POSSBILE EXPOSURES FROM RADIOLOGICAL TERRORISM

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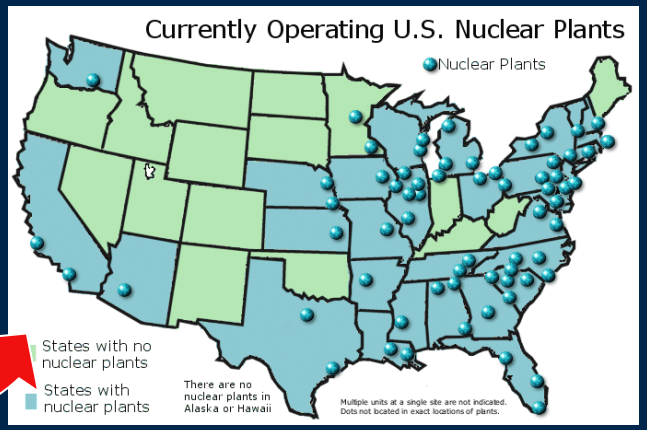
How can we predict what level of doses might be delivered to the public by terrorists?

1. Understanding of effects from nuclear testing
2. Extrapolations from accidents
3. Extrapolations from confiscations of orphan or illegally obtained radioactive sources
4. Calculations and dispersion models
5. Trying to imagine what terrorist's might be capable of.

Note that there is NO experience in dealing with, mitigating, or even knowing how terrorists might use, radiation to hurt the public. Everything at this point is speculation!

Potential Means of Terrorists to Expose the Public to Radiation

Targeted attack on nuclear facility



Improvised nuclear device

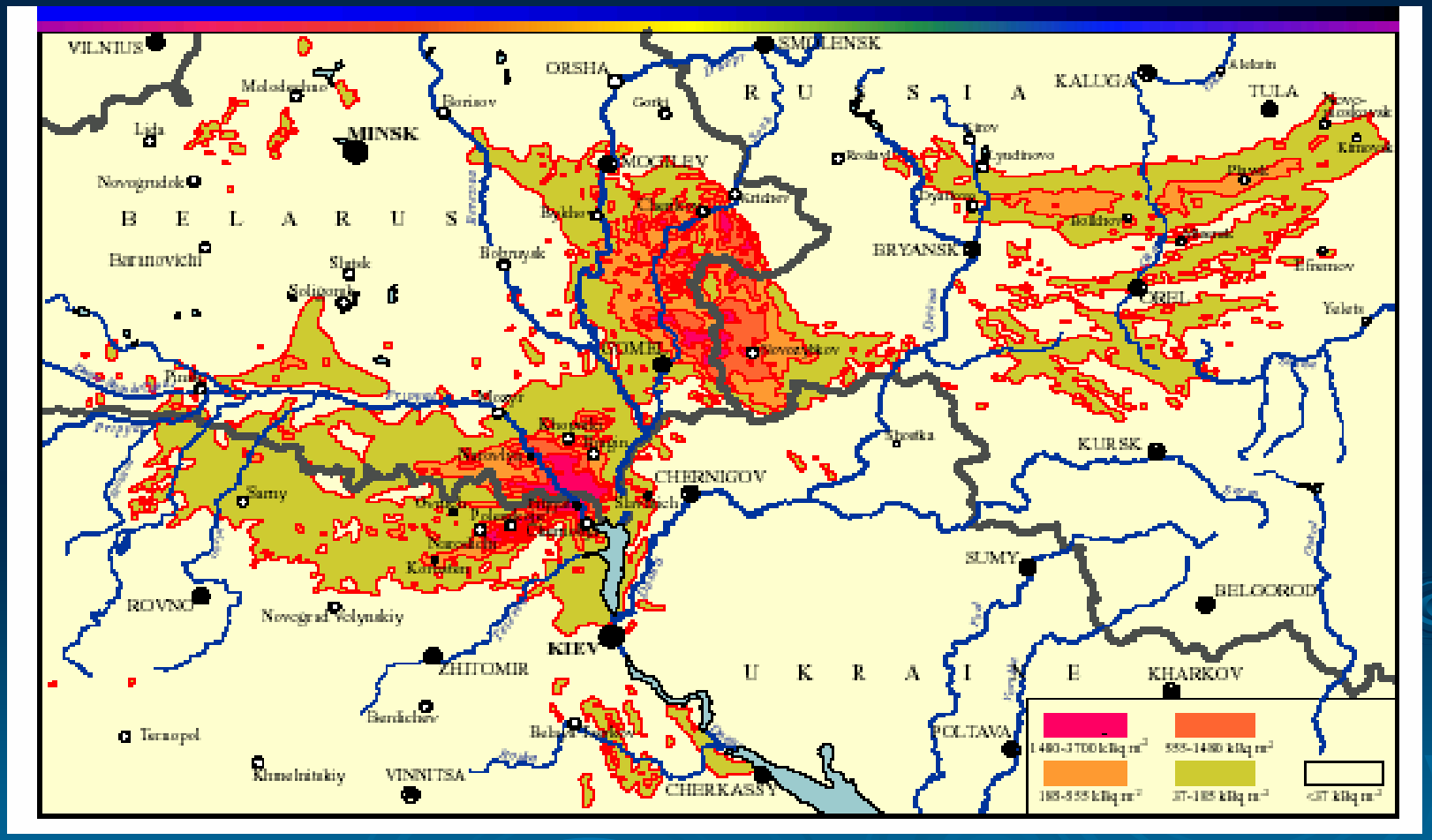
Dirty bomb

Hidden radiation source

NUCLEAR FACILITY DISASTERS

(not to be discussed in any detail, see course information on Chernobyl accident)

