Keys to Initiating Clinical Care in Radiological Emergencies

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Abstract

Keys to Initiating Clinical Care in Radiological Emergencies

When compared to other emergency situations, radiation overexposure events are relatively rare events, so many clinicians may not be experienced in the treatment these victims. Regardless of whether a radiological event was intentional (e.g. terrorism) or accidental, appropriate medical care is generally predicated by the dose delivered. But the clinician may not be equipped to estimate this dose. Conversely, a health physicist (radiation safety professional) can help with estimating the dose, but may not be knowledgeable of the appropriate medical interventions. To address this predicament, this presentation will:

- Describe the main types of overexposure events
- Identify the information needed to estimate the radiation dose received
- Provide examples of dose reconstruction calculations for the main types of overexposure scenarios
- Describe how this information impacts the medical tests and procedures to be applied
- Review the regulatory reporting requirements in cases of radiation overexposure
- Discuss the emerging issue of possible acts of domestic nuclear terrorism
- Provide a list of useful web and text references

Learning Objectives

- Describe the main types of overexposure events based on a 45 yr review of case reports in Texas
- Review the regulatory reporting requirements in cases of radiation overexposure
- Identify the information needed to estimate the radiation dose received
- Provide examples of dose reconstruction calculations for the main types of overexposure scenarios
- Describe how this information impacts the medical tests and procedures to be applied
- Identify resources for further assistance
- Discuss the emerging issue of possible acts of domestic nuclear terrorism
- Provide a list of useful web and text references

Radiation Uses

- Sources of radiation are used to society's benefit in a number of industries
  - Manufacturing, construction, medicine, safety
- Like combustion, electricity, and high pressures, when used appropriately, can be very safe, but if misused, can result in harm

Possible Radiation Effects

- Acute (immediate) and chronic (long term) effects
- Acute effects
  - <100 rem
    - no immediate effects
  - 100-200 rem
    - Mild nausea, vomiting
    - Loss of appetite
    - Malaise, fatigue
  - 200-400 rem
    - Nausea universal
    - Hair loss
    - Diarrhea, fatigue
    - Hemorrhages in mouth, subcutaneous tissues, kidneys

Radiation Effects

- Acute effects (con't)
  - 400-600 rem
    - Mortality probability 50%
  - 600-1,000 rem
    - Bone marrow destroyed
    - GI tract affected
    - Internal bleeding
    - Survival dependant upon prompt medical intervention
  - >1,000 rem
    - Rapid cell death
    - Internal bleeding, fluid loss
    - Death likely within hours

Radiation Effects

- Chronic effects
  - Possible effects on immune system
  - Possible increased risk of cancer (estimates vary with rate of delivery of dose. For acutely delivered doses, 1×10^{-3} increased cancer fatalities per rem)
  - Possible damage to reproductive systems can result in mutations passed on to subsequent generations
  - Psychological effects

The Basic Problem

- In cases of radiation exposure events, the recurrent question will always be: *what is the dose?*
  - A health physicist can help with estimating the dose – but do they have an understanding of the medical procedures to be dictated?
  - A physician can provide medical care – but do they have an understanding of radiation exposure issues?

