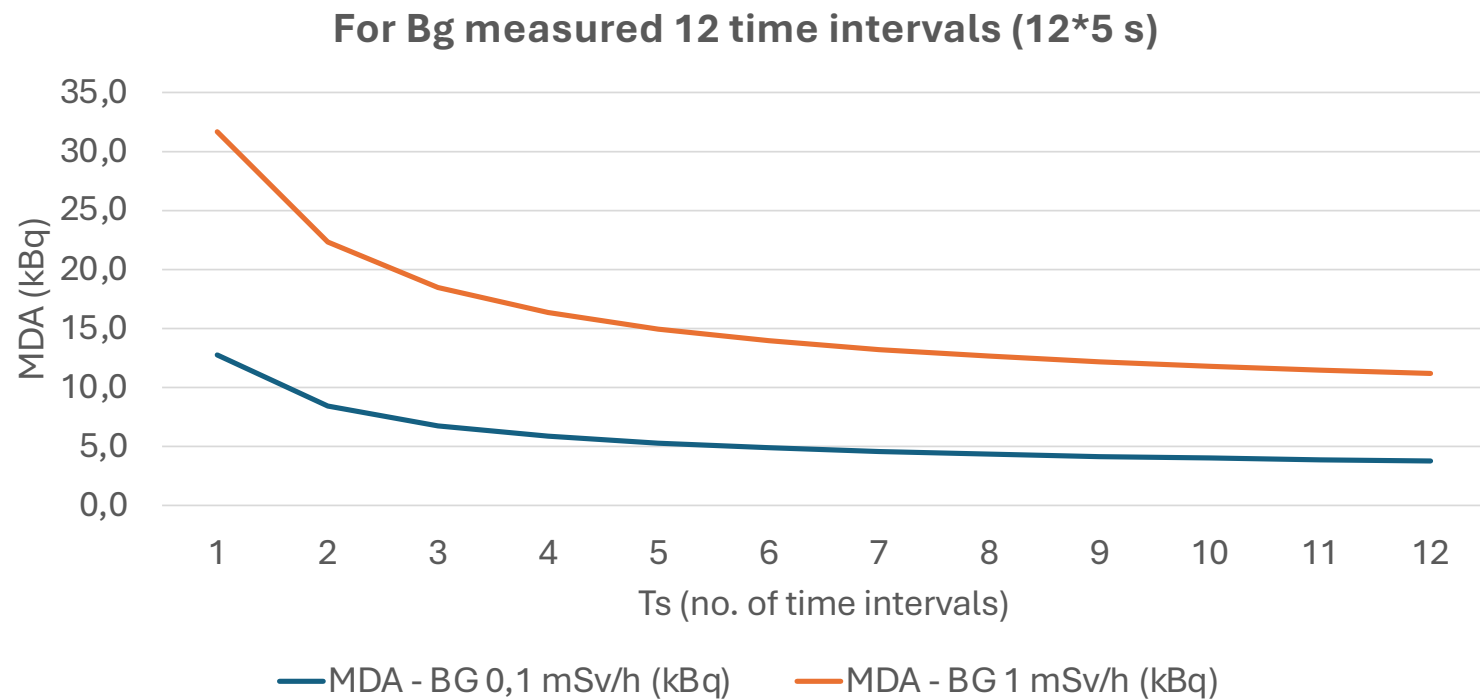
Longer BG counting reduces MDA significantly

- $L_D = 2,71 \left(1 + \frac{T_s}{T_b}\right) + 3,29 \sqrt{R_b T_s \left(1 + \frac{T_s}{T_b}\right)}$

- $MDA = \frac{2,71 \left(1 + \frac{T_s}{T_b}\right) + 3,29 \sqrt{R_b T_s \left(1 + \frac{T_s}{T_b}\right)}}{\epsilon \cdot P_\gamma \cdot T_s}$

- $MDA = \frac{k^2 + 2k \sqrt{R_b T_s \left(1 + \frac{T_s}{T_b}\right)}}{\epsilon \cdot P_\gamma \cdot T_s}$

Increased background affects MDA



Dose conversion

Direct in vivo quantification of thyroid activity eliminates variability in uptake as a confounding factor (10-50 %).

Factors influencing iodine uptake are generally grouped into dietary, medical, and biological categories.