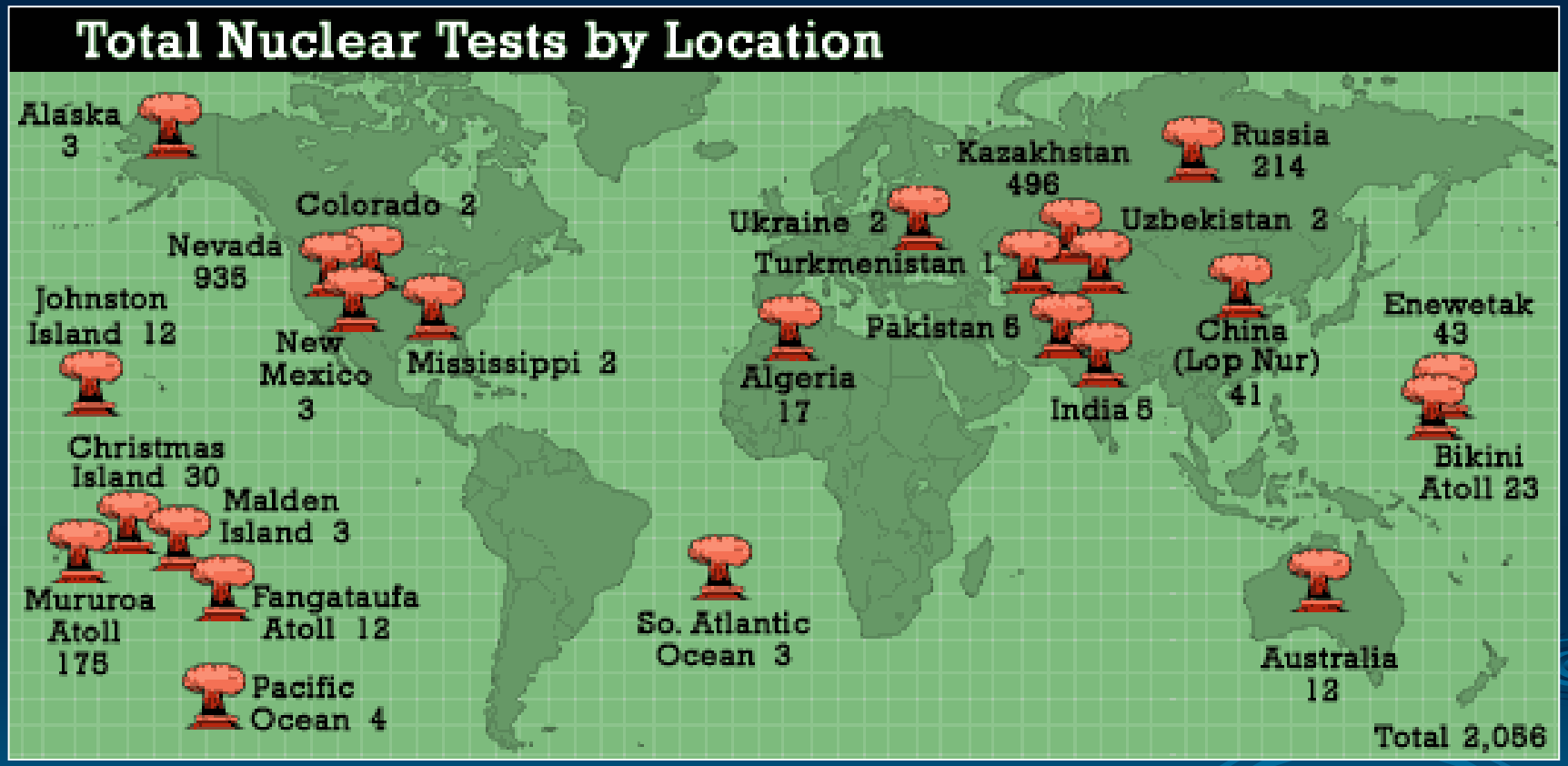
Though U.S. power plants are designed to be impervious to most kinds of external attempts to destroy them, the consequences of Chernobyl indicate the long-term problems that could follow a major release of radioactive materials.



LESSONS FROM NUCLEAR TESTING

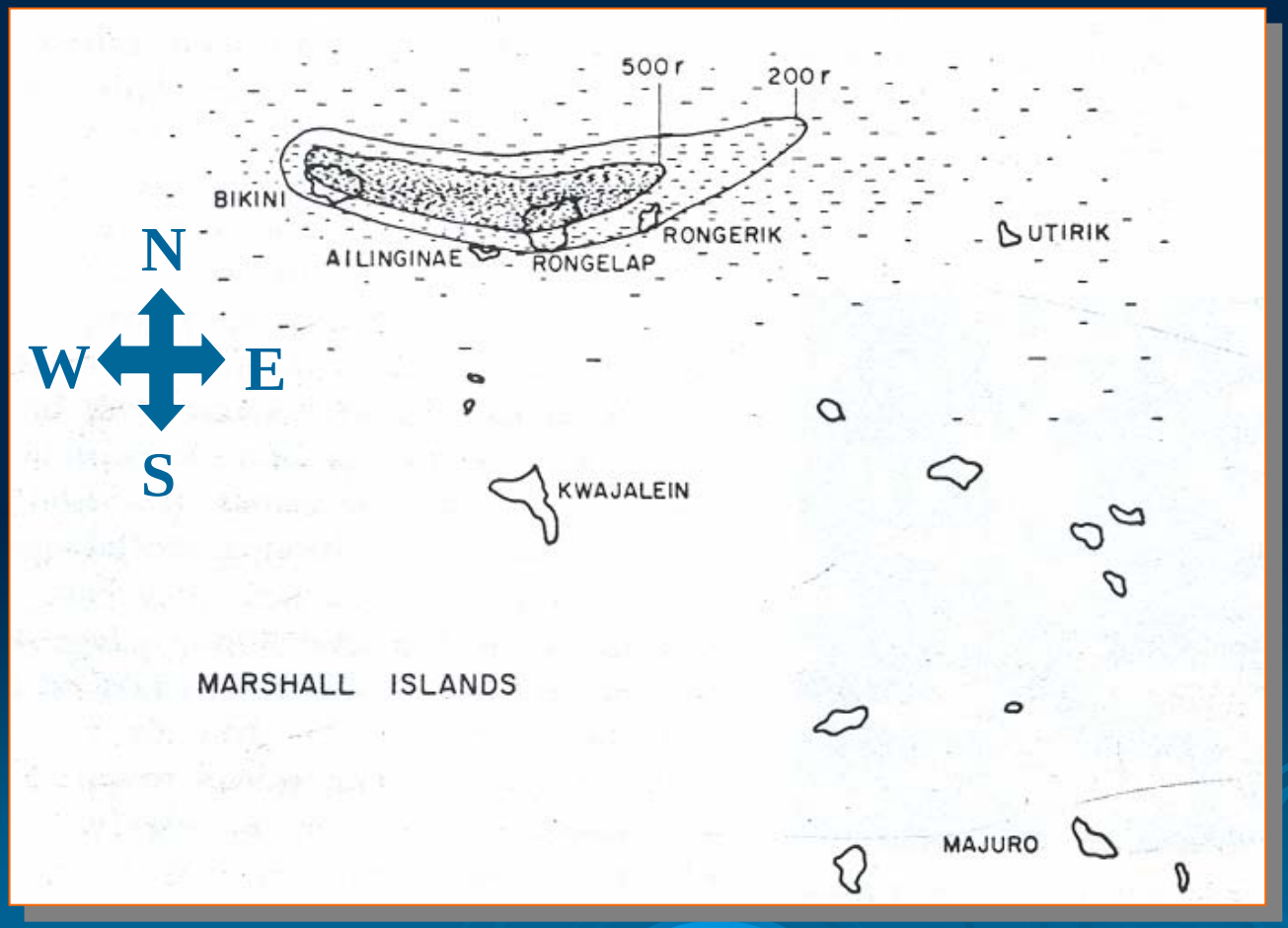
Where was there nuclear testing from which we can draw conclusions?

Answer: all over the globe



Deterministic as well as long-term stochastic health effects have been documented as a result of exposure to early nuclear weapons fallout.

Exposure of Marshallese following the 1954 BRAVO thermonuclear test at Bikini atoll is a good example.



Highly exposed Marshallese were cared for and medically followed for decades by Brookhaven National Laboratory under U.S. government sponsorship.

64 people on Rongelap,
18 on Ailinginae,
159 on Utrik.

