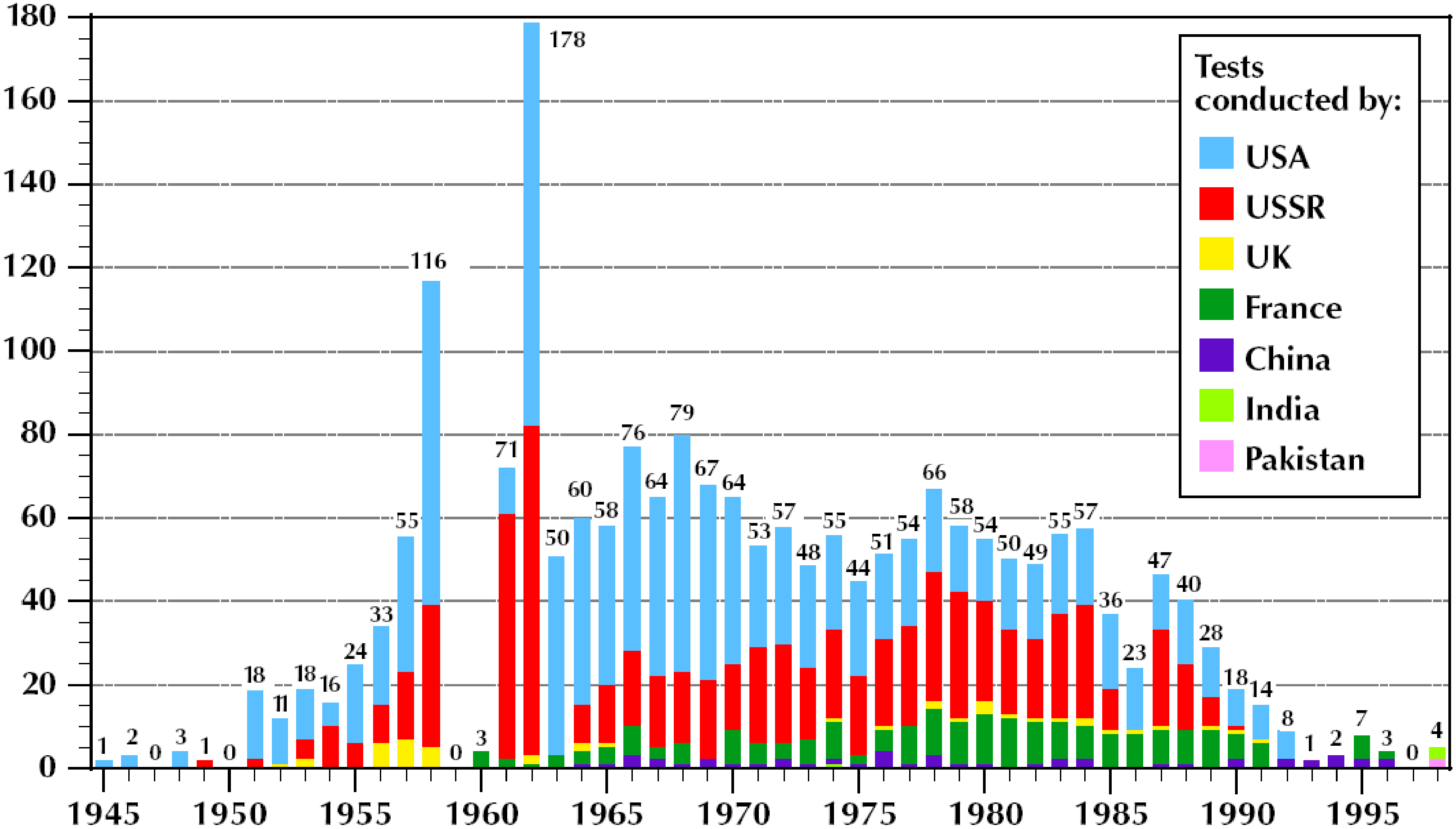
Session IV
of
LIVING IN A RADIOACTIVE WORLD

Presented by
Bruce W. Church
Consulting Health Physicist
May 1, 2006

Session IV
Nuclear Weapons

- Nuclear Weapons
- Testing & Fallout
- Summary of the effects of the Hiroshima & Nagasaki Explosions
- Improvised nuclear devices (INDs),
- RDDs-radiological dispersal devices and e.g., Dirty Bombs & Terrorism.)

Total Worldwide Nuclear Tests by Year (1945–98)



SOURCES:
U.S. Department of Energy; Natural Resources Defense Council; Arms Control Association

Coalition to Reduce Nuclear Dangers
June 1999

US Nuclear Tests – Total by Type

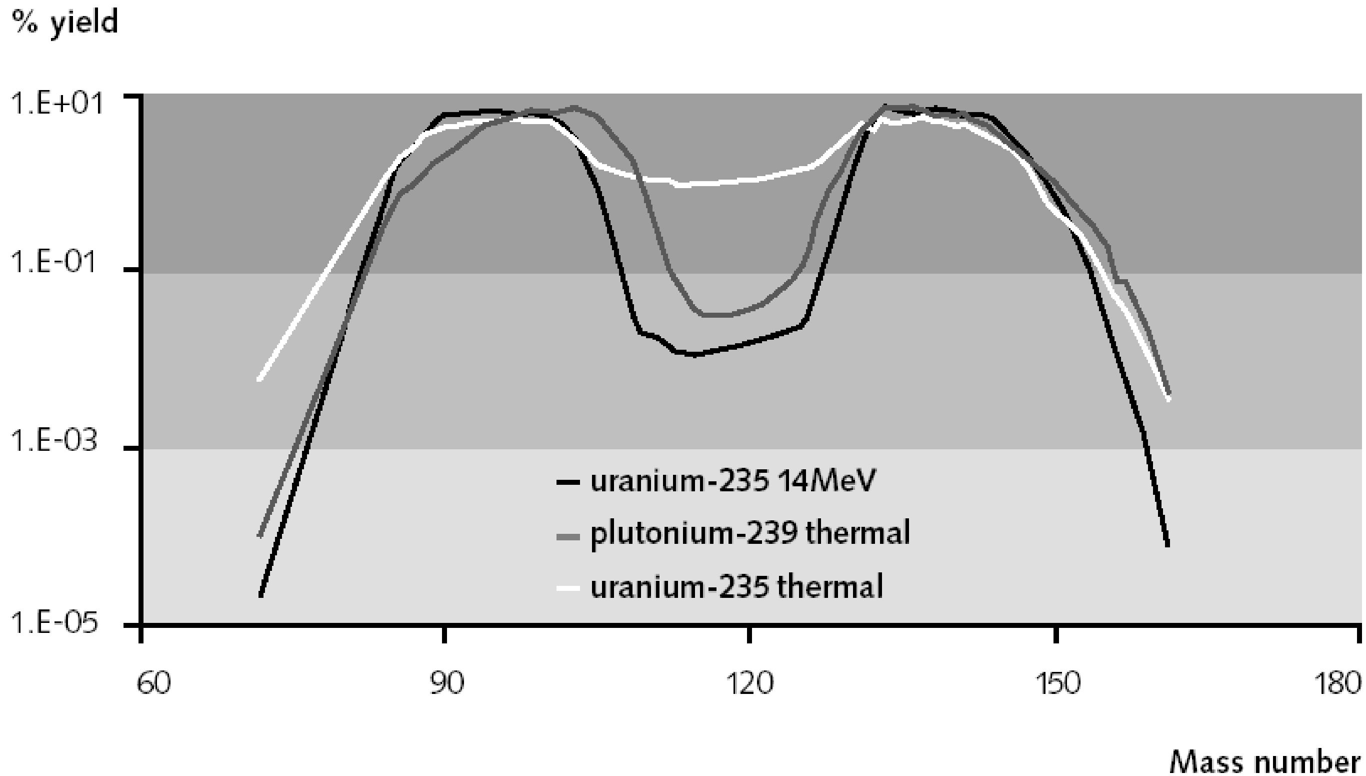
TYPE	**US**	**US – UK**
Airburst	1	0
Airdrop	52	0
Balloon	25	0
Barge	36	0
Rocket	12	0
Surface	28	0
Tower	56	0
Total Atmospheric	**210**	**0**
Crater	9	0
Shaft	739	24
Tunnel	67	0
Total Underground	**815**	**24**
Total Underwater	**5**	**0**
TOTAL TESTS	**1030**	**24**

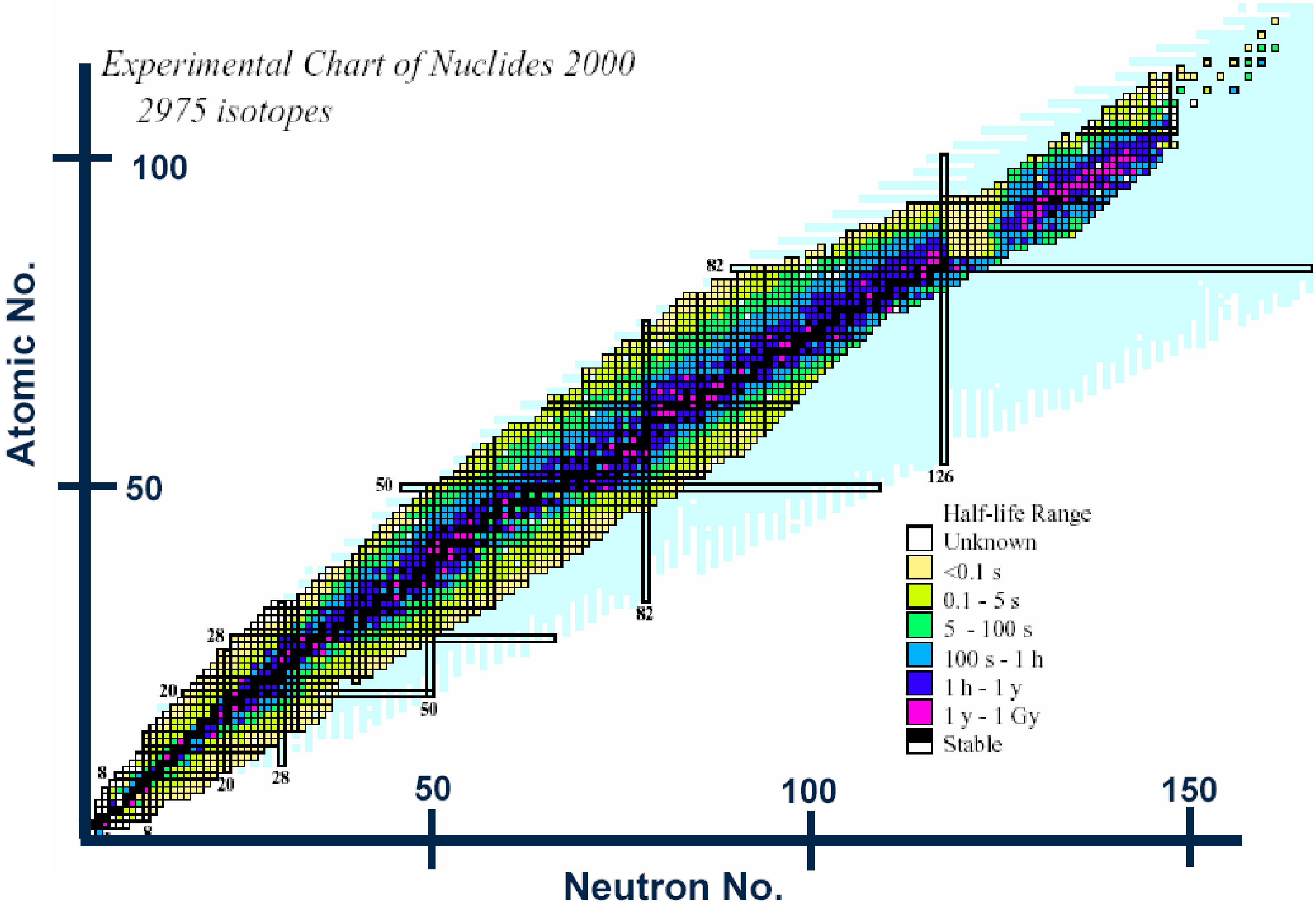
TOTAL MEGATONNAGES EXPENDED IN NUCLEAR TESTS, 1945-1996

	Atmosphere	Underground	Total
USA	141	38	179
Soviet Union	247	38	285
UK	8	0.9	8.9
France	10	4	14
China	21.9	1.5	23.4
Pakistan		(2 tests)	
India		(3 tests)	
TOTAL	427.9	82.4	510.3