Annual Radiation Dose Limit Primer

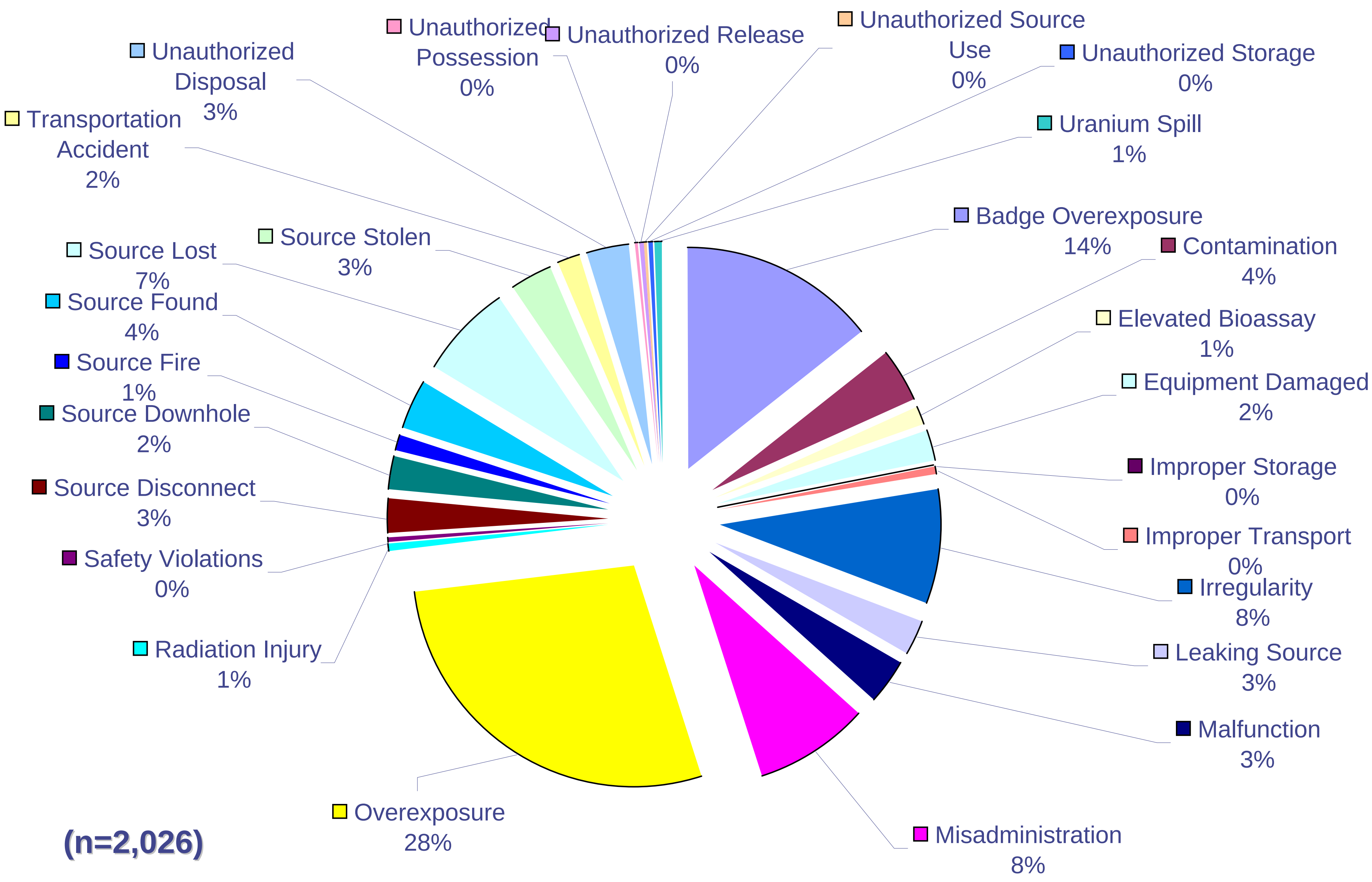
- Occupationally exposed individuals
  - 5 rem to the whole body
  - 50 rem to skin and extremities
  - 15 rem lens of eye
- Occupationally exposed minors
  - 0.5 rem
- Occupationally exposed embryo/fetus
  - 0.5 rem for the gestation period
- General public 0.1 rem
- Note: limits for total dose from sources external and internal to body

Overexposure Reporting Requirements

Area affected	24 hour notification	Immediate notification
Whole body	>5 rem	>25 rem
Lens of eye	>15 rem	>75 rem
Skin, extremities, organ	>50 rem	>250 rad

Summarized from 25 TAC 289.202 (xx)