Medical findings through 1990:

- First nodule in Rongelap (child) found in 1963.
- First nodule in Utrik (adult) in 1969.
- Evidence developed for a dose-dependent latency period.
- In Rongelap: 25% developed nodules, 7% developed papillary cancer.
- In Ailinginae: 21% developed nodules, 5% had occult cancer.
- In Utrik: 6% developed nodules, 2% papillary cancer, <1% follicular cancer, 4% occult cancer.
- Comparison group: 2% developed nodules, <1% developed papillary cancer, <1% occult cancer.

Estimates of thyroid absorbed dose at Rongelap (Gy) by BNL (1985)

AGE	Internal	External	Total
Adult Male	10	1.9	12
Adult Female	11	1.9	13
12-year old	16	1.9	18
9-year old	20	1.9	22
6-year old	24	1.9	26
1-year old	50	1.9	52
Newborn	2.5	1.9	4.4
In-Utero 3rd trimester	6.8	1.9	8.7

Maximum estimates were 4x greater.

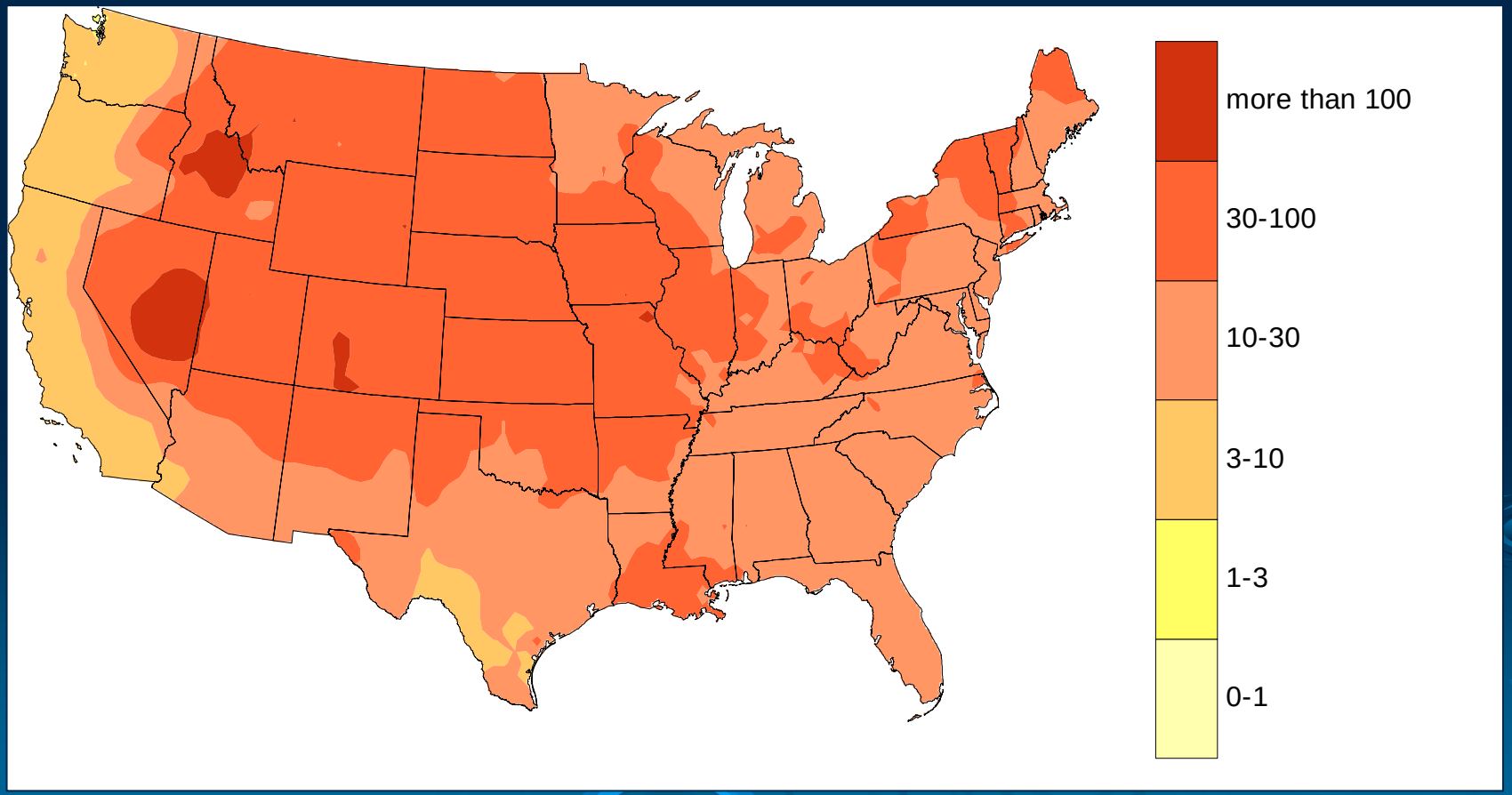
Doses at Ailinginae were about 1/3, and at Utrik about 1/8, of those at Rongelap.

It would be impossible for terrorists to reproduce the explosive yield of the BRAVO test, yet, that event confirmed that there are immediate and long-term health effects (other than death) from radioactive fallout, as well as considerable

- **long-term public fear and societal unrest**
- **accusations against the government including lawsuits**
- **economic damage, etc.**

In the continental U.S., nuclear testing also led to decades of debate and societal complaints about public exposure.

Geographic pattern of average internal dose (mGy) to the thyroid of a child born 1 January 1951 from ^{131}I from all NTS tests



EXTRAPOLATIONS FROM ACCIDENTS

Goiania, Brazil

September 1987

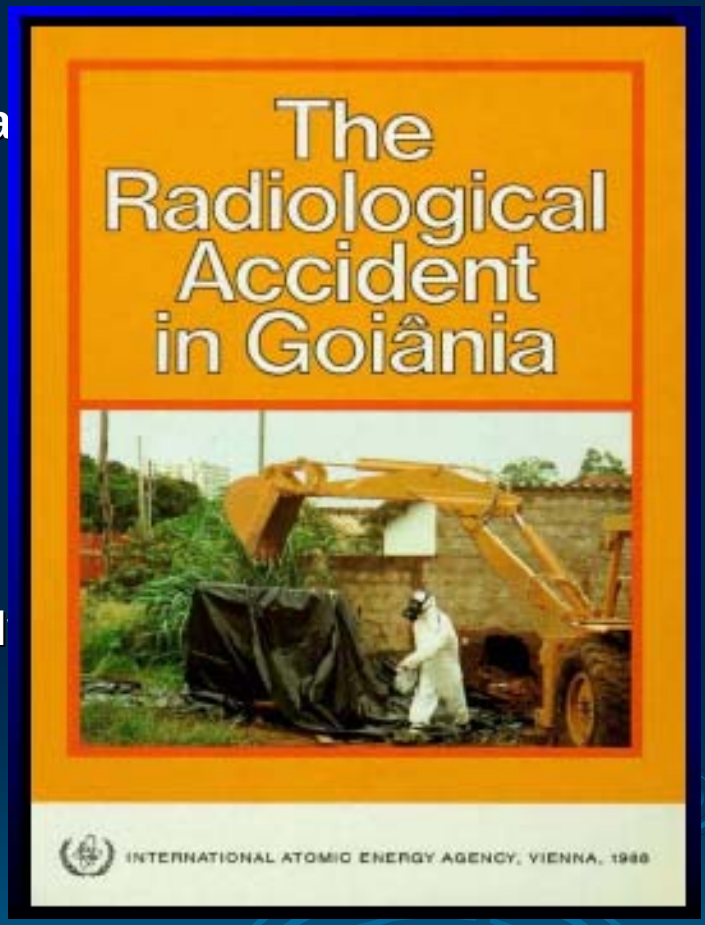
- Abandoned Cancer Clinic discarded canisters from radiotherapy machine
- Junkyard worker opened canisters revealing blue powder
- Citizens contaminated with radioactive Cesium-137