Fission Yield Curve

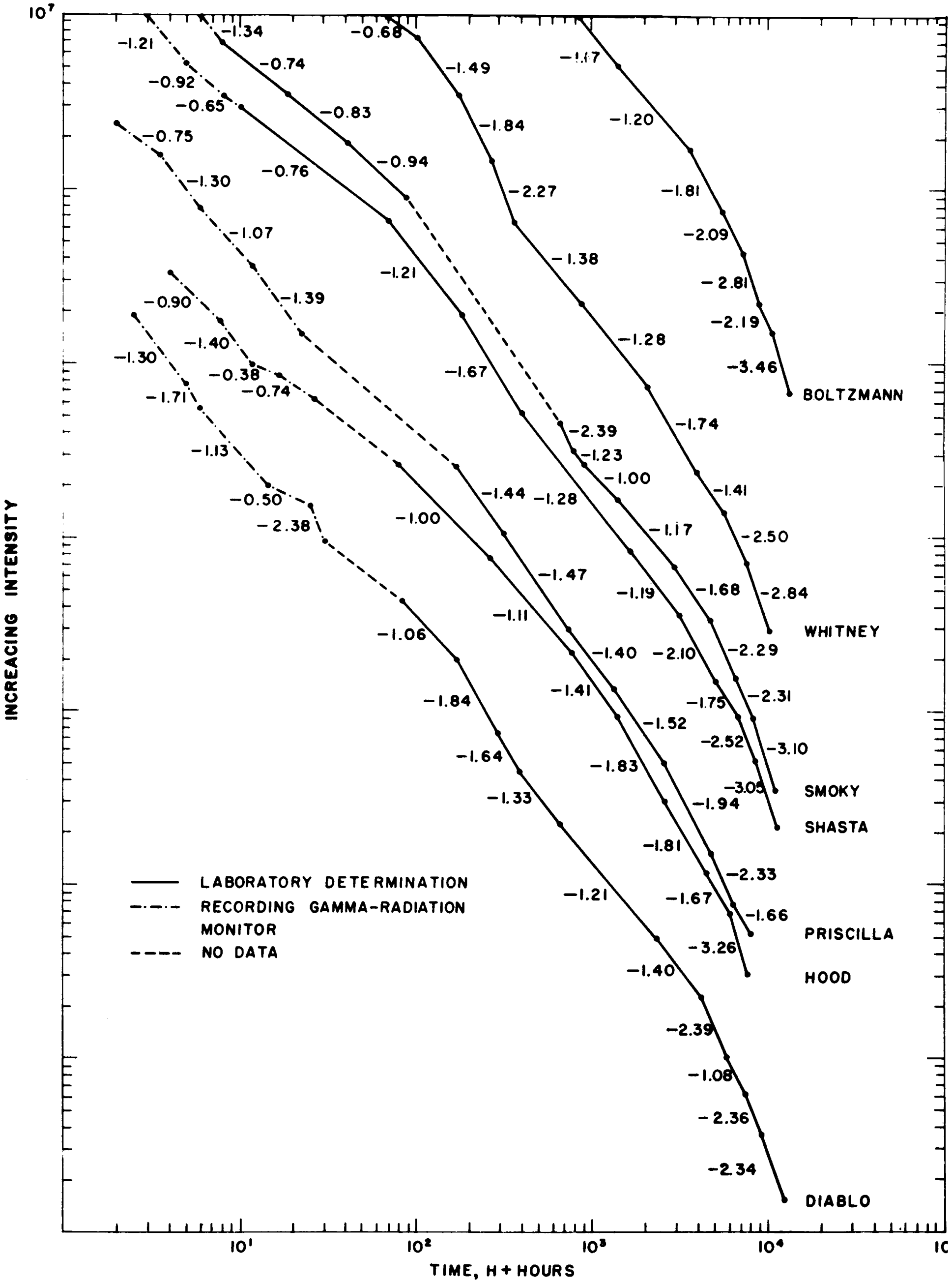
Figure 2 **Fission yield curves**




Experimental Chart of Nuclides 2000
2975 isotopes
Atomic No.
100
50
Neutron No.
50
100
150
82
50
28
20
8
126
Half-life Range
Unknown
<0.1 s
0.1 - 5 s
5 - 100 s
100 s - 1 h
1 h - 1 y
1 y - 1 Gy
Stable

EQUIVALENTS OF 1 KILOTON OF TNT

- The complete fission of 56 grams of fissionable material produces:
- Fission of 1.45×10^{23} nuclei
- 3×10^{23} atoms of fission products (two for each atom of fissionable material).
- One minute after the explosion this mass is undergoing decays at a rate of 10^{21} disintegrations/sec (equivalent to 3×10^{10} curies).
- Energy equivalents:
  - 1×10^{12} calories
  - 4.2×10^{19} ergs
  - 1.15×10^{6} kilowatt-hours



Gamma Decay Curves Fallout from Seven Shots.

Fallout Decay Curves

Gamma decay curves from seven tests from Operation Plumbbob. This slide shows that nuclear decay follow the same basic curve $t^{-1.2}$.

Historical Radiation Exposure Guide Development

1929 - U.S. Advisory committee on X-Ray & Radium Protection formed (forerunner of NCRP)
1931 - USACXRP publishes first recommendations - 0.2 R/day
1934 - ICRP recommends permissible dose of 0.2 R/day
1936 - USACXRP recommends reduction in permissible dose to 0.1 R/day
1942-1945 - Manhattan Engineering District formed
1948 - 0.3 R/wk
1950 - 0.3 rem/wk

Brief History of External Whole Body Exposure Guides for Public

Year	Exposure guide	Reference
1951	3.0 R/10 Weeks	AEC (Buster-Jangle Operation)
1953	3.0 R/10 weeks	AEC Safety Booklet-March 1953
1955	3.9 R/year	AEC (Teapot Operation)
1957	0.5 rem/year	NCRP (NBS HB-59)
1958	5.0 rem/30 years	ICRP Pub No. 1
1959	0.5 rem/year	NCRP (NBS HB-69) ICRP Pub. No.2
1960	0.170 rem/year (group) 0.5 rem/year (individual)	FRC Report No.1
1971	0.170 rem/year (group) 0.5 rem/year (individual) 0.1 rem/year student	NCRP Report No. 39
1977	0.5 rem/year	ICRP Pub No. 26
1987	Freq. Exposure 0.1 rem/year Infreq Exposure 0.5 rem/year Remedial action when freq. Exp > 0.5 rem	NCRP Report No. 91
1991	0.1 rem/year (individual)	ICRP Pub. No. 60
1993	0.1 rem/year	NCRP Report No. 116
1997	0.015 rem/year (individual)	USEPA/OSWER No. 9200 (cleanup criteria)

The primary contributors to Fallout in So. Utah

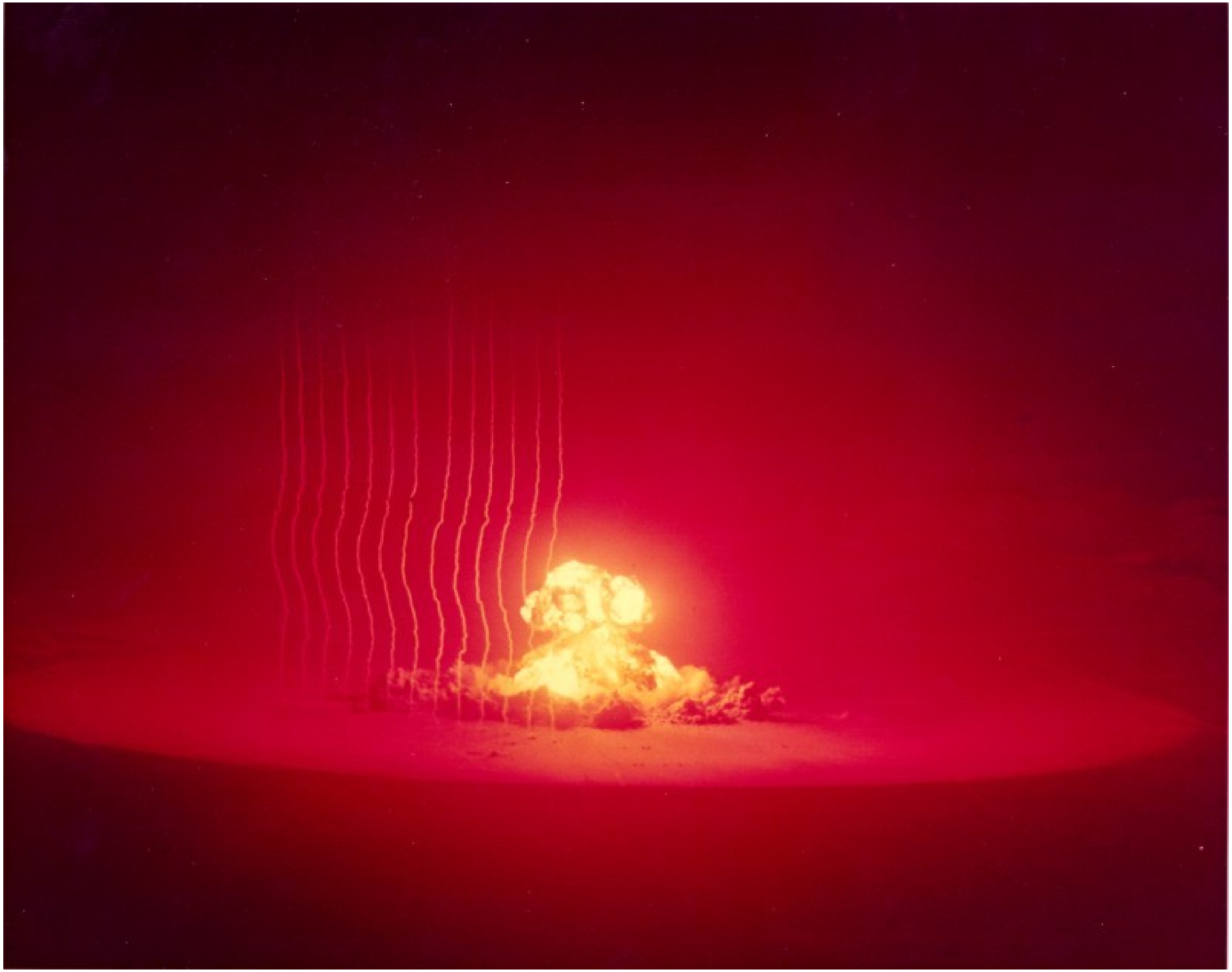
CUMULATIVE EXTERNAL EXPOSURE (Roentgen, R) FOR SELECTED UTAH COMMUNITIES

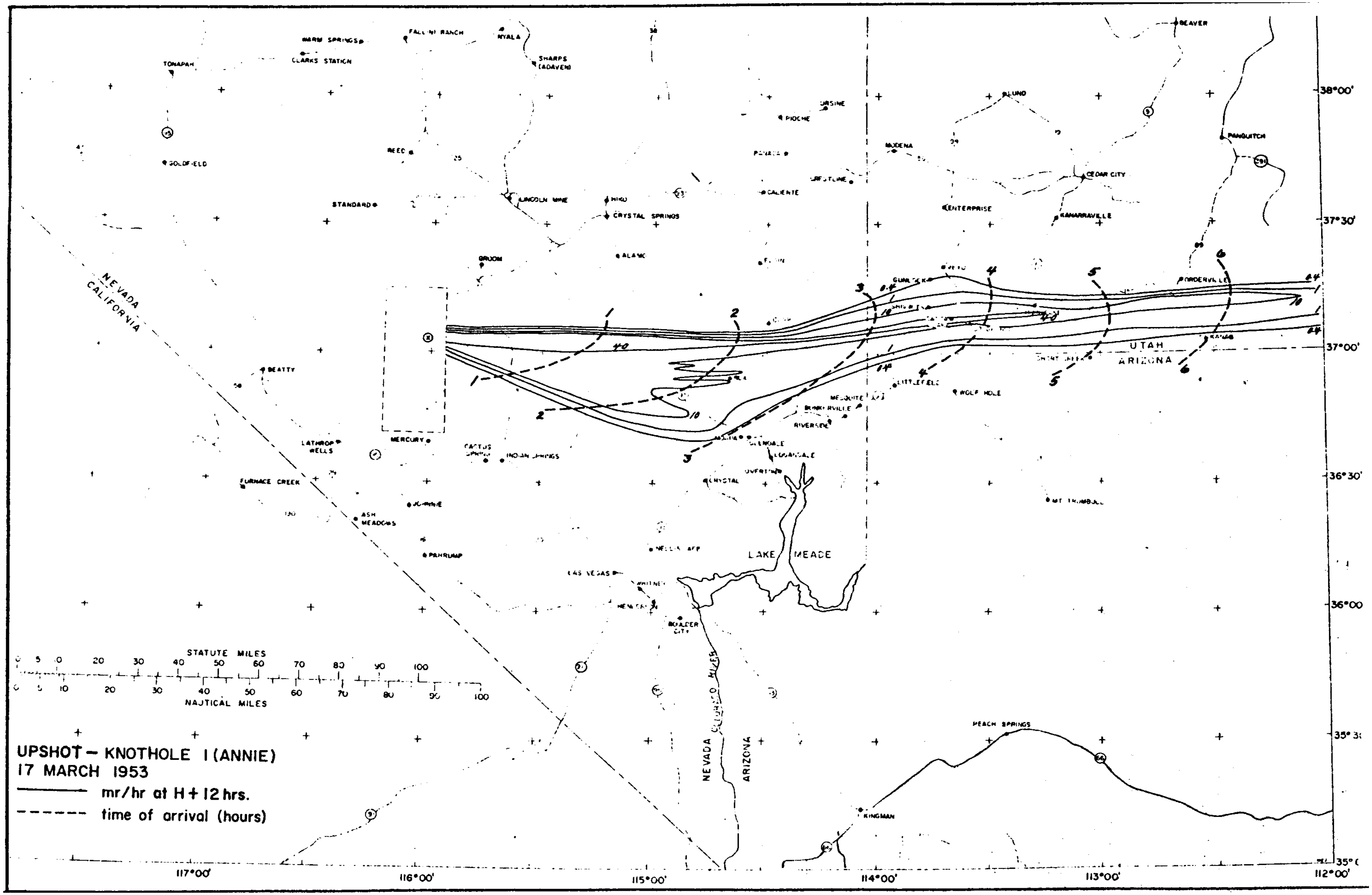
COMMUNITY	Exposure (R)	COMMUNITY	Exposure (R)
Beaver	0.25	Milford	0.10
Bryce Canyon	0.56	Mount Carmel	0.94
Cedar City	0.64	Mount Carmel Junction	0.85
Desert Range Exp. Station	0.10	Orderville	1.60
Enterprise	0.79	Paiute Indian Reservation	0.30
Garrison	0.88	Panguitch	0.70
Glendale	1.40	Parowan	0.42
Hamilton Fort	0.80	St. George	3.70
Hilldale	0.44	Santa Clara	4.30
Hurricane	3.50	Shivwits	3.60
Kanab	1.60	Springdale	2.70
La Verkin	3.70	Virgin	1.60
Lund	0.50	Zion Lodge	1.20

FALLOUT IN SOUTHERN UTAH - WASHINGTON, IRON, KANE, AND BEAVER COUNTIES

City	Event Name	Historical Dose Estimate	Percent of Total
St. George, UT			
(Washington County)	Annie (UK)	0.35	0.09
	Simon (UK)	0.01	0.00
	Harry (UK)	2.50	0.68
	Tesla (Teapot)	0.10	0.03
	Zucchini (Teapot)	0.04	0.01
	Priscilla (Plumbbob)	0.03	0.01
	Smoky (Plumbbob)	0.66	0.18
	Morgan (Plumbbob)	0.01	0.00
total		3.70	
Cedar City, UT			
(Iron County)	Fox (TS)	0.02	0.03
	Harry (UK)	0.25	0.39
	Apple I (Teapot)	0.03	0.05
	Zucchini (Teapot)	0.10	0.16
	Priscilla (Plumbbob)	0.03	0.05
	Smoky (Plumbbob)	0.21	0.33
total		0.64	
Kanab, UT			
(Kane County)	Simon (UK)	0.05	0.03
	Harry (UK)	1.55	0.97
total		1.60	
Orderville, UT			
(Kane County)	Harry (UK)	1.40	0.88
	Tesla (Teapot)	0.08	0.05
	Apple I (Teapot)	0.02	0.01
	Priscilla (Plumbbob)	0.04	0.03
	Smoky (Plumbbob)	0.04	0.03
	Morgan (Plumbbob)	0.02	0.01
total		1.60	
Beaver, UT			
(Beaver County)	Fox (TS)	0.05	0.20
	Met (Teapot)	0.20	0.80
total		0.25	

ANNIE (Operation Upshot-Knothole) – March 17, 1953





OPERATION UPSHOT-KNOTHOLE, ANNIE Event, March 17, 1953. Fallout pattern 1956.