Factor	Impact on Uptake
Low-Iodine Diet	Increases (Gland is "hungry")
Recent CT Scan	Decreases (Iodine blockade)
Graves' Disease	Increases (Hyperactivity)
Subacute Thyroiditis	Decreases (Cellular damage)
Prophylaxis	I-131 blockade after intake of stable iodine

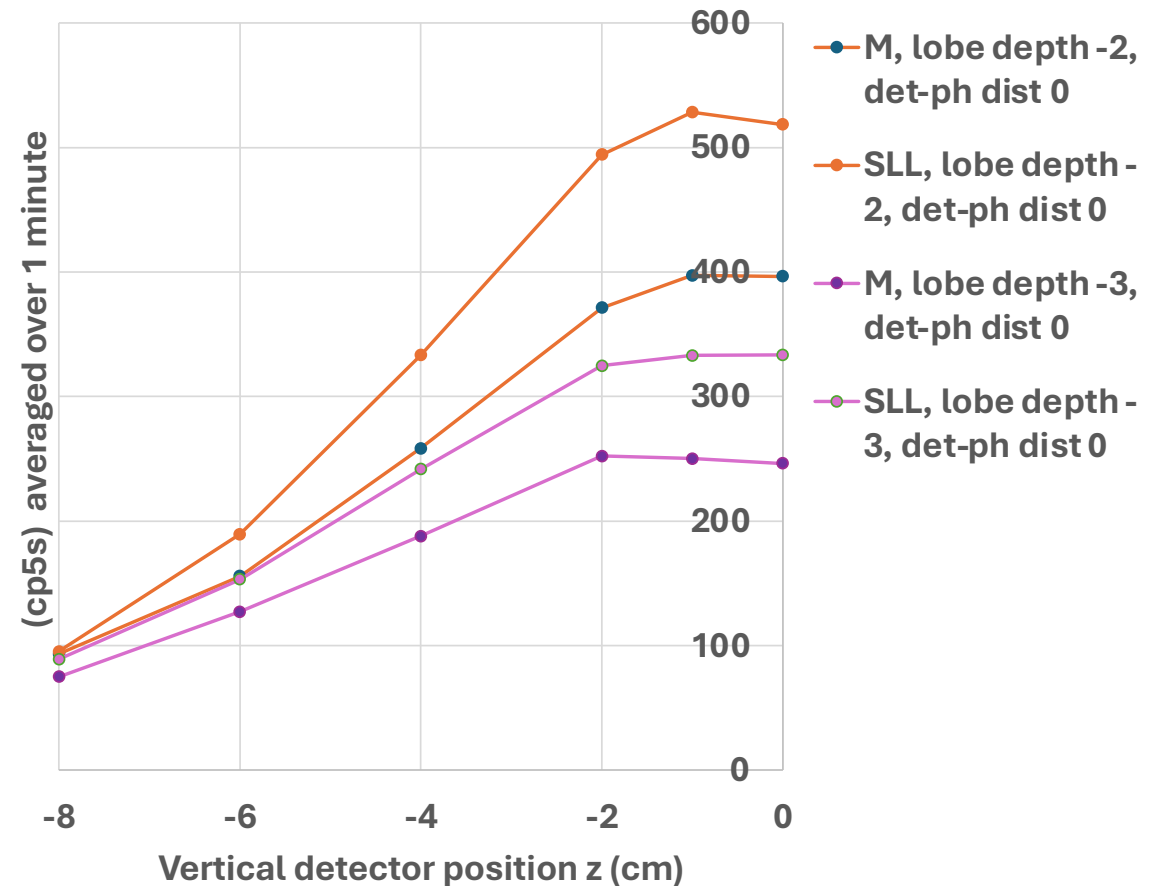
A (Bq)	1,00E+03
energy deposition per decay (MeV)	0,2
t1/2 (d)	8,05
lambda	9,96588E-07
number atoms $N=A/\lambda$	1003423255
mass (kg)	0,02
absorbed dose (Gy)	0,00161

Guess/apppraisal of non statistical uncertainty

For the detector in the middle and centred to the thyroid

- varying the source depth within the phantom illustrates how efficiency variability is influenced by both thyroid depth and the thickness of overlying tissue
- Detector phantom distance 0 cm

source depth	2 cm	3 cm	decrease
counts (cp5s)	397	246	0,62



Thank you for
your attention