^{137}Cs released

1350 Curies

Consequences:

- 1350 Ci cesium chloride source capsule removed from the protective housing of a teletherapy machine and subsequently punctured, causing release of free CsCl powder, which is spread from person to person over two weeks.
- 112,000 persons monitored for radiation exposure (10% of local population)
- 249 contaminated
- 151 contaminated internally and externall
- 49 hospitalized (20 with doses ranging from 100 to 800 rads)
- 28 with radiation burns
- 5 deaths (including 6-year-old girl internally contaminated with 5.2 mCi)



There have been many other accidents, mostly involving improper use and handling of radiation sources.

The problem of orphaned source is serious worldwide as it provides source material for dirty bombs.

About 400 radioactive sources are lost or stolen in the US every year (source CDC)

EXTRAPOLATIONS FROM CONFISCATIONS OF ORPHANED OR ILLEGALLY OBTAINED RADIOACTIVE SOURCES

Washington Post, May 4, 2004

Ukrainian Police Seize 'Dirty Bomb' Material, Arrest 3

KIEV, UKRAINE | Ukrainian security forces seized nearly 375 pounds of cesium-137, a highly radioactive material seen as a likely ingredient for a "dirty bomb," and arrested three people, authorities said Thursday.

The three men were from the southern city of Simferopol on the Crimean peninsula, police spokesman Yuriy Kondratyev said. An unspecified number of people were detained throughout Ukraine.

Police and state security agents acted on a tip-off that two buyers from the Ukrainian capital, Kiev, were ready to purchase cesium at an estimated price of $60,000 per container, Kondratyev said. (AP)

Let's assume for this example, that a terrorist places, in a public location, a Cs-137 source of 1% of the mass confiscated last week in the Ukraine.

How much activity is that?

What would the exposure rate be nearby where people might be passing?

What magnitude of doses might people acquire?

0.01 x 375 lb x kg/2.2 lb x 1000 g/kg = 1,700 g

1,700 g x 87 Ci/g = 1.5 x 10^5 Ci of Cs-137 !

Note: this is about 1.4% of the radiocesium released by the Chernobyl accident.

Problem #2: *What is the dose rate in air at 1 m distance from a 1 Ci (Curie) point source of ^{137}Cs?* (Note: 1 Ci = 3.7×10^{10} dis/sec)

Cesium-137 decays by releasing a 0.662 MeV gamma ray in 85% of the disintegrations. Thus, the energy fluence ψ (energy per area) would be:

ψ = [(0.662 MeV/dis) x 0.85 x 3.7×10^{10} dis/s] / [4 π (100 cm)^2]
= 1.66×10^5 Mev/(cm^2 s)

$D_{air} = \psi \, (\mu_{en} / \rho)$

= [illegible] (0.0027 cm^2/g) = 4.47×10^3 Mev/(g s)

Example from last Week

Now convert to joules and kg, then to Gy

D_{air} = 4.47×10^3 Mev/(g s) x 1.6×10^{-13} J/MeV
= 7.2×10^{-7} J/(kg s)
= 7.2×10^{-7} Gy/s
= 7.2×10^{-7} Gy/s x 3600 s/hr
= 2.58×10^{-3} Gy/hr
= 2.6 mGy/hr per Ci at 1 m distance

Using the calculated value of 2.6 mGy/hr per Ci at 1 m distance, we can calculate the dose rate (in air or to tissue) due to the terrorist's source:

$$\frac{2.6\ \text{mGy}}{\text{Ci}} \times 1.5 \times 10^{5}\ \text{Ci} \times \frac{1\text{Gy}}{1000\,\text{mGy}} \times \frac{1\text{hr}}{60\,\text{min}} = 6.5\,\frac{\text{Gy}}{\text{min}}\,(\text{to air})\,\text{at}\,1\text{m}$$

Note that tissue dose to the whole-body would be about 70% of the dose rate to air $\cong$ **4.6 Gy/min**

Note that the dose rate would be ~1.1 Gy/min at 2 m distance.

Should this source be positioned in an area where people congregate or even pass by, considerable dose (even fatal doses) could be given unknowingly to people.

HOW, AND/OR WHERE, MIGHT SUCH EXPOSURES TAKE PLACE?

There are many, many types of public places where sources could be hidden and the public unknowingly exposed.

What can we conclude?

It seems possible that terrorist's could hide radioactive sources of considerable magnitude in the public sector and unknowingly expose members of the public to high doses, though improvements in border inspection will continue to diminish this possibility in the continental U.S.

Terrorists would likely fatally expose themselves in placing a source, though that apparently is not a deterrent.

The numbers of people exposed would likely not be more than a few thousand before symptoms were recognized.

The fear that this would induce worldwide is unimaginable.

CALCULATIONS AND DISPERSION MODELS

In 2003, DTRA, IDA, and Los Alamos National Laboratory, as part of the Discrete Fury experiment series, constructed and detonated a mock dirty bomb at the NTS containing 721 g of stable cesium chloride (equivalent to a source term of approximately 50,000 Ci (which some believe would be an extremely large RDD) and a 4.5 kg C-4 charge.

Note: 50,000 Ci would be 0.07% of the activity claimed to have been confiscated in the Ukraine.

Measurements and dispersion model predictions were made to estimate the number of people, assuming a population density of 0.25 people/m^2 (representative of typical Times Square traffic) that received doses above acceptable limits by inhalation pathway.

From a review of the outcome of the experiments and calculations, DHHS concluded:

- RDDs containing Cs-137 pose a credible threat to national security
- The maximum credible source could exceed 100,000 Ci (about the same as example of the hidden source)
- Persistent aerosol release fractions as high as 60% of the original mass might be suspended in the air for 15-20 min after detonation
- The most likely number of people exposed >10 ALI (200 uCi) is about 2500 for 13.5 kCi explosion.
- Prussian Blue (PB) could be administered therapeutically to persons likely to have inhaled more than 200 uCi of Cs-137 (1 ALI)
- The U.S. should have a sufficient supply to PB to initiate therapy in persons with a detectable internal contamination after at least one maximum credible RDD (~100 kCi) or 4-5 large (~10 kCi) RDDs of Cs-137.