HARRY (Operation Upshot-Knothole) – May 19, 1953

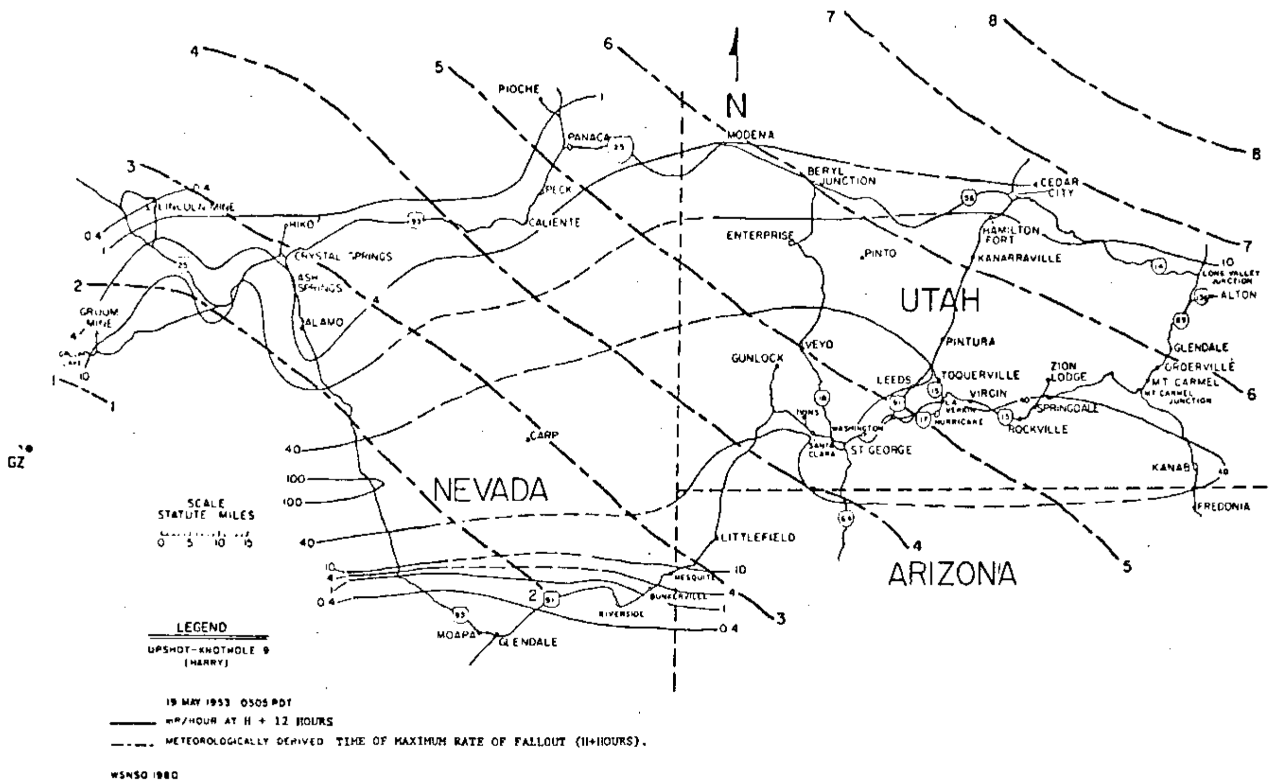


Figure 9. Extended range fallout pattern contours (mR/hr at H + 12 hours) and meteorologically derived time of maximum rate of fallout (H + HOURS).

OPERATION UPSHOT-KNOTHOLE, HARRY Event, May 19, 1953. Fallout pattern reanalyzed by Weather Service Nuclear Support Office in 1980.

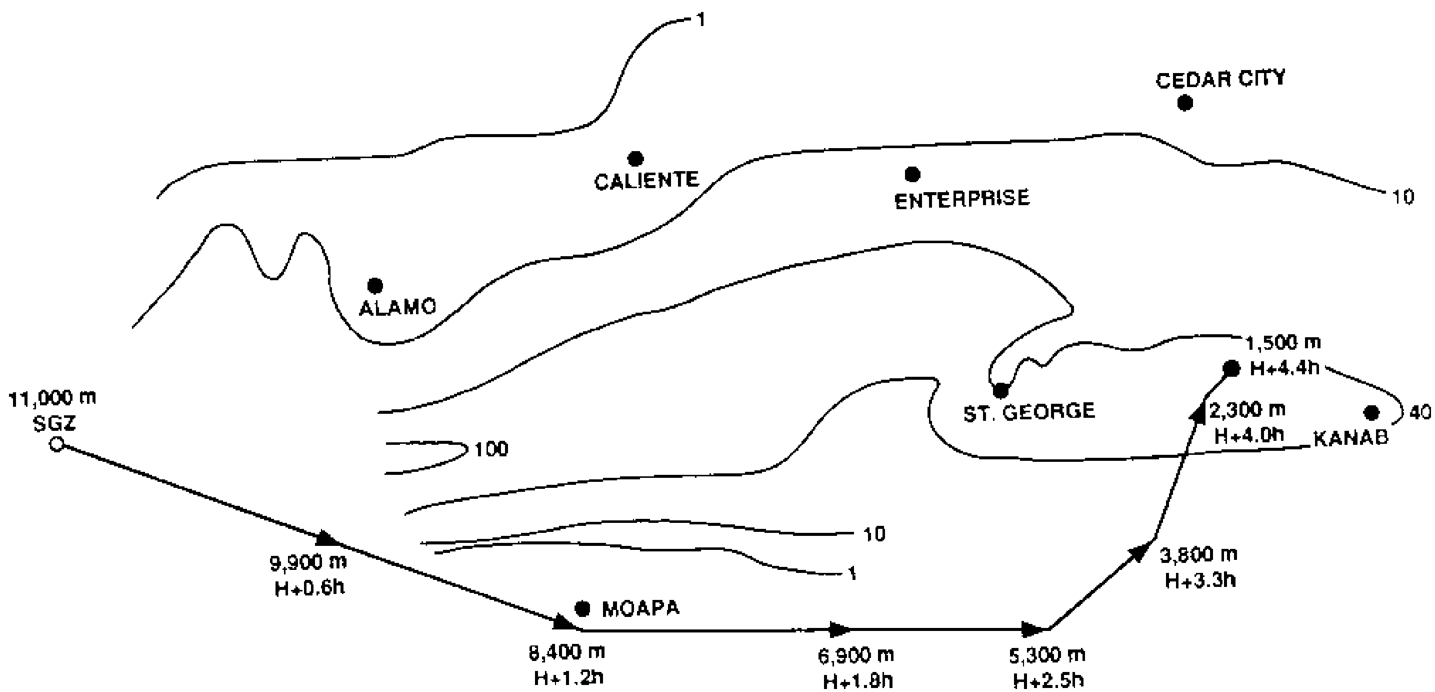
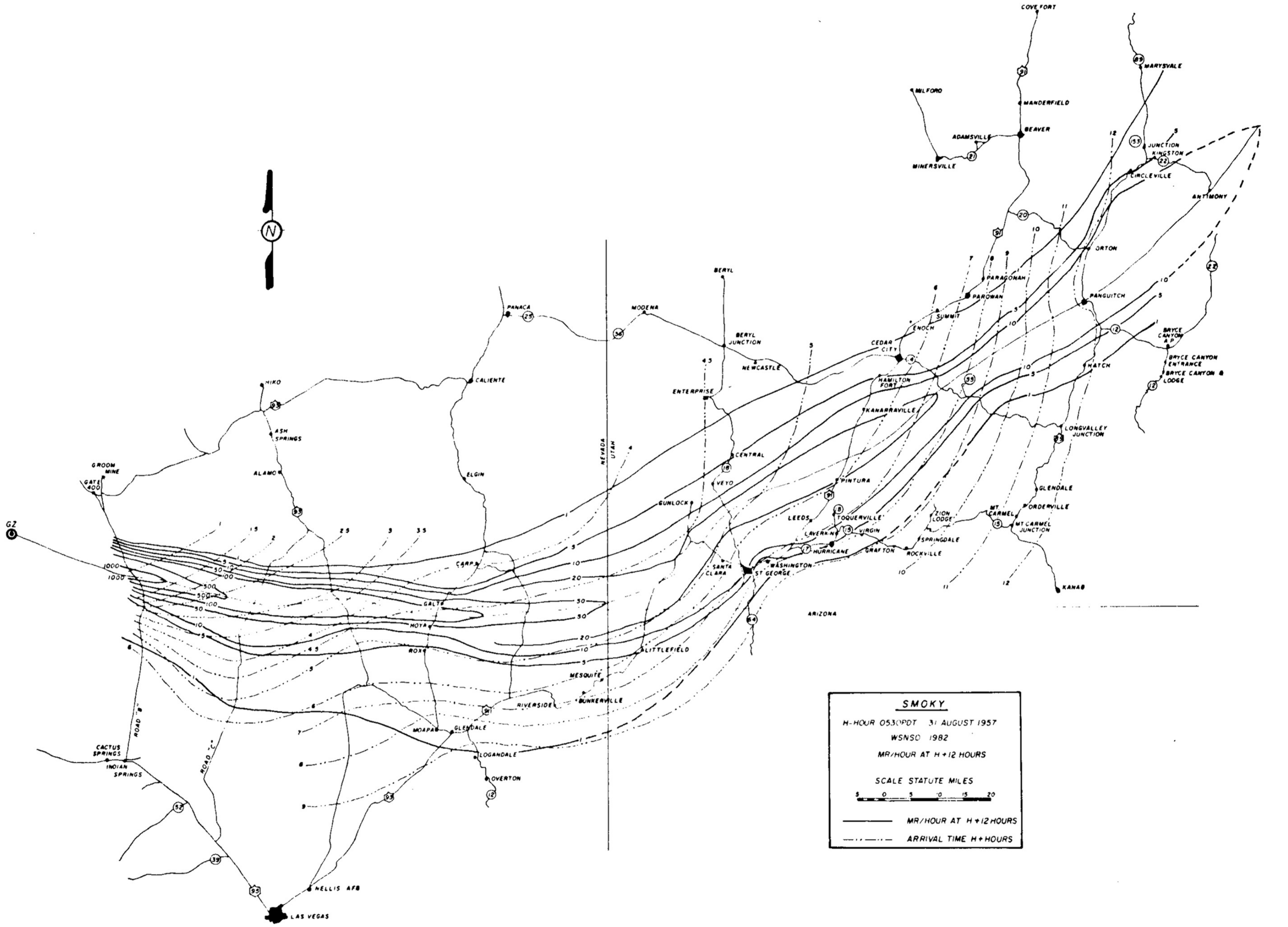


Fig. 3. Fallout particle trajectory (path), shown by the heavy line with arrowheads, as it falls from 11,000 m ASL to 1,500 m ASL in 4.4 h. The numbers by the arrowheads are the altitude of the particle and the time (H + h) it reached that altitude. Thin lines are fallout contours (mR h^{-1} at H + 12 h) from the WSNSO HARRY analysis.

OPERATION UPSHOT-KNOTHOLE, HARRY Event, May 19, 1953.
Fallout particle path shown by heavy line with arrowheads.

SMOKY (Operation Plumbbob) – August 31, 1957



OPERATION PLUMBBOB, SMOKY Event, August 31, 1957. Fallout pattern reanalyzed by Weather Service Nuclear Support Office in 1982.