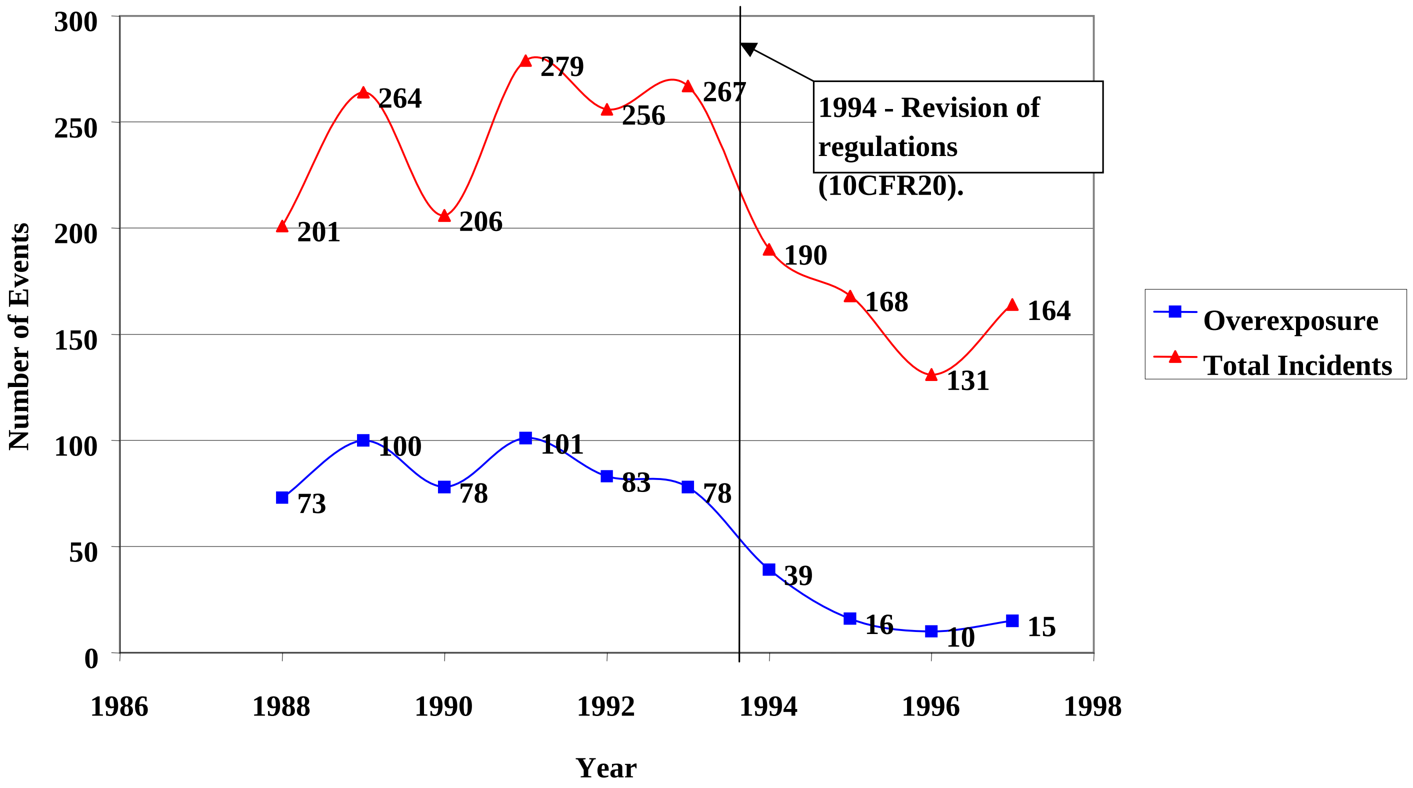
Summary of Reported Incidents in Texas from 1988-1997