- PB reduces the biological half-life of cesium in the body from about 80 days in adults, to 30 days. Hence, between half to two-thirds (at most) of the likely internal dose could be avoided by its continued use over several months.

- Following the conclusions noted, DHHS recommended the U.S. Government to acquire PB for the Strategic National Stockpile to treat 100,000 adults (3x per day for 10 days) including the needs of DOD and VA. Cost would be ~$25M.

NCRP (2001) made their own estimates of gamma whole-body oses that might be received by improvised nuclear explosions

Approximate distance (m) over which a 4 Gy dose from prompt radiation might be received

Yield (kt)	Distance (m)
0.01	250
.1	460
1	790
10	1,200

How many people might live within a radius of 460 m?

Answer: About 6,000 in NYC, however, note that the average rush hour density of people in Times Square is about 30x the living density. Special events, e.g., New Year's Eve would exceed even the rush hour density by many times.

Additional NCRP calculations

Residual Absorbed Dose (Gy) in 1st hour after detonation

Yield (kt)	1,000 m	2,000 m	10,000 m
0.01	6.7	1.5	0.02
.1	38	8.3	0.1
1	210	47	0.6
10	1,200	260	3.5

WHAT MIGHT TERRORIST'S BE CAPABLE OF?

The Federation of American Scientists studied three different terrorist scenarios (http://www.fas.org/faspir/2002/v55n2/dirtybomb.htm):

1. A dirty bomb explosion involving Cs-137 (beta and medium energy gamma emitter) near the U.S. Capitol.

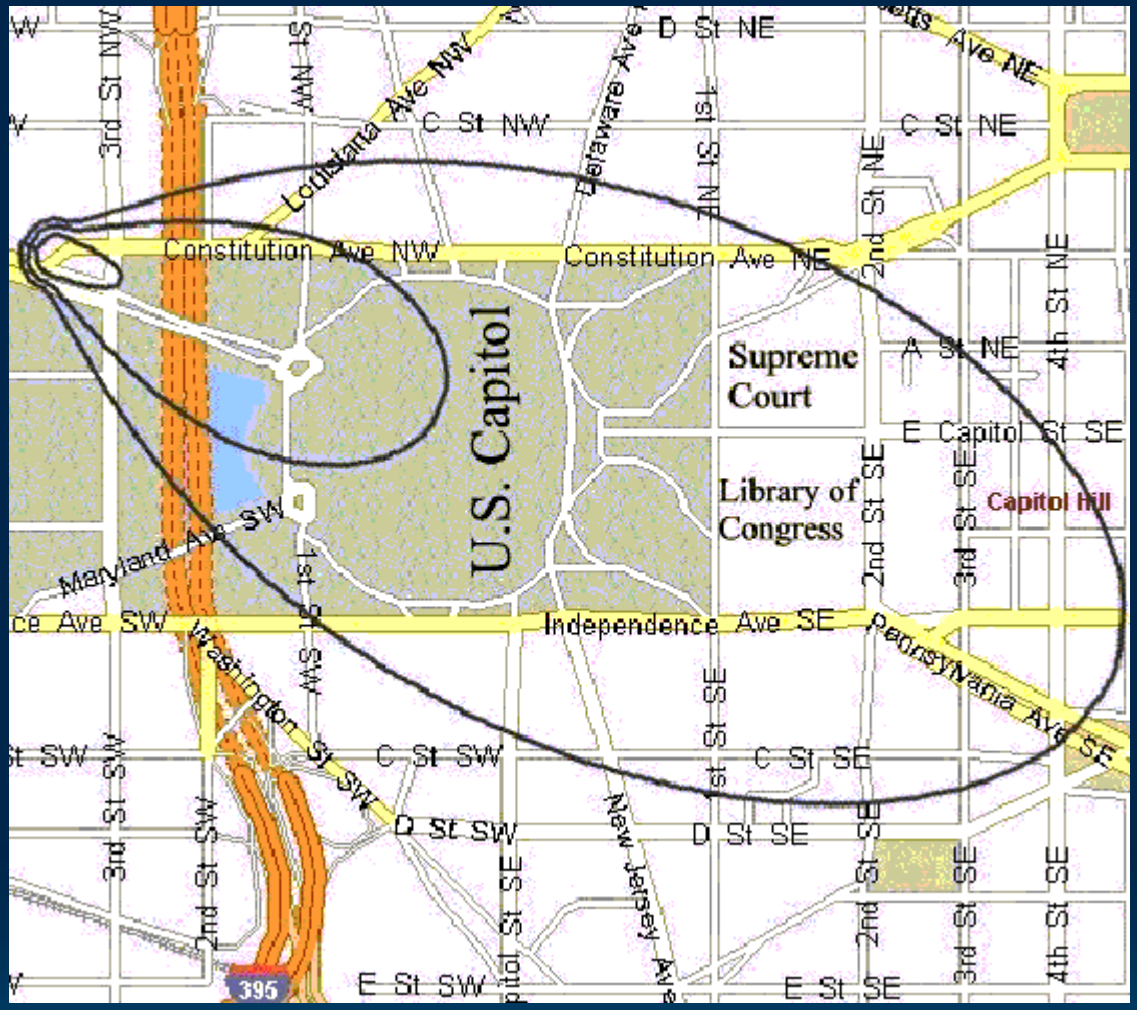
2. A dirty bomb explosion involving Co-60 (beta and higher energy gamma emitter) in Manhattan.

3. A dirty bomb explosion involving Am-241 (primarily an alpha emitter) in Manhattan.

The report of these calculations did not provide with dose levels or give exact source activity strengths, but each scenario shows the potential for modest increases in health risks and immense economic damage.

Cs-137 Dirty Bomb (Washington, DC)

- Lost medical guauge of the type actually lost in North Carolina in 2002.
- Passing of cloud would no necessitate evacuation.
- About 40 city blocks contamined above EPA contamination limits.