Cumulative Estimated Exposure (mR) for all Nevada Tests Through 1969

Soil Concentration Levels for Selected Cities

SOIL CONCENTRATION LEVELS FOR NATUALLY OCCURRING RADIONULCIDES AT THESE SPECIFIC LOCATIONS

GAMMA SPECTROSCOPY ANALYSIS

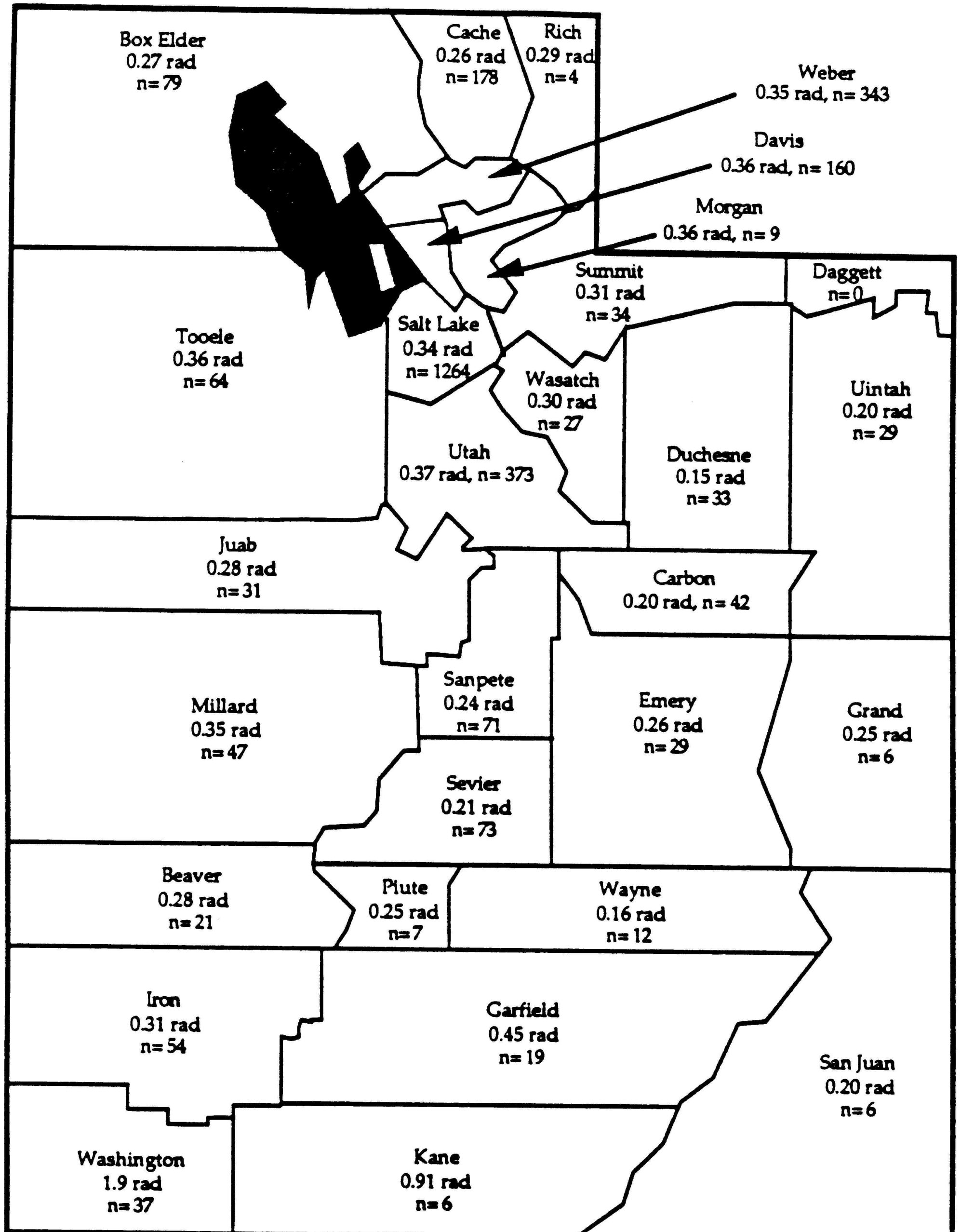
City, State	Sample Number	U-238 (pCi/g)	Th-232 (pCi/g)	K-40 (pCi/g)
Cedar City, UT	E-35	2.30	2.16	46.90
Kanab, UT	E20A	3.28	2.93	70.60
St. George, UT	EML3	2.00	1.82	56.50
Beatty, NV	BE32	4.94	6.54	116.70
Las Vegas, NV	SH07	4.13	2.53	40.10
Kingman, AZ	FM01	3.62	6.14	102.70
Mesa, AZ	NM25	3.73	4.49	80.80
Los Angeles, CA	BA29	2.29	4.46	75.90
Farmington, NM	NM21	3.27	3.14	92.80
Albuquerque, NM	AQ01	3.16	3.02	59.30
South Rim-Grand Canyon, AZ	FM08	4.08	4.01	62.70
Flagstaff, AZ	FM45	3.67	4.11	57.40

SOIL CONCENTRATION LEVELS FOR CESIUM-137 AND PLUTONIUM-239/240 IN SPECIFIC LOCATIONS

City, State	Sample No.	Cs-137 (nCi/m^2)	Pu-239/240 (nCi/m^2)
Cedar City, UT	E-35	67.8	1.8
Kanab, UT	E20A	72	2.1
St. George, UT	EML3	80.3	3
Beatty, NV	BE32	36.2	5.9
Las Vegas, NV	SH07	40.2	2
Kingman, AZ	FM01	52.3	1.2
Mesa, AZ	NM25	41.8	0.9
Los Angeles, CA	BA29	40.8	0.9
Farmington, NM	NM21	46.2	1.3
Albuquerque, NM	AQ01	61.2	1.2
South Rim-Grand Canyon, AZ	FM08	91.2	2.6
Flagstaff, AZ	FM45	82.4	1.8

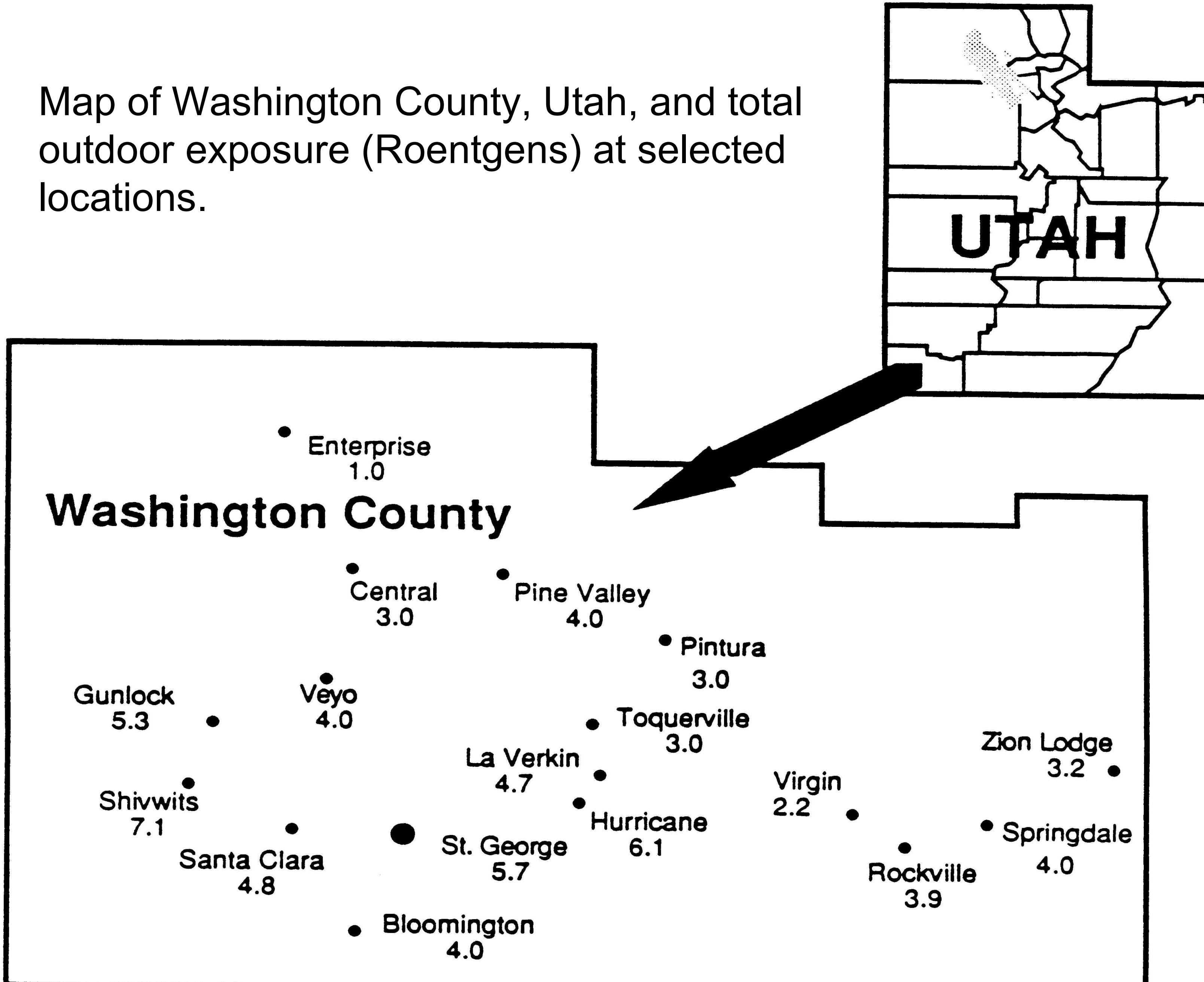
Summary of Thyroid Cohort Study Dosimetry Based on Residence in 1965, n=3545.

	WASHINGTON CO. UTAH	GRAHAM CO. ARIZONA	LINCOLN CO. NEVADA	OVERALL
NUMBER OF SUBJECTS	1896	1369	280	3545
MEAN (rad)	17	1.3	5.0	9.8
MEDIAN (rad)	7.2	0.36	2.8	2.5
MINIMUM (rad)	0.0	0.0	0.0	0.0
MAXIMUM (rad)	461	45	84	461
VARIANCE	704	14	88	443



Map of Utah showing the average of mean bone marrow doses (rad) to subjects (n) who remained in a single county during the entire period of fallout and for whom no assumptions were needed to reconstruct residential history. "n" includes only subjects who were born before 1952 and who died after 1958, thus accumulating the total potential exposure from Nevada Test Site fallout.

Map of Washington County, Utah, and total outdoor exposure (Roentgens) at selected locations.



Release information from DOE/NV 317

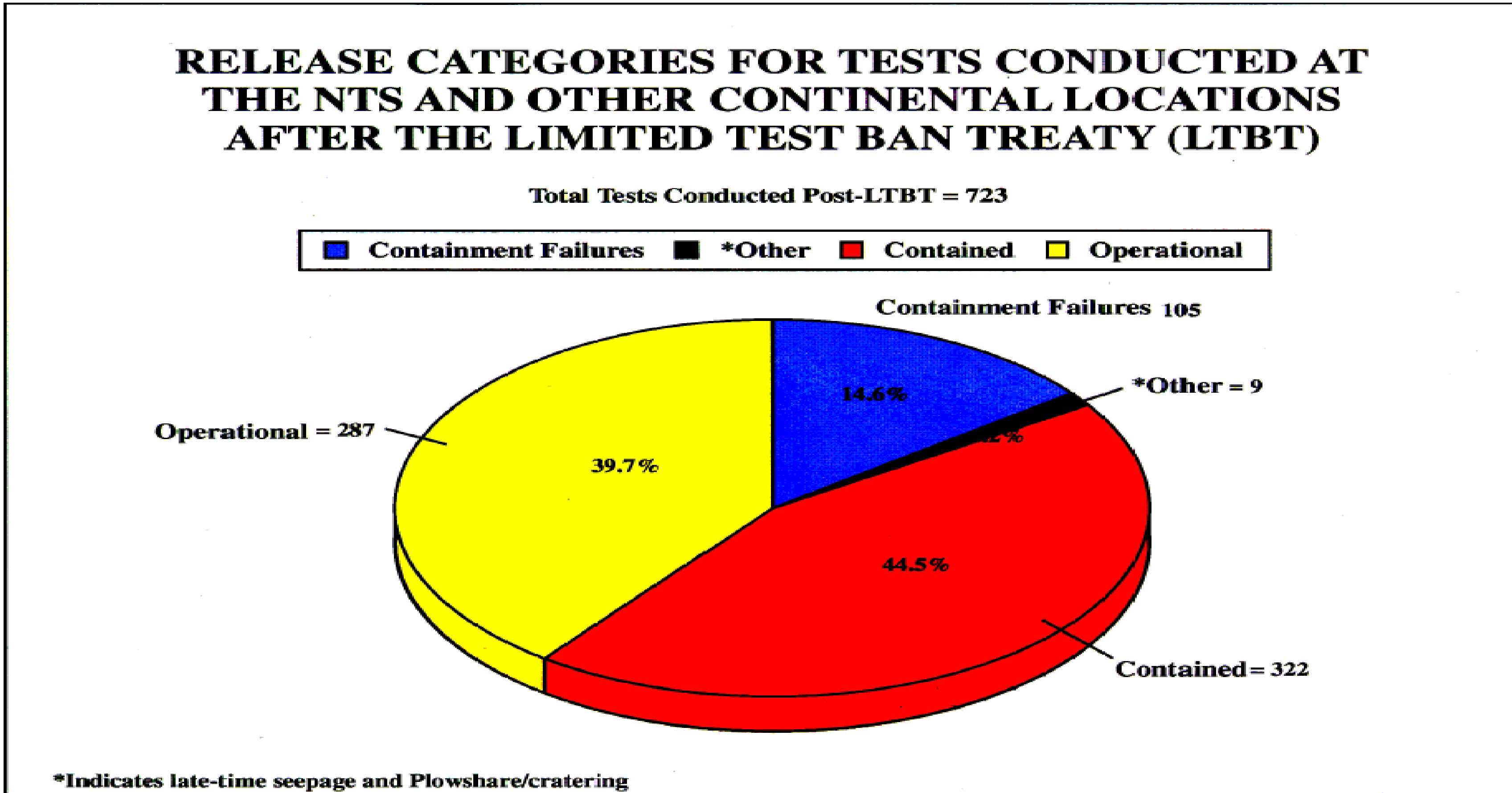


Figure 1. Release categories.

Information from DOE/NV 317

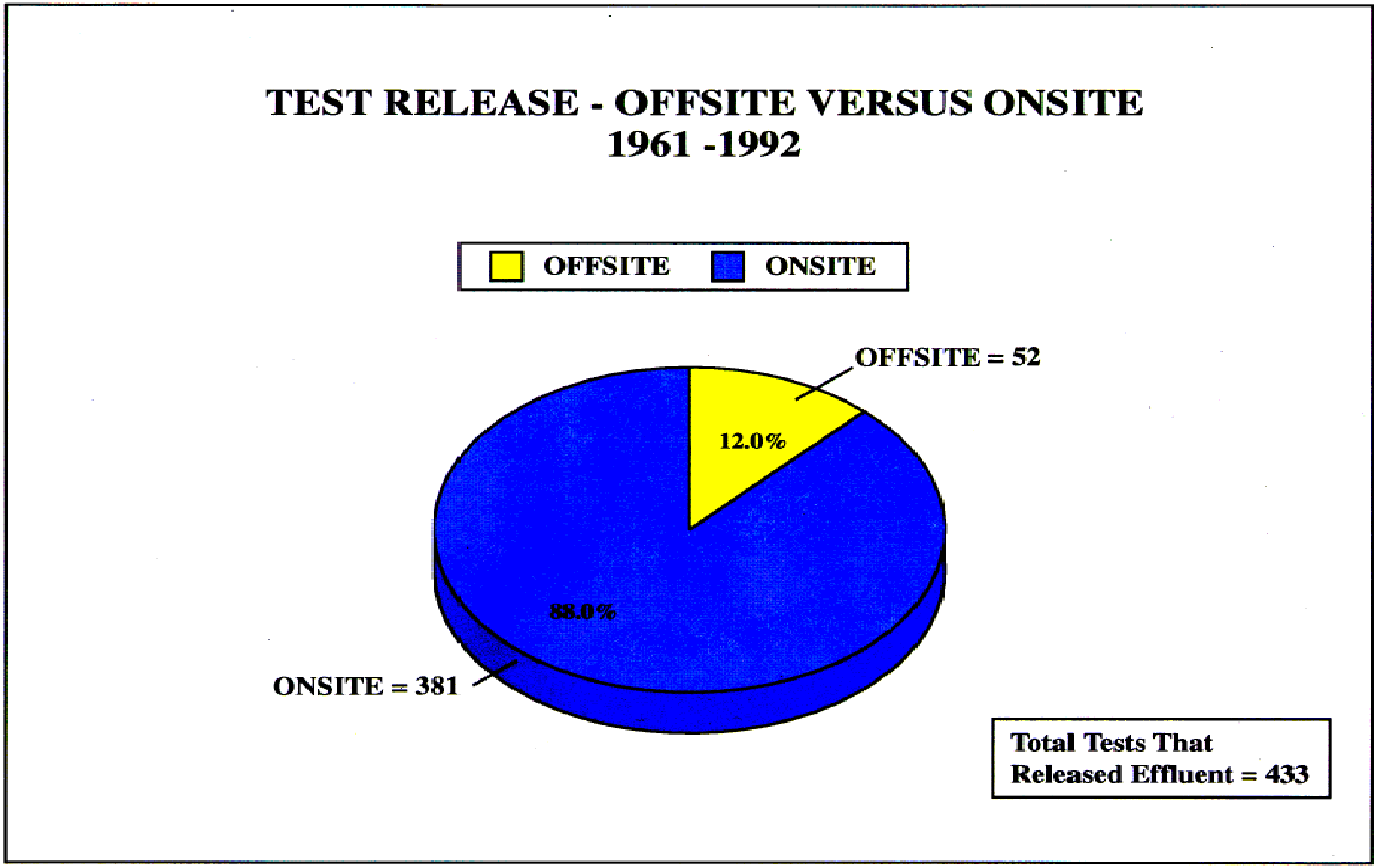


Figure 2. Offsite versus onsite releases.