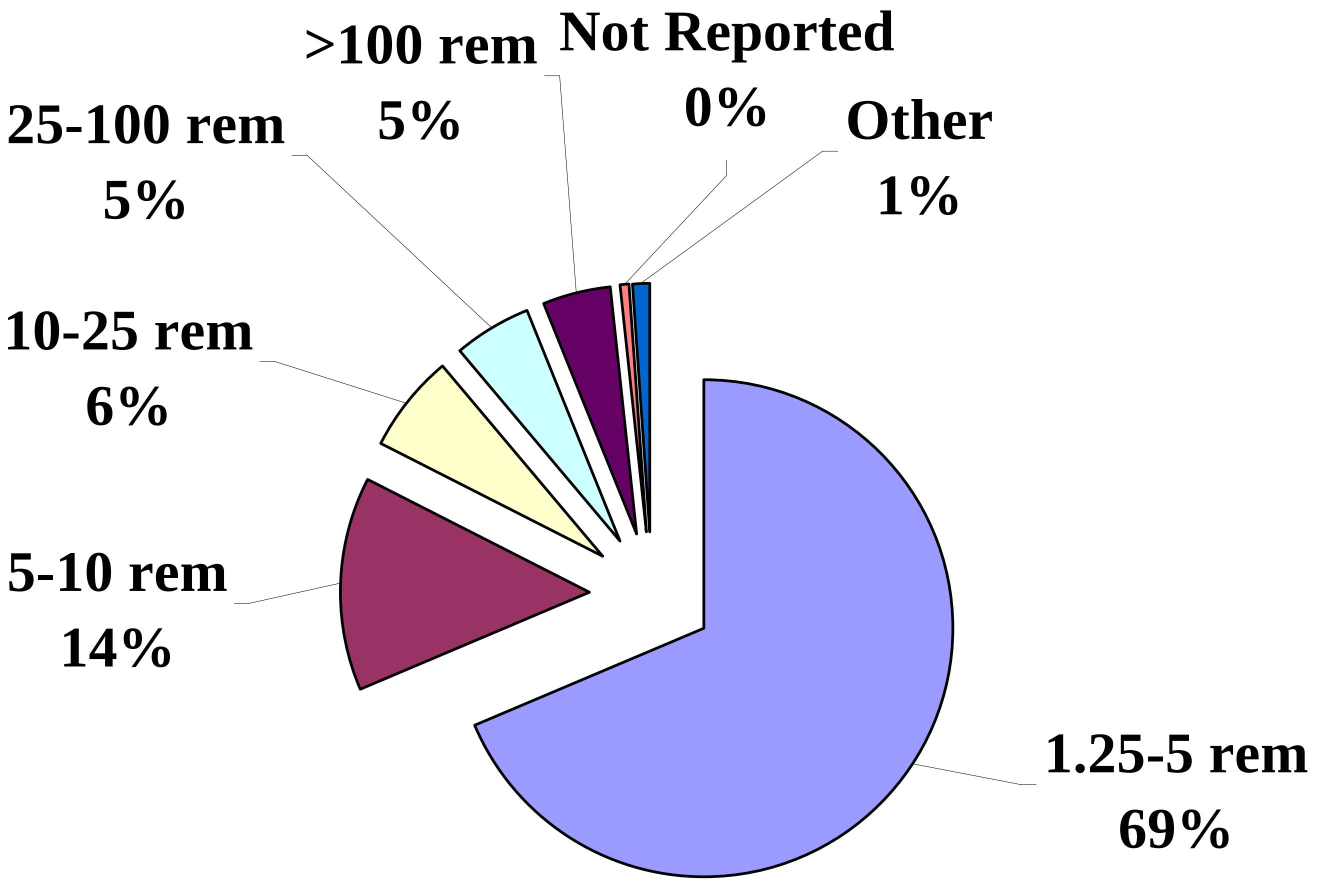
(n=2,026)

Reported Incidents in Texas 1988-1997 (n = 2,126)

Figure 2: Summary of overexposure and total incidents reported to the Texas Department of Health, Bureau of Radiation Control from 1988 to 1997.