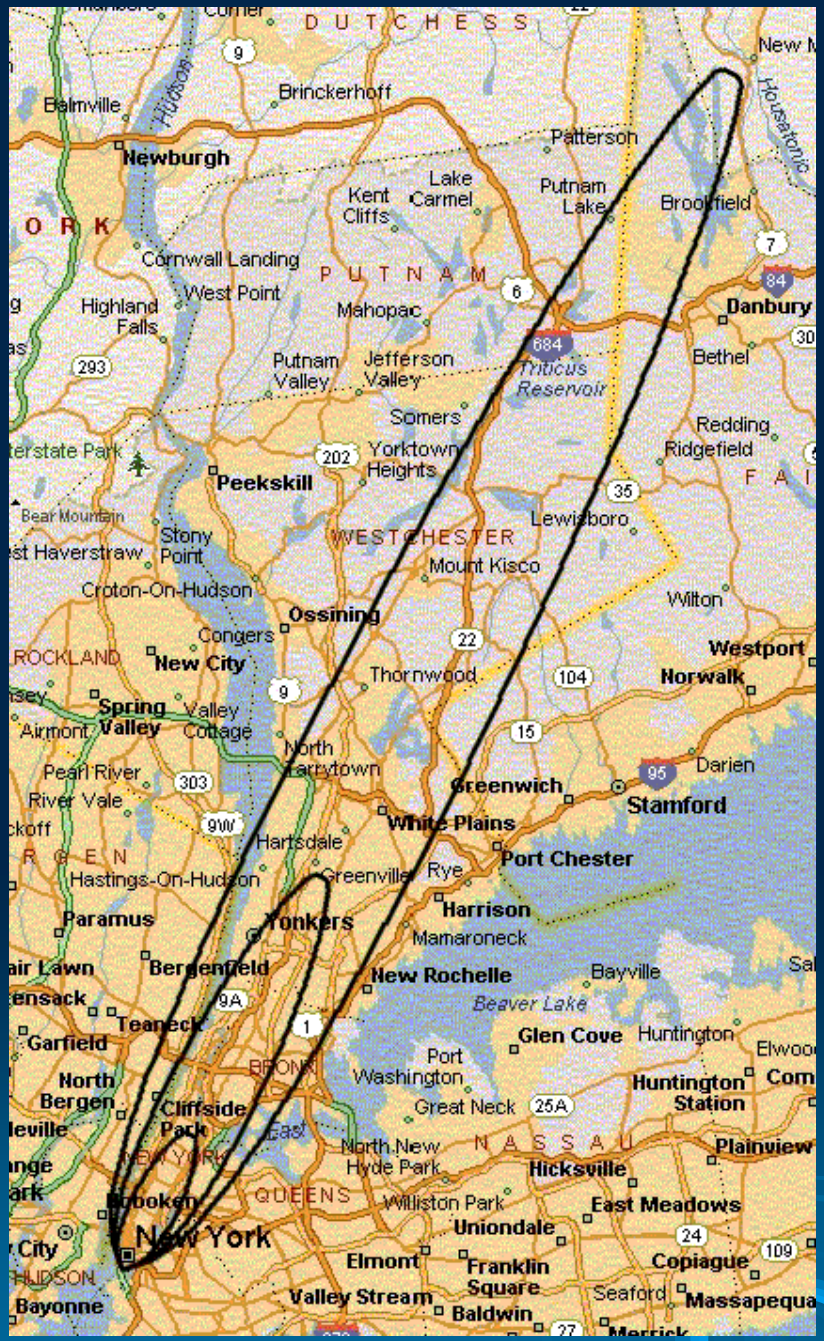
Inner Ring: One cancer death per 100 people due to remaining radiation

Middle Ring: One cancer death per 1,000 people due to remaining radiation

Outer Ring: One cancer death per 10,000 people due to remaining radiation
EPA recommends decontamination or destruction

Co-60 Dirty Bomb (NYC)

- Assumed a single source similar to those which are used by the hundreds in a food irradiation facility (source size is about 1” diamater, 1 ft. long)
- No immediate evacuation required.
- In an area of about 300 city blocks, the additional cancer burden would be projected to be 1 in 10 for 40 years.

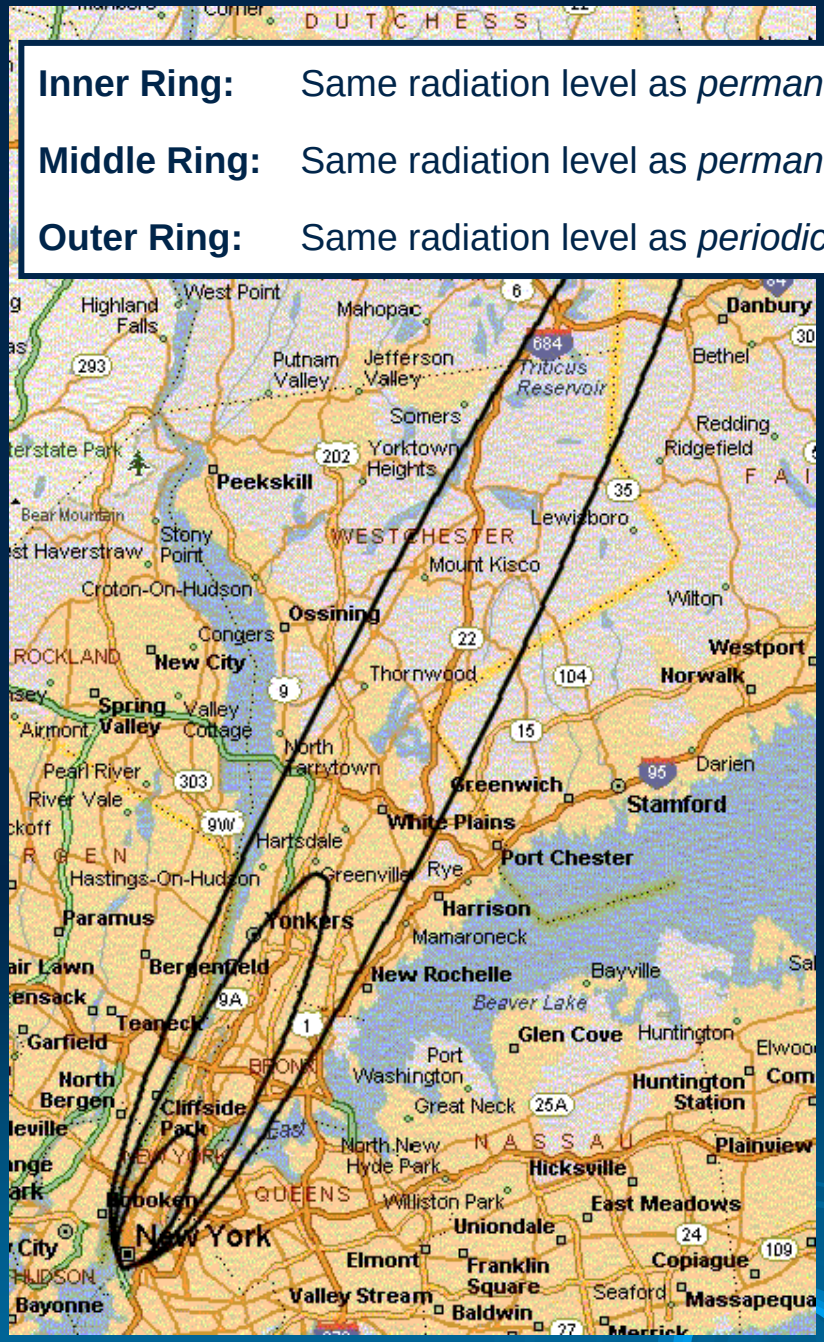


Inner Ring:	One cancer death per 100 people due to remaining radiation
Middle Ring:	One cancer death per 1,000 people due to remaining radiation
Outer Ring:	One cancer death per 10,000 people due to remaining radiation EPA recommends decontamination or destruction