Test:	**BANEBERRY**		
Date:	12/18/70	**Sponsor:**	LRL
Time:	0730 PST	**Depth of Burial:**	912 ft
Location:	NTS U8d	**Purpose:**	Weapons Related
Type:	Shaft	**Yield:**	10 kt
Release Detected:	Offsite	**Type of Release:**	Test

Test Release at R+12 Hours, in Curies: 6.7×10^6

Isotopes Identified in the Release: Gross fission products

Cloud Direction: Northeasterly, parts of the cloud moved over Nevada, Utah, and Wyoming; another fraction moved towards California

Maximum Activity Detected in Air Offsite: 230 picocuries of ^{131}I per cubic meter and 3,400 picocuries of ^{133}I per cubic meter of air at Stone Cabin Ranch, Nevada

Maximum Gamma Exposure Rate Detected Offsite: Less than 1 mR/h in populated areas; 0.6 mR/h at Stone Cabin Ranch, Nevada

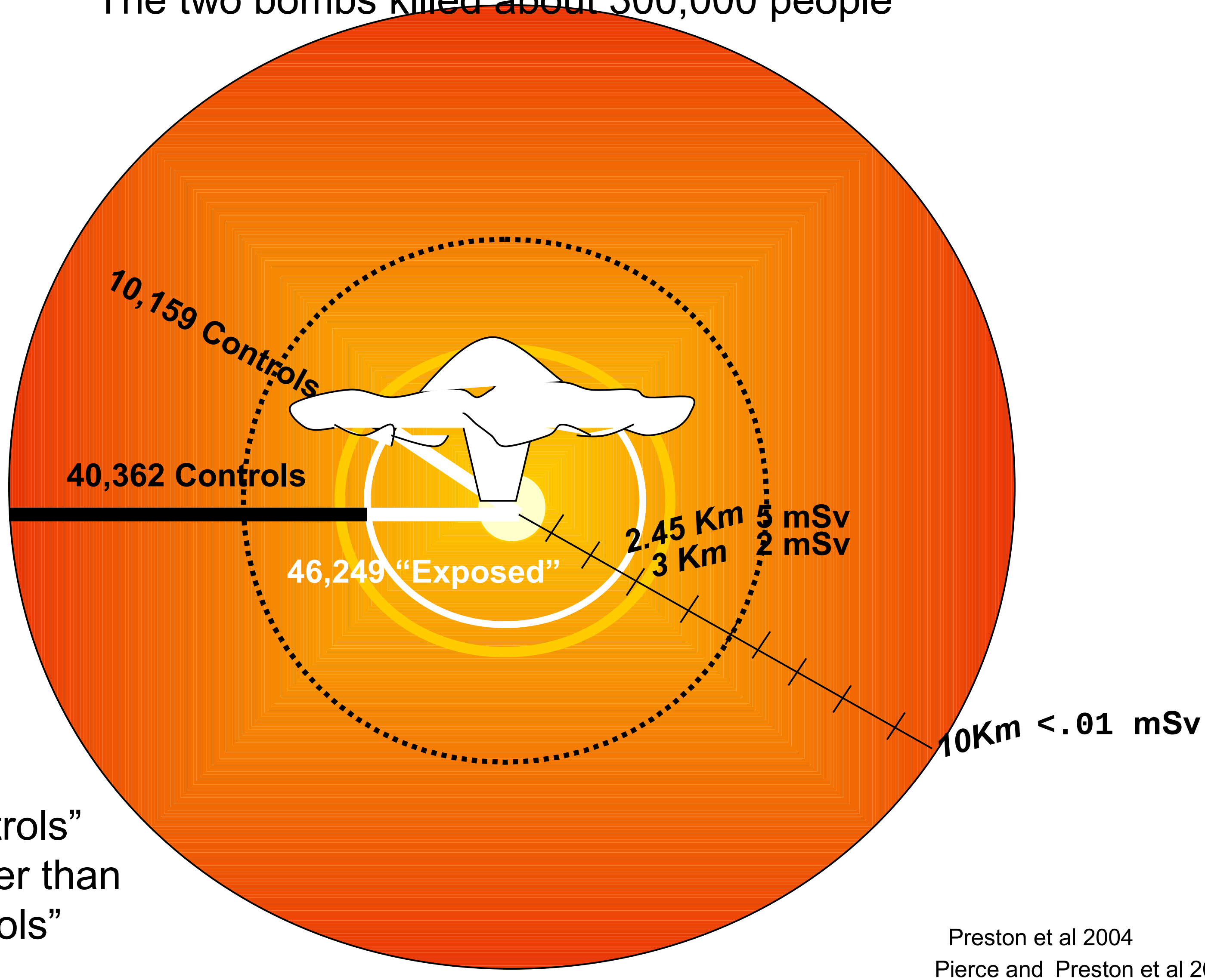
Maximum Iodine Level Detected Offsite: 810 picocuries of ^{131}I per liter in milk at the McCurdy Ranch near Beatty, Nevada

Maximum Distance Radiation Detected Offsite: 0.05 mR/h at Austin, Nevada

Release Summary: Venting occurred from a fissure near surface ground zero at H+3.5 minutes. The effluent venting rate steadily decreased with time, but visible vapor continued to emanate from the fissure for 24 hours after the detonation.

A-BOMB SURVIVOR STUDIES

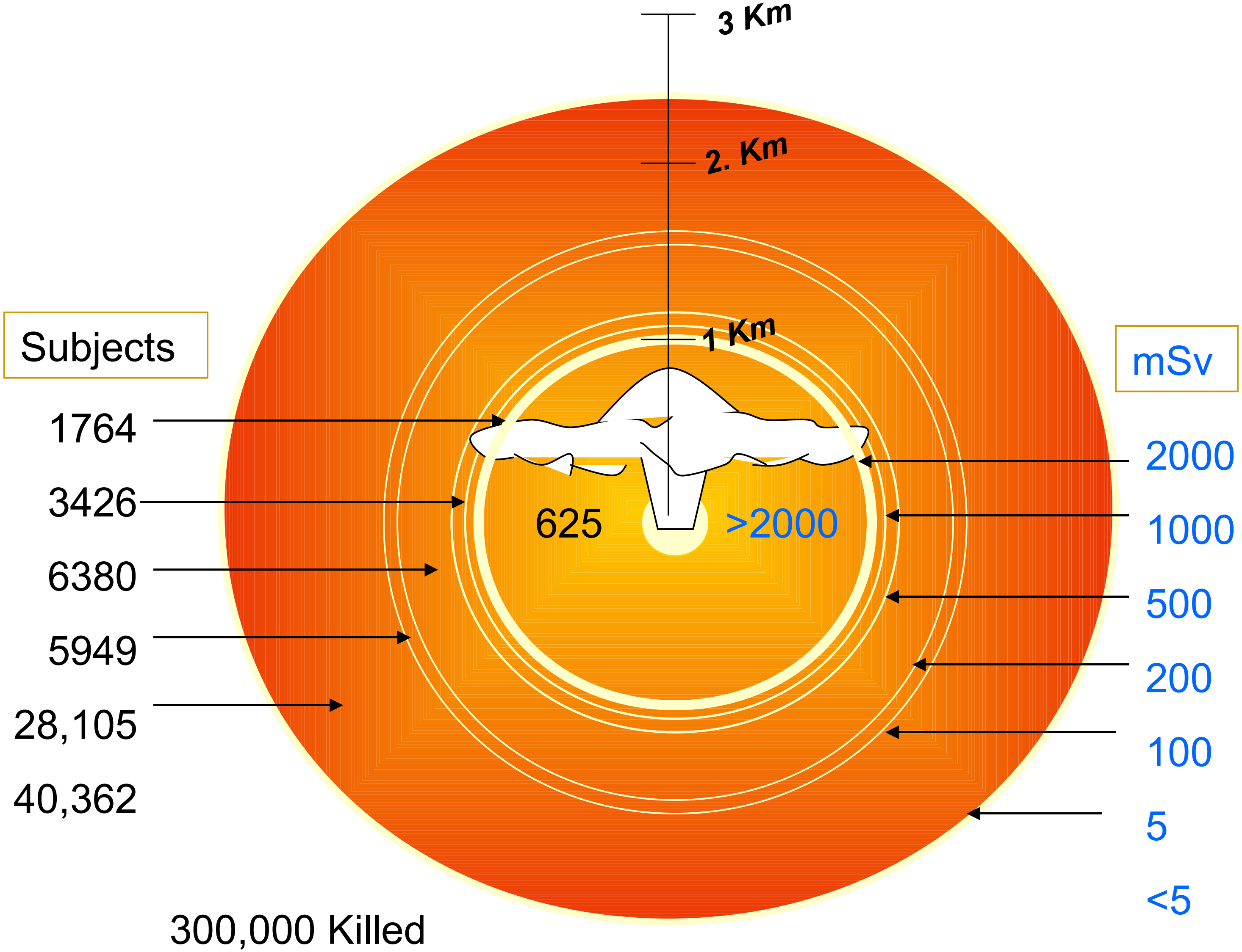
The two bombs killed about 300,000 people



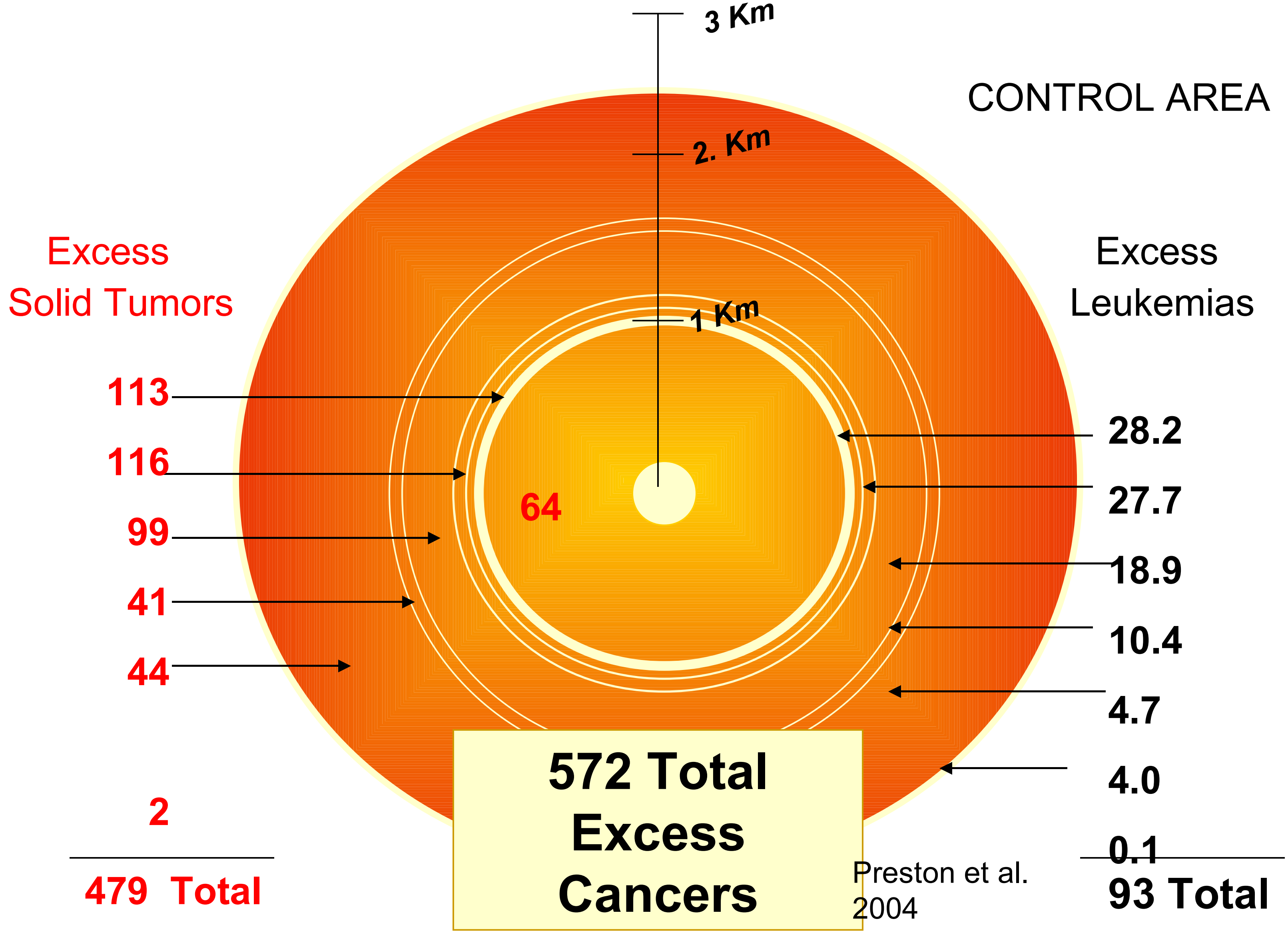
“Close in controls”
5% less cancer than
“Distant controls”