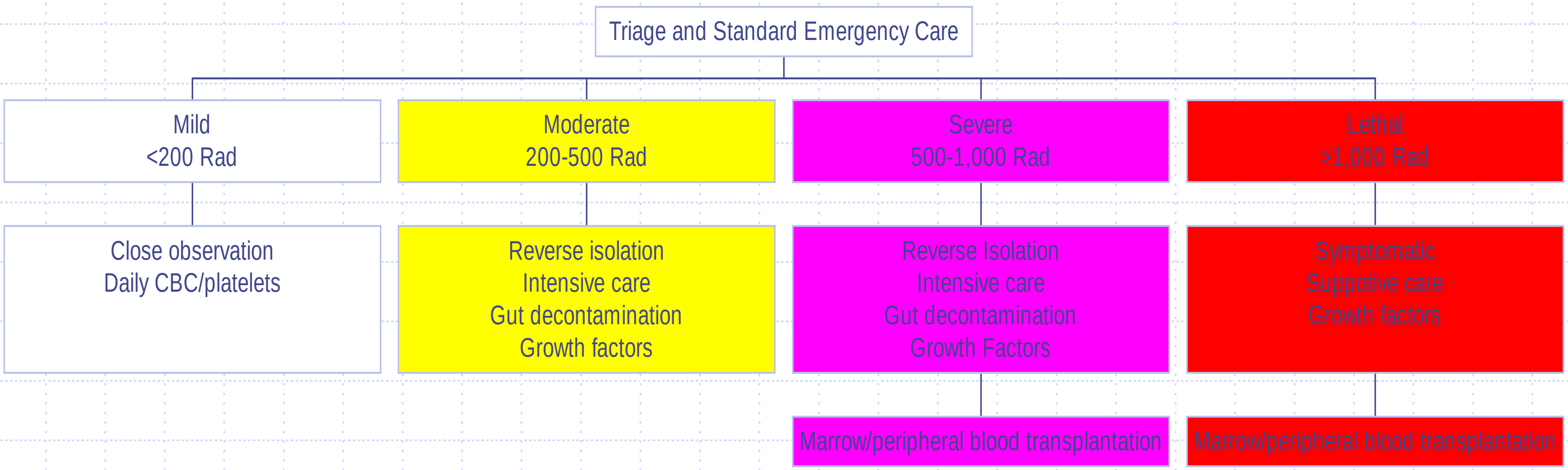
Results by Total Dose



Medical Decisions Based on Dose

(whole body dose, not considering localized doses, such as to hands or feet)

Consensus Summary on the Treatment of Radiation Injuries



Advances in the Biosciences, Vol.94 pp. 325-346, 1994 Elsevier Sciences Ltd. Great Britain

Information Needed

- In the absence of personal dosimetry or portable survey instrument measurements, the following is needed to develop some estimate of the dose:
  - Isotope (or source)
  - Activity (or strength)
  - Exposure configuration (hand, pocket, distance, inhalation?)
  - Duration
  - Source containments (sealed or unsealed)
- Key point – how accurate do you need to be?

Four Overexposure Configurations

- Gamma external to whole body
- Neutron source external to whole body
- Beta skin dose
- Inhalation

Gamma Sources

- Common sources
  - Cs-137
  - Co-60
  - Ir-192

  - (note –these sources accounted for 60% of all the overexposures examined in Texas, and are likely contaminants for “dirty bombs”)

Worker holds 100-Ci Cs-137 source for 15-min

- By thumb rule 6CEN/d^2:

$$6 \times 100 \times 0.6616 \times 0.85 / (1\,ft)^2 = 774\text{rad}\left(\pm 20\%\right)$$

- By Specific Exposure Rate Constant (Γ):

$$0.33 \, {R\,m^2}\big/{h\,Ci} \times {100Ci}\big/{(0.1m)^2} \times {0.955rad}\big/{R} \times 0.25h$$

$$= 788rad$$

  - This assumes that the source was held 0.1m (approx. 4in) from body. You would use the same formulation as above for the “on contact” reading of the hand, but assume something like 1mm, 1cm, or 0.5in for the distance.
  - Discussion item: what health effects might you expect, and over what time period, for such a dose scenario?

Neutron Sources

- Common *isotopic* sources
  - PuBe
  - AmBe
  - PoBe

Worker places 5-Ci AmBe source in chest pocket for 60 min

- RHH Rule-of-Thumb (IAEA 1979) states that the neutron fluence rate divided by 7000 gives an approximation for the dose equivalent rate:

$$H\left({rem}/{h}\right) \approx \frac{\phi\left(\frac{n}{cm^2 s}\right)}{7000}$$

- A 5-Ci AmBe source emits approx. 1.3E6 neutrons per cm^2 per s at 1cm (assumed for on-contact):

$$H = 1.3E6 \, {n}/{cm^2 s} \div 7000 \approx 186 \, {rem}/{h}$$

Worker places 5-Ci AmBe source in chest pocket for 60 min (con't)

- Another, more involved method includes a "first collision approximation:"

$$\dot{D} = \sum_{1}^{n} \phi(E_n) \times E_n \times \sum_{i1}^{in} \left(N_i \sigma_i (E_n) f_i \right) \left({}^{Gy}\!/\!_{s} \right)$$

  - This approximation overestimates the dose of the first collision by forcing each (elastic) collision to result in the transfer of one-half the neutron kinetic energy. This overestimation is then offset because each neutron only undergoes one collision.