Inner Ring: Same radiation level as *permanently closed* zone around Chernobyl

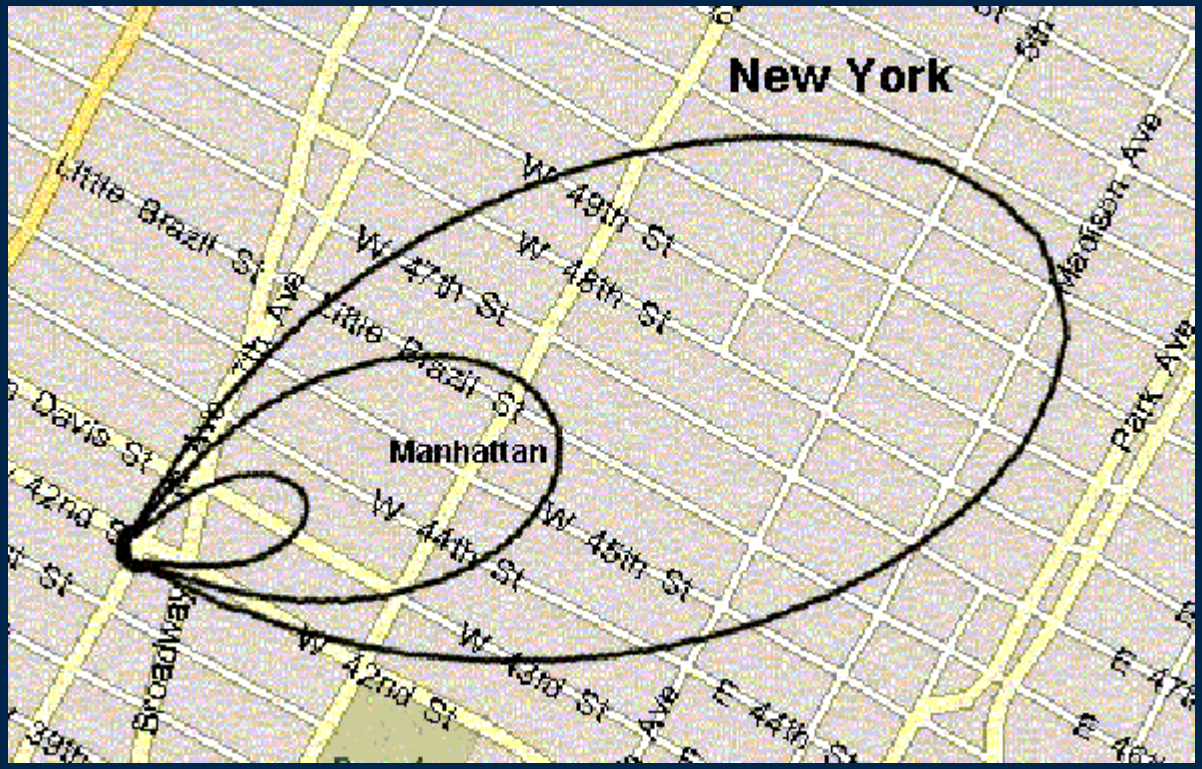
Middle Ring: Same radiation level as *permanently controlled* zone around Chernobyl

Outer Ring: Same radiation level as *periodically controlled* zone around Chernobyl



Am-241 Dirty Bomb (NYC)

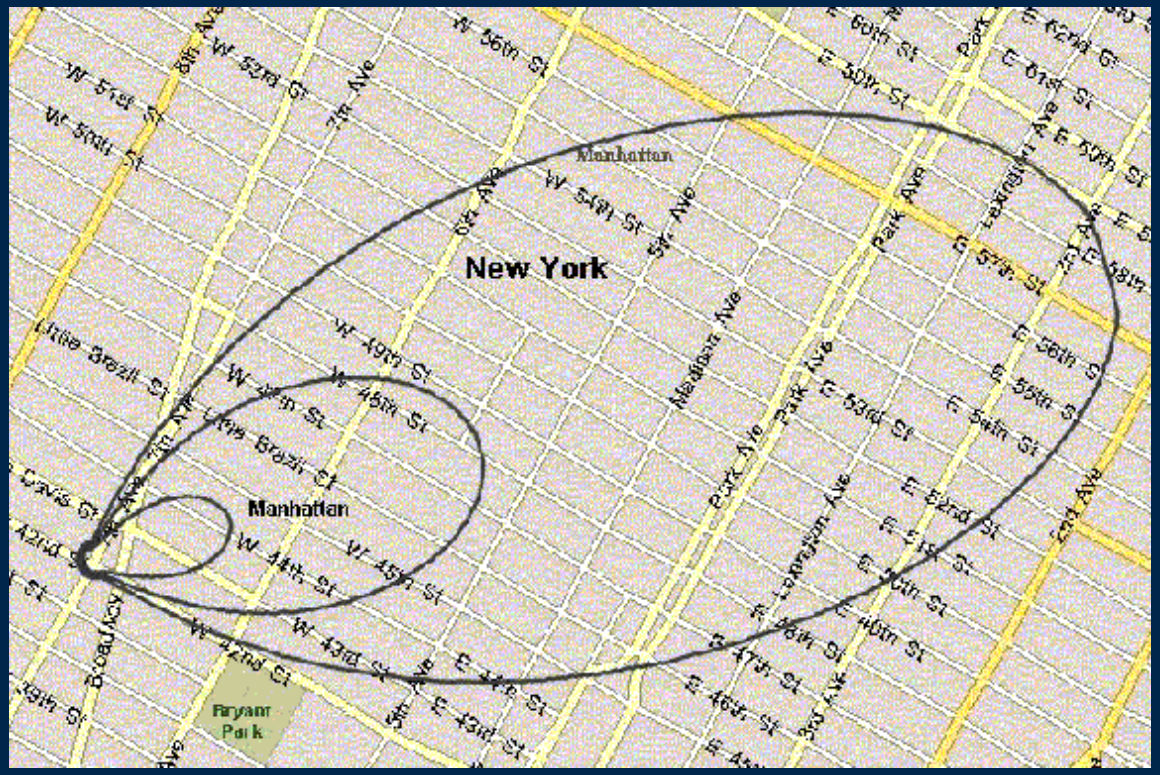
- Am-241 is an alpha emitter, but also has a low energy gamma ray.
- Calculations assumed a single source used in oil well surveying. One pound of TNT used as explosive.
- An area 2 km long (60 city blocks) would be contaminated above EPA guidelines. If decontamination required demolishing buildings, cost would exceed $50B.



Inner Ring: All people must receive medical supervision

Middle Ring: Maximum annual dose for radiation workers exceeded

Outer Ring: Area should be evacuated before radiation cloud passes



Inner Ring: One cancer death per 100 people due to remaining radiation

Middle Ring: One cancer death per 1,000 people due to remaining radiation

Outer Ring: One cancer death per 10,000 people due to remaining radiation
EPA recommends decontamination or destruction

FAS CONCLUSIONS

- Radiological attacks constitute a credible threat.
- Radioactive materials that could be used for such attacks are stored in thousands of facilities around the US, many of which may not be adequately protected against theft by determined terrorists.
- Some of this material could be easily dispersed in urban areas by using conventional explosives or by other methods.
- While radiological attacks would result in some deaths, they would not result in the hundreds of thousands of fatalities that could be caused by a crude nuclear weapon.
- Attacks could contaminate large urban areas with radiation levels that exceed EPA health and toxic material guidelines.
- Contamination of areas the size of tens of city blocks at a level that might require prompt evacuation and would undoubtedly create terror in large communities even if radiation casualties were low.