Preston et al 2004
Pierce and Preston et al 2000

A-BOMB SURVIVOR STUDIES



A-BOMB SURVIVOR STUDIES



Atomic Bomb Survivor Excess Cancer

Population of Survivors Studied 86,611

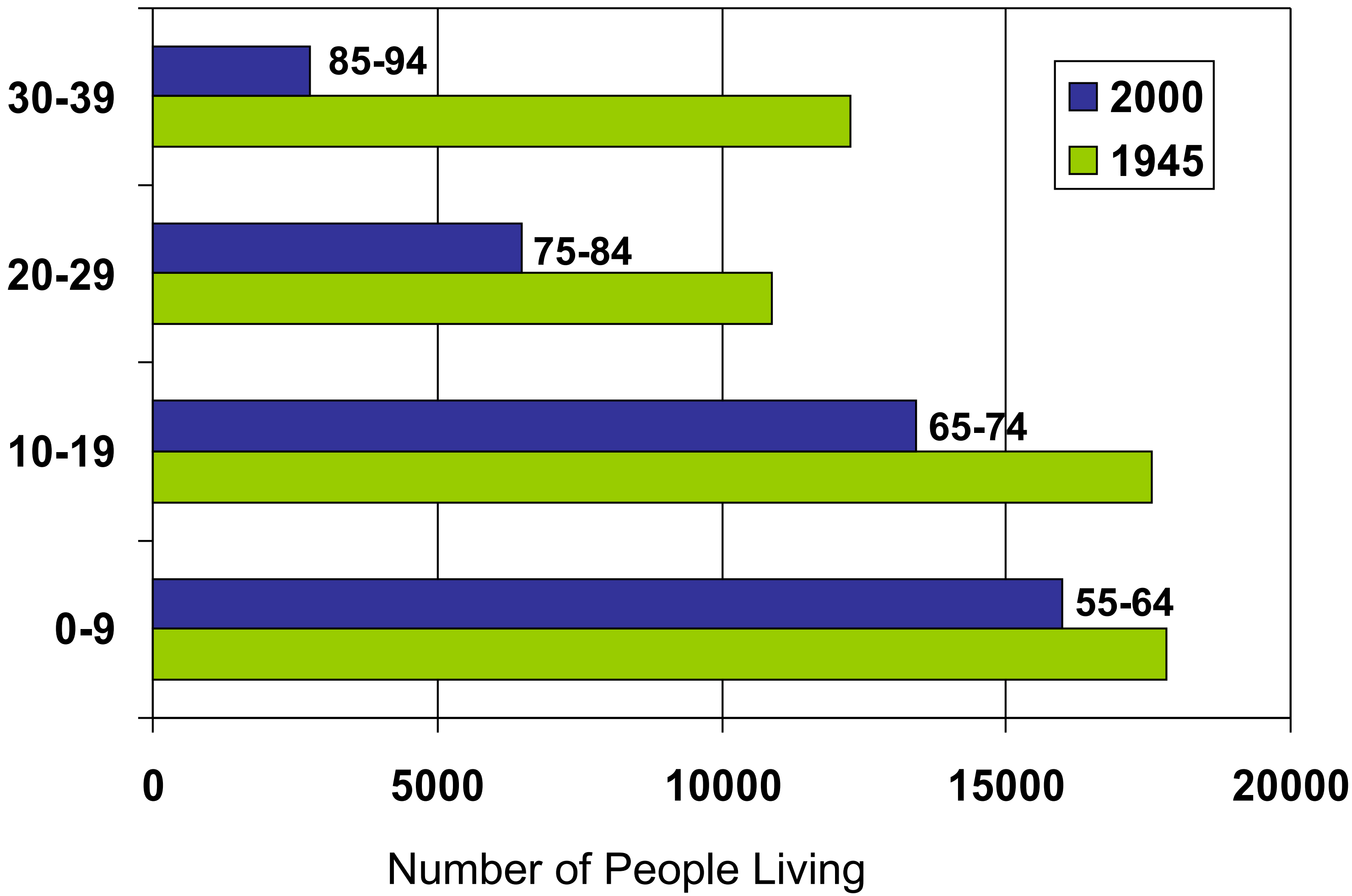
Total Solid Cancers observed after the Bomb 10, 127 Total
Solid Cancers Expected without Bomb 9, 647

Total Solid Cancer Excess 479

Excess Tumor 479 + **Excess Leukemia 93** = **572**

Preston et al. 2004

Age Groups of A-Bomb Survivors



Preston et al. 2004

Casualties at Hiroshima (~15 kt) and Nagasaki (~21 kt)

Zone	Population	Killed	Injured
0 to 0.6 mi	31200	26700	3000
0.6 to 1.6 mi	144800	39600	53000
1.6 to 3.1 mi	80300	1700	20000
Subtotal Hiroshima	256300	68000	76000
0 to 0.6 mi	30900	27200	1900
0.6 to 1.6 mi	27700	9500	8100
1.6 to 3.1 mi	115200	1300	11000
Subtotal Nagasaki	173800	38000	21000
Grand total	430100	106000	97000

From "The Effects of Nuclear Weapons", Glasstone & Dolan,1977

Casualties at Hiroshima and Nagasaki

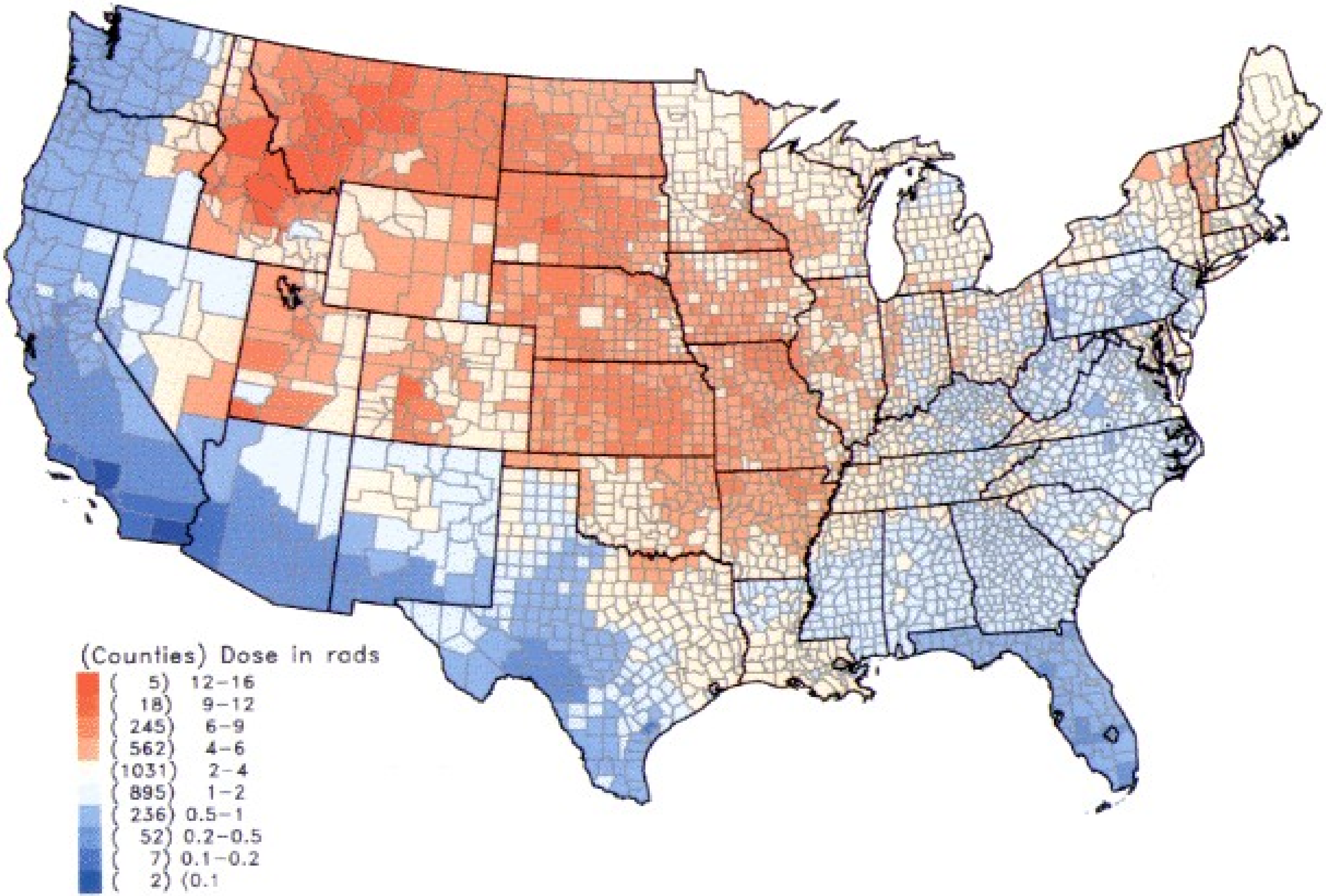
Casualties at Hiroshima and Nagasaki (Cancer Studies in Survivors)

Zone	Close in Survivor Studies	No. of Survivors	Dose (rem)	Excess Solid Tumors	Excess Leukemias
0 to 0.6 mi		625	200	64	-
0.6 to 0.9		11570	50-100	229	74.8
0.9 to 1.24		5949	10-20	140	15.1
1.24 to 1.55 mi.		28105	0.5-10	-	4
1.55 to 6.2 mi		40362	0.5	2	0.1
Grand total				479 excess solid tumors	93 excess Leukemias
0 to 1.5 mi.	46,249 Exposed -10,159 controls	Close in controls" 5% less cancer than "Distant controls"			
1.5 to 6.2 mi.	40,362 controls				

Casualties at Hiroshima and Nagasaki (Initial casualties vs survivor cancers)

Zone	Population	Killed	Injured	Close in Survivor Studies	No. of Survivors in Study	Dose (rem)	Excess Solid Tumors	Excess Leukemias
0 to 0.6 mi	31200	26700	3000		625	200	64	-
0.6 to 0.9					11570	50-100	229	74.8
0.9 to 1.24					5949	10-20	140	15.1
0.6 to 1.6 mi	144800	39600	53000					
1.24 to 1.55 mi.					28105	0.5-10	-	4
1.55 to 6.2 mi					40362	0.5	2	0.1
1.6 to 3.1 mi	80300	1700	20000					
Subtotal Hiroshima	256300	68000	76000					
0 to 0.6 mi	30900	27200	1900					
0.6 to 1.6 mi	27700	9500	8100					
1.6 to 3.1 mi	115200	1300	11000					
Subtotal Nagasaki	173800	38000	21000					
Grand total	430100	106000	97000				479 excess solid tumors	93 excess Leukemias
0 to 1.5 mi.				46,249 Exposed ;10,159 Controls	Close in controls" 5% less cancer than "Distant controls"			
1.5 to 6.2 mi.				40,362 Controls				

Per capita thyroid doses resulting from all exposure routes from all tests (Ref. NIH Iodine Study)



Health Physics Society Position on Risk of Cancer resulting from Exposure to Ionizing Radiation - Apr.,1999

1. Health effects have primarily only been observed in populations exposed to high doses at high dose rates.
2. The Life Span Studies of the Japanese survivors, exposed at high doses and high dose rates, form the most significant basis for estimates of risk from radiation.
3. The risk (i.e., chance) that any given cancer is related to a given radiation exposure depends on the amount of that exposure (i.e., dose) as well as other factors such as type of cancer, age at exposure, gender, and time since exposure.
4. The lowest doses at which an increase in any type of cancer is attributed to radiation exposure in the Japanese studies is greater than the 5 rem (0.05 Sv) used by the VA as a screening level for compensation evaluations.
5. The risks on a "per dose basis" of exposure to low dose, low dose-rates are less than those due to high dose, high dose-rates.

From these scientific facts the Society makes the opinion that there is no justification for assuming a presumptive causation of a cancer without consideration of all factors listed in #3 above, including dose.

Statement on Cancer and Radiation Dose by the Council of Scientific Society Presidents – Wingspread Conference 1997, Racine, WI

"A substantial body of scientific evidence demonstrates statistically significant increases in cancer incidence for acute whole-body exposures of adults to ionizing radiation at doses of about 10 rem and greater."