Worker places 5-Ci AmBe source in chest pocket for 60 min (con't)

- With a 5-Ci AmBe source, at a distance of 1-cm, in contact for one hour, for a reference energy spectrum (Gollnick), this method gives, for the 0.26-MeV energy bin example:

♐	E (MeV)	E (J)	Element	% Mass	N (atoms/k	f	♦(barns)	N♦f
1.56E+05	0.26	4.2E-14	O	71.39	2.69E+25	0.111	3.63	1.08E+01
			C	14.89	6.41E+24	0.142	3.75	3.41E+00
			H	10	5.98E+25	0.5	8.5	2.54E+02
			N	3.47	1.49E+24	0.124	3.25	6.00E-01
			Na	0.15	3.93E+22	0.08	3.128	9.83E-03
			Cl	0.1	1.70E+22	0.053	1.701	1.53E-03
								Sum
		Dose Rate (tissue, rad		run (hour	Total Dose (Rads)			2.69E+02
		1.75E-04		1	6.29E-01			

- Discussion: why is neutron dose estimation so difficult? Hint: How do scattering and absorption cross-sections change with neutron kinetic energy?

Worker places 5-Ci AmBe source in chest pocket for 60 min (con't)

- Summing over all energy bins in the assumed AmBe distribution:

	E	Fractional E	Dose rate (rad/s)	
	0.1	0.005	4.06E-05	
	0.13	0.007	6.95E-05	
	0.17	0.007	8.15E-05	
	0.2	0.01	1.28E-04	
	0.26	0.012	1.75E-04	
	0.34	0.013	2.20E-04	
	0.42	0.015	3.13E-04	
	0.5	0.017	3.53E-04	
	0.65	0.018	4.18E-04	
	0.825	0.02	5.32E-04	
	1	0.023	7.40E-04	
	1.33	0.027	9.53E-04	
	1.67	0.03	1.08E-03	
	2	0.042	1.64E-03	
	2.6	0.058	2.50E-03	
	3.4	0.098	5.19E-03	
	4.2	0.135	7.47E-03	
	5	0.158	9.16E-03	
	6.5	0.145	8.36E-03	
	8.25	0.135	8.37E-03	
	10	0.04	2.57E-03	
	13.3	0.005	3.52E-04	
Total Dose Rate (rad/s)			5.07E-02	
	Total in rad/hr		1.83E+02	

- Approx. 183 rad in 1 hour

  - Discussion: What would you do if there were an appreciable thermal component to the AmBe source spectrum?

Beta Sources

- Common sources
  - H-3
  - C-14
  - P-32
  - S-35
  - Ca-45

Lab tech spills 250μCi of P-32 on skin

- Rule of thumb: for beta particles energies >0.6-MeV, dose rate through the skin is 9rad/h per 1μCi/cm^2:

$$9\left(\frac{rad}{h} \Big/ \frac{\mu Ci}{cm^2}\right) \times \frac{250\,\mu Ci}{10 cm^2} \times 0.5\text{h} = 112.5\text{rad}$$

  - This assumes 0.5h elapses until worker is completely decontaminated and that the contaminated area amounted to 10 cm^2.

Lab tech spills 250μCi of P-32 on skin (con't)

- Beta particles are observed to decrease exponentially (approximate) in traversing matter, in spite of their being *directly ionizing* radiation, because:
  - All electrons follow a tortuous path in matter due to their small mass, and
  - Betas are "born" over a spectrum of kinetic energies.