COULD TERRORIST'S DEVELOP AND DETONATE A NUCLEAR WEAPON (not just a dirty bomb?)

(a) Plutonium needed to make a bomb:

- 4 kilograms: Weight of a solid sphere of plutonium just large enough to achieve a critical mass with a beryllium reflector. Diameter of such a sphere: 2.86 in (7.28 cm). Diameter of a regulation baseball: 2.90 in (7.36 cm).
- 4.4 kilograms: Estimated amount used in Israel's fission bombs.
- 5 kilograms: Estimated amount needed to manufacture a first-generation fission bomb today.
- 6.1 kilograms: Amount used in "Trinity" test in 1945 and in the bomb dropped on Nagasaki.
- 15 kilograms: Weight of a solid sphere of plutonium just large enough to achieve a critical mass without a reflector. Diameter of such a sphere: 4.44 in (11.3 cm). Diameter of a regulation softball: 3.82 in (9.7 cm).

Data from Wisconsin Project on Nuclear Arms Control

TRACKING WEAPONS OF MASS DESTRUCTION
the RISK REPORT

(b) Plutonium generated by various reactors:

- 5.5-8 kilograms/year: North Korea's 20-30 megawatt (thermal) Yongbyon reactor moderated by graphite.
- 12 kilograms/year: Pakistan's 50 megawatt (thermal) Khushab reactor moderated by heavy water.
- 9 kilograms/year: India's 40 megawatt (thermal) Cirus reactor moderated by heavy water.
- 25 kilograms/year: India's 100 megawatt (thermal) Dhruva reactor moderated by heavy water.
- 40 kilograms/year: Israel's more than 100 megawatt (thermal) Dimona reactor moderated by heavy water.
- 230 kilograms/year: Iran's 1,000 megawatt (electric) Bushehr reactor supplied by Russia and moderated by ordinary water.
- 230 kilograms/year: North Korea's 1,000 megawatt (electric) power reactor to be supplied by a consortium sponsored by the United States and moderated by ordinary water.

(a) Uranium-235 needed to make a bomb:

- 15 kilograms: Weight of a solid sphere of 100 percent uranium-235 just large enough to achieve a critical mass with a beryllium reflector. Diameter of such a sphere: 4.48 in (11.4 cm). Diameter of a regulation softball: 3.82 in (9.7 cm).
- 16 kilograms: Amount needed for an Iraqi bomb design found by UN inspectors.
- 50 kilograms: Weight of a solid sphere of 100 percent uranium-235 just large enough to achieve a critical mass without a reflector. Diameter of such a sphere: 6.74 in (17.2 cm), comparable to an average honeydew melon.
- 60 kilograms: Reported amount used in Hiroshima bomb "Little Boy."

What size might we expect terrorists to be able to develop, steal, or successfully detonate? Remember these data…

Yield (kt)	1,000 m	2,000 m	10,000 m
0.01	6.7	1.5	0.02
.1	38	8.3	0.1
1	210	47	0.6
10	1,200	260	3.5

Some insight to that question might be gained from reviewing the specifications of the a-bombs used in Japan.

Weight: 9,700 lbs
Length: 10 ft.; Diameter: 28 in.
Fuel: Highly enriched uranium; "Oralloy"
Uranium Fuel: approx. 140 lbs; target - 85 lbs and projectile - 55 lbs
Efficiency of weapon: poor
Approx. 1.38% of the uranium fuel actually fissioned
Explosive force: 15,000 tons of TNT equivalent

Weight: 10,800 lbs
Length: 10 ft 8 in.; Diameter: 60 in.
Fuel: Highly enriched plutonium 239
Plutonium Fuel: approx. 13.6 lbs; approx. size of a softball
Plutonium core surrounded by 5,300 lbs of high explosives; plutonium core reduced to size of tennis ball
Efficiency of weapon: 10 times that of Little Boy
Approx 1.176 Kilograms of plutonium converted to energy
Explosive force: 21,000 tons of TNT equivalent

Can we protect ourselves?

How would you recognize a “dirty bomb”?

June 13, 2003. Thai police officers made an arrest in the parking lot of a Bangkok hotel after a man offered to sell agents a metal container that he said contained uranium. The seller told police he expected to be paid $240,000.

An analysis of the material later revealed it was not uranium but cesium-137…

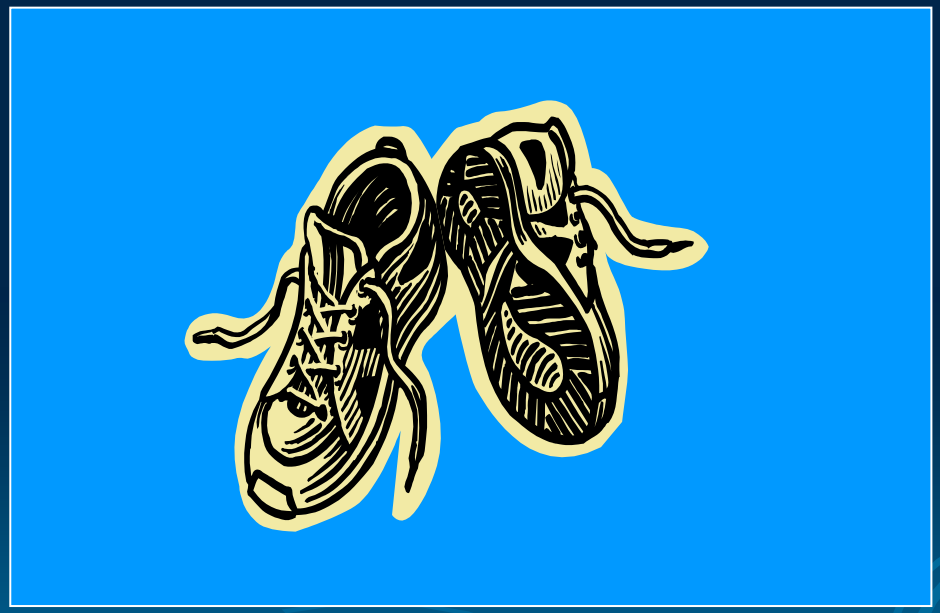
Since protection against radiation can be are maximized by:

Decreasing time of exposure

Maximizing distance between you and the source

Increasing shielding (probably less practical than the others),

One of the protective best tools you might considering having on hand would be **good shoes** to immediately leave the area.



There are many other, often dubious, tools for the fearful.

MY OWN VIEWS

- Possible terrorist actions involving radioactive materials and/or radiation will open few epidemiologic research opportunities, but undoubtedly, if there are such terrorist events, speculation about health effects will continue for many, many, years.

- The value of epidemiology will include helping to convey an understanding of the possible short and long-term health consequences.

- Compensation will likely be demanded.

- There will be tremendous economic loss for a variety of reasons.

- The public's fear of radiation will increase in an unprecedented way.

Remember…radiation can cause more than cancer…