Attributable Percents from Various Risk Factors

Attributable Percents

Risk Factor	Percentage (%)
Tobacco	30
Adult diet / obesity	30
Sedentary lifestyle	5
Occupational factors	5
Family history of cancer	5
Viruses and other biologic agents	5
Perinatal factors / growth	5
Reproductive factors	3
Alcohol	3
Socioeconomic status	3
Environmental pollution	2
Ionizing / ultraviolet radiation	2
Prescription drugs / medical procedures	1
Salt / other food additives / contaminants	1

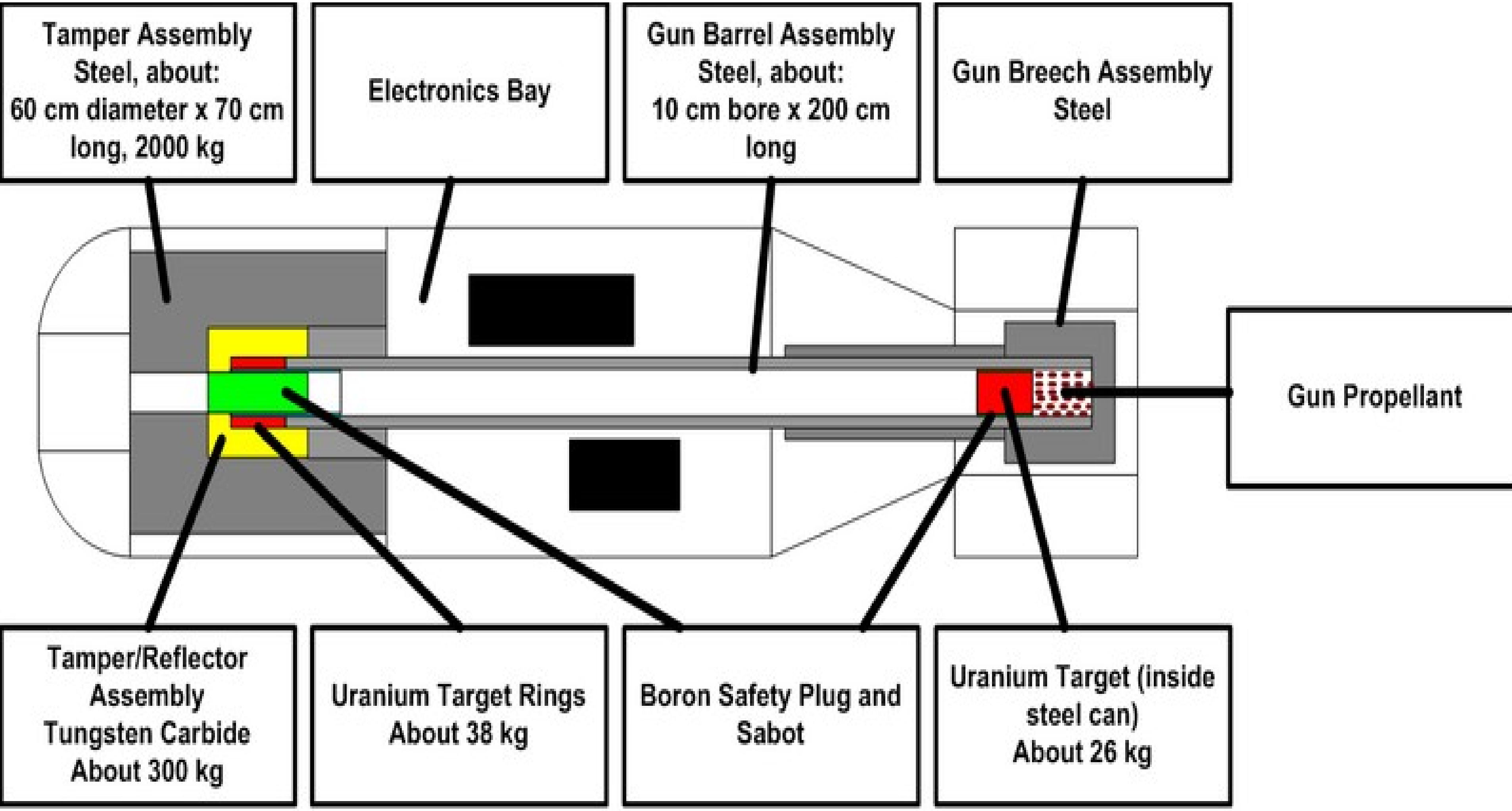
Harvard Report on Cancer Prevention. *Cancer Causes Control* 7 (suppl 1), 1996

Potential Terrorist Scenarios

- Radiological
  - Radiological dispersion device; e.g., “dirty bomb”
  - Malicious use of radioactive substances
- Nuclear
  - Attack on nuclear facility
  - Nuclear weapon
  - Improvised nuclear device (IND)

Improvised Nuclear Device

- Little Boy



Mark-1 “Little Boy” Model 1850
Uranium Gun-type Nuclear Bomb Design
Internal Cross Section (hypothetical)

What Is an RDD?

- A *radiological dispersal device (RDD)* is an unconventional weapon that a terrorist might use to destabilize a community, as described at right. Although often used to represent a dirty bomb, the radioactivity in an RDD could also be distributed passively (nonexplosively), such as through spraying or spreading by hand. Alternately, a *radiological exposure device (RED)* might be used, which would simply involve placing a radioactive source in a public area to expose people passing by.

Radiological Dispersal Device:

- Any method used to deliberately disperse
- radioactive material to create terror or
- harm. A dirty bomb is an example of an
- RDD. It is made by packaging explosives
- (like dynamite) with radioactive material
- to be dispersed when the bomb goes off.

RDDs-Where Would the Radioactive Material Come From?

- Radionuclides are used in a variety of industry, medicine, and scientific research applications, as illustrated by the examples below. Many of these are in sealed sources, used in civil engineering (in flow gauges and to test soil moisture and material thickness/integrity for construction), in petroleum engineering (in well logging for oil exploration), in the airline industry (in fuel gauges and to check welds and structural integrity), in medicine (cancer treatment, pacemakers, and diagnostics), in homes (smoke detectors), and to make electricity (in radiothermal generators or RTGs, that generate power in remote areas ranging from lighthouses to outer space).

Examples of Radionuclides in Common Use

Medicine		Industry/Commerce				Science
Diagnosis	*Treatment*	*Energy, Defense*	*Testing, Production*	*Food, Agriculture*	*Home*	*Research*
Tracer, flow *(Tc-99m, I-131)*	Gamma knife, blood/tissue sterilization *(Cs-137, Co-60)*	Commercial electricity *(U, Pu)*	Nondestructive test of structural integrity, radiographic imaging *(Co-60, Ir-192)*	Food product sterilization *(Co-60)*	Smoke detector *(Am-241)*	High-energy physics *(Cf-252, U-235)*
Tissue scan for clot, mass *(Ga-67)*	Needle, seed implants *(Cs-137, Ir-192, Ra-226)*	Remote power *(Sr-90)*	Density, moisture gauges *(Am-241, Cs-137)*	Pest (fruit fly) sterilization *(Cs-137, Co-60)*	Luminescent watch/clock dial *(H-3)*	Biokinetics *(Pu, Sr-90, others)*
X-ray *(Cs-137, Co-60)*	Pacemaker *(Pu-238)*	Defense/weapons *(Pu, H-3, U and depleted U)*	Material thickness, flow, conveyor, level gauges *(Am-241, Cs-137, Co-60, Kr-85)*	Seed, spice sterilization *(Cs-137, Co-60)*	Gas camping lantern *(Th-232)*	Biological tracer, protein/synthesis *(C-14, H-3, N-15 P-32, S-35)*

Which Radionuclides Are of Most Concern?

Nine isotopes of
interest for RDDs are:

- Americium-241 *(Am-241)*
- Californium-252 *(Cf-252)*
- Cesium-137 *(Cs-137)*
- Cobalt-60 *(Co-60)*
- Iridium-192 *(Ir-192)*
- Plutonium-238 *(Pu-238)*
- Polonium-210 *(Po-210)*
- Radium-226 *(Ra-226)*
- Strontium-90 *(Sr-90)*

Basic Radiological Properties of Nine Key Radionuclides for RDDs						
				Radiation Energy (MeV)		
Isotope	*Half-Life (years)*	*Specific Activity (Ci/g)*	*Decay Mode*	*Alpha (α)*	*Beta (β)*	*Gamma (γ)*
Americium-241	430	3.5	α	5.5	0.052	0.033
Californium-252	2.6	540	α (SF, EC)	5.9	0.0056	0.0012
Cesium-137	30	88	β, IT	-	0.19, 0.065	0.60
Cobalt-60	5.3	1,100	β	-	0.097	2.5
Iridium-192	0.2 *(74 d)*	9,200	β, EC	-	0.22	0.82
Plutonium-238	88	17	α	5.5	0.011	0.0018
Polonium-210	0.4 *(140 d)*	4,500	α	5.3	-	-
Radium-226	1,600	1.0	α	4.8	0.0036	0.0067
Strontium-90	29	140	β	-	0.20, 0.94	-

SF = spontaneous fission; IT = isomeric transition; EC = electron capture. A hyphen means not applicable. The radiation energies for cesium-137 include the contributions of barium-137 metastable (Ba-137m), and those for strontium-90 include the contributions of yttrium-90.

Radioactive Sources

- 157,000 licensed users in U.S.
- 2,000,000 devices containing radioactive sources
- Approximately 400 sources lost or stolen in U.S. every year

CDC

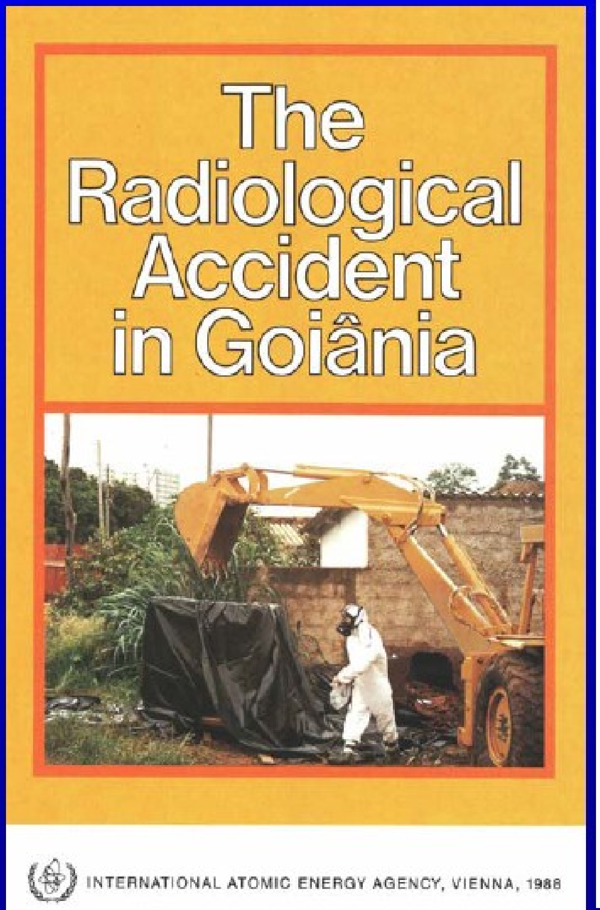
Sources Around the World

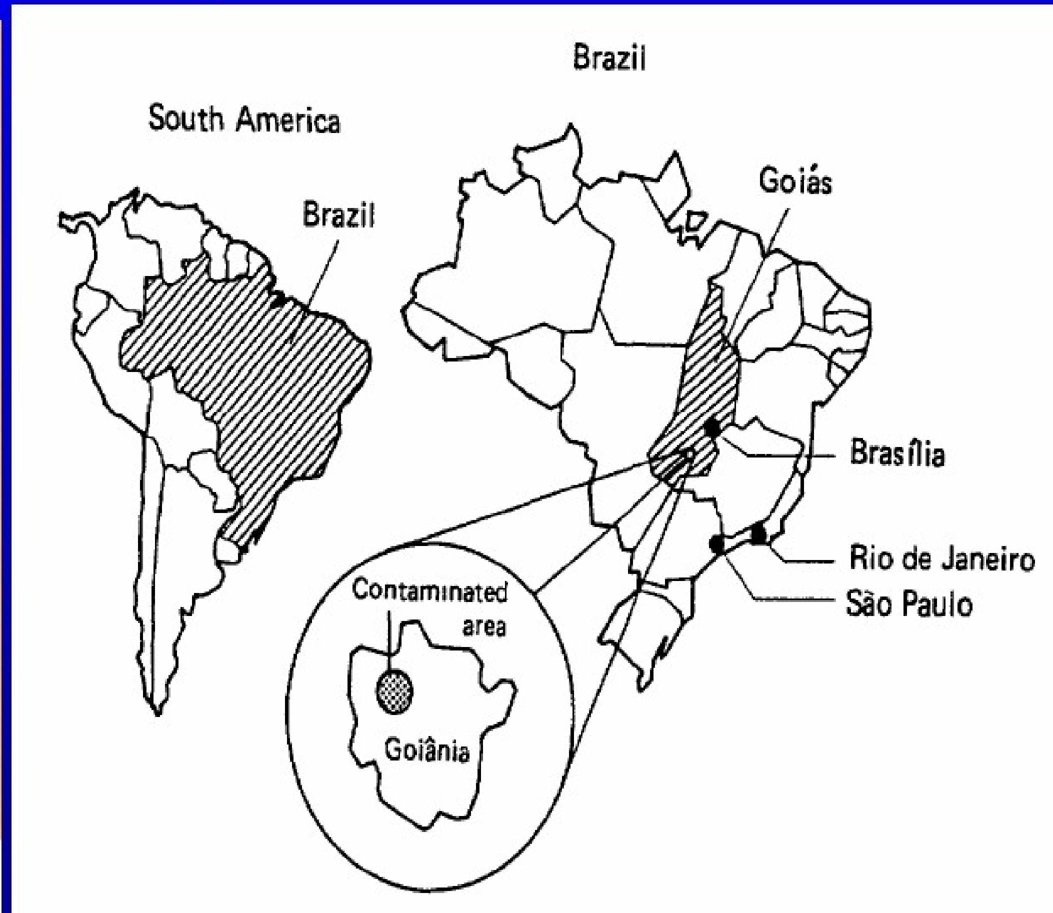
Recovered transport container

Sources used in mobile cesium irradiators in the former Soviet Union

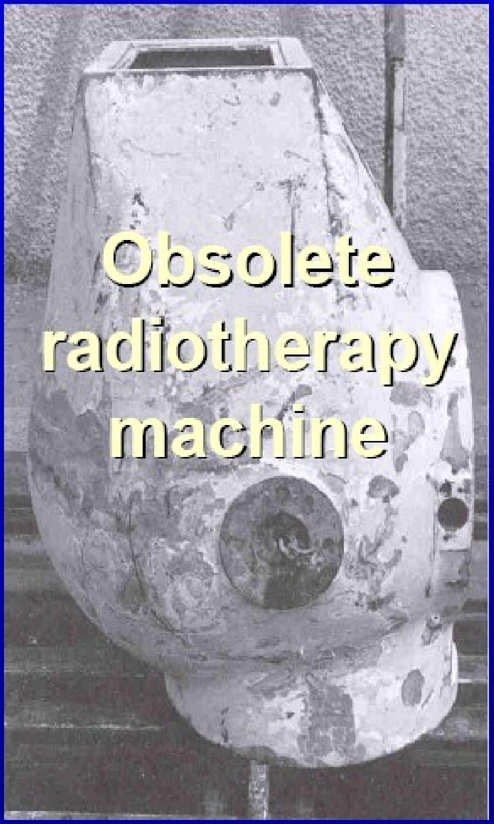
Photos courtesy of the International Atomic Energy Agency (IAEA)