Lab tech spills 250μCi of P-32 on skin (con't)

- This fact enables us to make use of an empirical approximation for a beta interaction coefficient*:

$$\mu_{\beta,air} = 16\left(T_{\max} - 0.036\right)^{-1.4}\left({cm^2}/{g}\right)$$

$$\mu_{\beta,tissue} = 18.6\left(T_{\max} - 0.036\right)^{-1.37}\left({cm^2}/{g}\right)$$

*Cember 1996

Lab tech spills 250μCi of P-32 on skin (con't)

- This "beta-ray absorption coefficient" may be used to determine on-contact skin dose:

$$\dot{D}_\beta\left({}^{Gy}\!/_{h}\right)=\left({}^{Bq}\!/_{cm^2}\times{}^{tps}\!/_{Bq}\times 0.5\times T_{avg}\,{}^{MeV}\!/_{t}\times 1.6E-13\,{}^{J}\!/_{MeV}\right.$$

$$\left.\times\,\mu_{\beta,tiss}\left({}^{cm^2}\!/_{g}\right)\times 3.6E3\,{}^{s}\!/_{h}\times e^{-\mu_{\beta,tiss}\times 0.007}\right)\div\frac{0.001\frac{J}{g}}{Gy}$$

  - This assumes half of the beta particles are directed into the skin, the remainder into surrounding air. This also assumes that a depth of 0.007g/cm^2 is the critical depth for the basal layer of skin.

Lab tech spills 250μCi of P-32 on skin (con't)

- Evaluating for P-32 (T_{max}=1.71-MeV, T_{avg}=0.7-MeV), at 250μCi over 10cm^2 spill area:

$$\mu_{\beta,tissue} = 18.6(1.71 - 0.036)^{-1.37}\left({cm^2}/{g} \right) = 9.18$$

$$\dot{D}_\beta\left({Gy}/{h} \right) = \Bigg({9.25E5Bq}/{cm^2} \times {tps}/{Bq} \times 0.5 \times 0.7\,{MeV}/{t} \times 1.6E-13\,{J}/{MeV}$$

$$\times 9.18\left({cm^2}/{g} \right) \times 3.6E3\,{s}/{h} \times e^{-9.18\times 0.007} \Bigg) \div {0.001\frac{J}{g}}/{Gy} = 1.605\,{Gy}/{h}$$

Lab tech spills 250μCi of P-32 on skin (con't)

- If we integrate this dose rate over the time that *any* activity remains on the person we have a conservative estimate of the skin dose. For example, using our previously calculated skin dose rate and assuming that contamination is completely removed within one-half hour of the occurrence:

$$D_T = \frac{\dot{D}_o}{\lambda}\left(1 - e^{-\lambda t}\right) = \frac{1.605\left(Gy/h\right)}{2.02E-3\left(h^{-1}\right)}\left(1 - e^{-2.02E-3\times 0.5}\right)$$

$$= 0.802Gy(skin) \cong 80rad$$

Lab tech spills 250μCi of P-32 on skin (con't)

- If we use the previous formula normalized to an areal activity of 1 Bq cm^{-2}, we can calculate a dose conversion factor (DCF) for any beta emitting nuclide, which may then be used at any time in the future (like a Γ, but for beta skin contamination):

$$DCF\left(\frac{\frac{Gy}{h}}{\frac{Bq}{cm^2}}\right) = \left[\left({}^{tps}/_{Bq} \times 0.5 \times T_{avg}\ {}^{MeV}/_{t} \times 1.6E-13\ {}^{J}/_{MeV} \times \mu_{\beta,tiss}\left({}^{cm^2}/_{g}\right) \times 3.6E3\ {}^{s}/_{h} \times e^{-\mu_{\beta,tiss}\times 0.007}\right) \div \frac{0.001\frac{J}{g}}{Gy}\right]$$

  - Discussion: Can we say that $\mu_{\beta,tiss}$ is similar to the μ/ρ we use for photons? μ_{tr}/ρ? μ_{en}/ρ?