Goiânia, Brazil





Goiânia Radiological Release

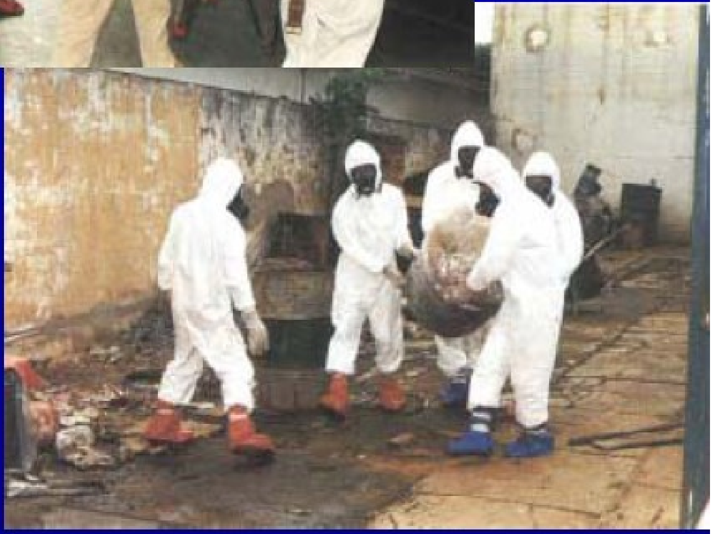


Photos courtesy of the International Atomic Energy Agency (IAEA)

CDC

Goiânia Morbidity

- **249 exposed; 54 hospitalized**
- **Eight with radiation sicknes**
- **Four people died**
- **112,000 people monitored** (>10% of total population)



Photos courtesy of the International Atomic Energy Agency (IAEA)

Illustrative Case Study: 1987 Radiological Accident in Goiania, Brazil

- In September 1987, a hospital in Goiania, Brazil, moved to a new location and left its radiation cancer
- therapy unit behind. Found by scrap metal hunters, it was dismantled and the cesium chloride source
- containing 1,400 Ci of cesium-137 was removed. Pieces were distributed to family and friends, and
- several who were intrigued by the glow spread it across their skin. Eleven days later, alert hospital staff
- recognized symptoms of acute radiation syndrome in a number of victims.
- The ensuing panic caused more than 112,000 people – 10% of the population – to request radiation
- surveys to determine whether they had been exposed. At a makeshift facility in the city's Olympic
- Stadium, 250 people were found to be contaminated. 28 had sustained radiation-induced skin injuries
- (burns), while 50 had ingested cesium, so for them the internal deposition translated to an increased risk
- of cancer over their lifetime. Tragically, 2 men, 1 woman, and 1 child died from acute radiation
- exposure to the very high levels of gamma radiation from the breached source.
- In addition to the human toll, contamination had been tracked over roughly 40 city blocks. Of the
- 85 homes found to be significantly contaminated, 41 were evacuated and 7 were demolished. It was
- also discovered that through routine travels, within that short time people had cross-contaminated
- houses nearly 100 miles away. Cleanup generated 3,500 m3 radioactive waste at a cost of $20 million.
- The impacts of this incident continued beyond the health and physical damage to profound
- psychological effects including fear and depression for a large fraction of the city's inhabitants.
- Further, frightened by the specter of radioactive contamination, neighboring provinces isolated Goiania
- and boycotted its products. The price of their manufactured goods dropped 40% and stayed low for
- more than a month. Tourism, a primary industry, collapsed and recent population gains were reversed
- by business regression. Total economic losses were estimated at hundreds of millions of dollars. A key
- lesson learned from this incident is the importance of enhancing the broader understanding of radiation.
- This fact sheet is intended to help support that objective.
- (For additional information see: International Atomic Energy Agency (IAEA), 1988, *The Radiological*
- *Accident in Goiania*, Vienna, Austria.)

Time: ***Decrease*** **time spent near the radioactive source**

Distance: ***Increase*** **distance between you and the source**

Shielding: ***Increase*** **the physical shielding between you and the source**

Common Shelters

Structure	Dose Reduction Factors
Wood Frame (1st floor)	10%
Wood Frame (Basement)	40%
Masonry	40%
Large building	80%

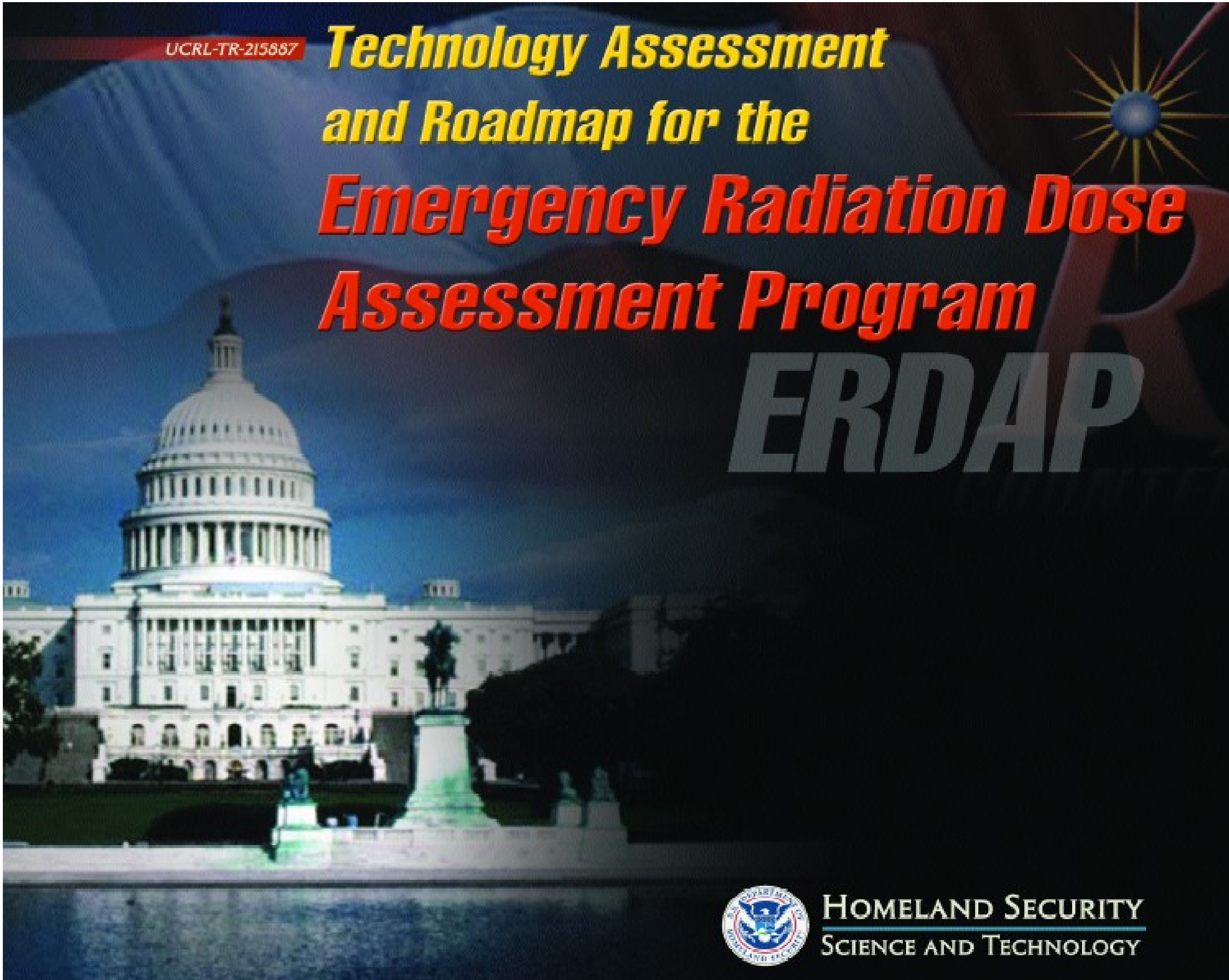
From the Environmental Protection Agency's *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, Appendix C*

CDC

UCRL-TR-215887

Technology Assessment and Roadmap for the Emergency Radiation Dose Assessment Program

ERDAP



HOMELAND SECURITY
SCIENCE AND TECHNOLOGY

Table 1. Summary of what we know and don't know about current and emerging dosimetry technologies.

	What we know	What we don't know
Current Methods and Tools		
Measurement of radioisotope contamination	Many available handheld detectors for external assessment. Internationally accepted guidelines for radiation dose estimation. Available instrumentation for body fluid analysis, limited high-throughput capability.	Radiation dose estimation models need more attention, and may have significant inaccuracies, especially for sub-populations.
Biological and clinical signatures of radiation dose	Lymphocyte depletion is not detectable in the first 24 hours for less than 5 Gy. Lymphocyte kinetics will be logistically difficult to obtain within this time period and vary significantly from individual to individual. Time-to-vomiting is limited in sensitivity (only 35% of victims vomit with a 2 Gy exposure) and is widely variable from individual to individual. Conventional/cytogenetic chromosome aberration assessment (scoring 1000 metaphase spreads) takes 48-72 hours and has demonstrated capability to estimate doses from 0.20 to 6.0 Gy (acute photon equivalent dose), while cytogenetic triage (scoring 40-50 metaphase spreads) becomes difficult below 1 Gy. The current U.S. cytogenetics capability is limited to less than 500 standard assessments over a 2-week period. These methods may not accurately predict partial-body or organ-specific exposure.	Effect of dose rate on lymphocyte counts or depletion rate is not known. Psychosomatic impact on time-to-vomiting is not established for a mass casualty situation. Shorter-turnaround (24 hour) cytogenetic chromosome aberrations are not yet well benchmarked.
Pre-positioned physical dosimeters	Current technology meets dose threshold and dynamic range requirements. May not accurately predict partial-body or organ-specific exposure.	Shelf-life, longevity not well established for SIRAD cards. Social and medical questions about how to interpret "significant radiation exposure" readings and false positives.

Emerging Technologies

Physical changes in human tissues	OSL and EPR could enable accurate and safe estimation of dose from non-invasive in vivo measurements in teeth, with a threshold at or below 1.5 Gy. Ultrasound may provide evidence of local radiation injury around wounds. Potential for turnaround and throughput in 1 min / assay timeframe.	OSL sensitivity significantly below 15 Gy is anticipated from theoretical arguments, but has not yet been established experimentally. *In vivo* EPR dosimetry sensitivity and potential inter-individual variation effects are unknown. OSL and EPR field equipment (portable, etc.) has not been demonstrated. Dose sensitivity of ultrasound is not established.
Personal items and other fortuitous dosimeters	Several materials have been demonstrated to provide very accurate dosimetry, with a detection threshold well below 1.5 Gy. Potential for turnaround and throughput in 5 min / assay timeframe. Hard to depend on this approach for all victims, since dosimetry materials are fortuitous. May not accurately predict partial-body or organ-specific exposure.	Con-ops and instrumentation for widespread use have not been established.
Biological markers	Several mRNA and protein candidates demonstrated to be dose dependent, with sensitivity well below the 1.5 Gy action threshold. Hand-held devices for blood cell counting, breath gases analysis, and triage medical recording involving the tagging of casualties will assist with triage. Instrumentation concepts (protein and PCR assays) have been demonstrated for other applications, and could provide 5 min turnaround and throughput and / or be run in a highly multiplexed format. Potential for a self-administered disposable format for proteins. May not accurately predict partial-body or organ-specific exposure – this could be addressed with significant further research.	Time dependence and variation with confounding factors such as age, stress, and health status have not been well established. Instrumentation throughput, ruggedness, accuracy and sensitivity have not been established for this application. Organ-specific markers have not been established. Utility of other biological markers such as metabolites need investigation. Ability of markers to detect/differentiate whole or partial body exposures are unknown.

What should be Done?

Table 2 lays out deliverables & a time table for a National Program in Emergency Radiation Dose Assessment!

- Clarify device needs and requirements
- Maximize use of existing technologies
- Pursue longer range research & development to fill gaps with existing technologies
- Conduct a demonstration program to assess the value of existing and proposed technologies

Table 2. Suggested Goals for National Program in Radiation Assessment.

<table>
<tr><th></th><th>1 year</th><th>1 to 3 years</th><th>3 to 5 years</th></tr>
<tr><td rowspan="2">Systems analysis to clarify device needs and requirements</td><td>Analyze scenario for one radiological and one nuclear incident type.

Define relative roles of physical and bio-dosimetry, perform cost-benefit analyses for dosimetric systems.</td><td>Provide initial estimate of operational device requirements for R/N scenario's for physical and bio-dosimetry tools.

Evaluate hospital instruments and technicians to determine capability to perform required measurements.</td><td rowspan="2">Refine estimates based on progress in laboratory experiments and initial field demonstrations.

Work with instrument manufacturers to modify hospital-based instruments to be capable of measuring threat isotopes, and provide training to technicians.</td></tr>
<tr><td colspan="2">Determine optimum size and organization of a national cytogenetics network.

Evaluate competing technologies and define the most effective role of pre-positioned dosimeters.

Develop criteria to distinguish the added value of emerging dosimetry technologies. Evaluate and compare competing technologies to select the best available.</td></tr>
<tr><td>Short-range efforts to maximize use of existing technologies</td><td>Define a blueprint to stabilize a U.S. cytogenetics capability and developing pre-positioned dosimeter concepts.

Establish deployable hematology capability - radiation response team resource.</td><td>Establish a national cytogenetics laboratory network composed of reference laboratories supplemented with satellite scoring laboratories.

Develop high-throughput sample-assessment system for radioisotope contamination.

Pilot pre-positioned dosimeters.</td><td>Test system in well-controlled round robins and practice exercises.

Establish standardized cytogenetics protocols and develop standard calibration curves.</td></tr>
<tr><td rowspan="3">Longer-range research on emerging dosimetry technologies</td><td rowspan="3">Initiate parallel efforts in emerging physical and biological dosimetry, define decision tree for technology assessment.</td><td>OSL, EPR and ultrasound: assess sensitivity, person-to-person variability, and safety of prototype systems.

Hand-held breath gas analysis, blood cell counters, and triage medical recording/tagging systems.</td><td rowspan="2">Develop working prototypes for con-ops and performance-based down select after ~year 5.</td></tr>
<tr><td>Fortuitous dosimeters: develop con-ops, develop and assess field prototype detectors.</td></tr>
<tr><td colspan="2">Molecular markers: demonstrate sensitivity, person-to-person variability / sensitivity to confounding factors; demonstrate field prototypes that meet sensitivity and other operational requirements.</td></tr>
<tr><td>Demonstration programs</td><td>Define a field demonstration plan that leverages state and national exercises.</td><td>Conduct field demonstrations that verify performance of existing technologies.</td><td>Conduct field demonstrations of emerging dosimetry prototypes.</td></tr>
</table>