Lab tech spills 250μCi of P-32 on skin (con't)

- Another method makes use of a set of tabular conversion factors derived from a complex computational transport model:

$$2.1E-2\left(\frac{Sv}{y}\Big/\frac{Bq}{cm^2}\right)\times 422\left(\frac{rem\ y\ Bq}{Sv\ h\ \mu Ci}\right)=8.862\left(\frac{rem}{h}\Big/\frac{\mu Ci}{cm^2}\right)$$

$$\frac{250\mu Ci}{10cm^2}\times 8.862\left(\frac{rem}{h}\Big/\frac{\mu Ci}{cm^2}\right)\cong 221.55\,{}^{rem}\!/_{h}\ \text{ or }\ 111 rem \text{ in } 0.5h$$

*RHH and Gollnick, after Kocher and Eckerman 1987.

- Discussion: what might be the reason for the difference in results between these two methods?

Worker Inhales 30mCi I-125

- Divide given activity by the stochastic ALI (for WB risk) or non-stochastic ALI (for organ risk):

$$30{,}000\,\mu Ci \big/ 200\,\mu Ci \times 5rem = 750rem\left(WB - CEDE\right)$$

$$30{,}000\,\mu Ci \big/ 60\,\mu Ci \times 50rem = 25{,}000rem\left(\text{thyroid CDE}\right)$$

  - The ALI(NS) is appropriate for the thyroid, rather than the ALI(S), and this is indicated in 289TAC25. These ALIs incorporate intake-to-uptake models, pharmacokinetic models for distribution, all source-target geometries for said models, and all radiative emissions.
  - Approx. 30% of the iodine uptake is incorporated by the thyroid with a 40d *biological* half-life. The remainder circulates throughout the body and is eliminated with a 10d half-life.
  - Discussion: We often use the term “seeker” (e.g., bone seeker, thyroid seeker) to describe a radioactive chemical species – is this bad or good?

Who Do I Call For Assistance?

- California Radiologic Health Branch
  - 916-327-5106
- REAC/TS
  - 423-576-3131
- Radiation Internal Dose Information Center
  - 423-576-3449
- Key reference:
  - Ricks, RC, Berger, ME, O'Hara, F; The Medical Basis for Radiation-Accident Preparedness, Parthenon Publishing Group, New York, 2002

Current Developments: “Domestic Radiological Terrorism”

- Foreseeable terrorist threats involving sources of radiation, in rank order of probability
  - 1. Dirty weapon
    - conventional explosive dispersing radioactive sources
  - 2. Conventional explosive at “nuclear facility”
    - a dispersal event rather than a criticality, or nuclear fission event
  - 3. Tactical nuclear device
    - device capable of criticality, or fission
    - self-built or stolen

Why are "Dirty Bombs" Ranked First?

- Conventional explosives can be obtained from many sources
- Although not as readily available, potential radioactive contamination sources could take several forms:
  - Examples: gauges, testing sources, waste materials
  - (note: sources not necessarily domestic)
- High "population terror" potential, given public's apprehension about radiation
- Of 26 terror acts in US in past 22 years, 17 have involved explosives (www.cdi.org)

Why Aren't Nuclear Facilities Ranked First?

- Commercial nuclear facilities are guarded 24 hrs/day, 365 days/yr by heavily armed, well trained personnel
- Security systems well coordinated with local, state and federal agencies
- Plants occupy sites with buffer zones
- Containment structures quite robust: 4-6 ft concrete, reactor vessels 9-12 inches thick
- Other safety design features

What About Tactical Nuclear Weapons?

- Although small “backpack” devices have been developed, expected use unlikely given difficulties with obtaining, maintaining, and operating such devices
- Nonetheless, in current climate, possibility of use exists, hence some discussion of effects and countermeasures is warranted
- Detonation may not be limited to ground or underground bursts – elevated detonation in highrise building plausible

Conventional Terrorist Explosion: Is It “Dirty”?

- Emergency responders should always perform monitoring at site for various types of radiation emissions
- If radiation detected, establish appropriate exclusion zones, handle casualties accordingly
- Smoke may contain radioactive materials, so respiratory protection necessary
- Secure area
- Notifications for added assistance and controls
- Population doses likely very low

Explosion at a Nuclear Facility

- Examples include a nuclear power facility, radioactive waste site, or nuclear weapons facility
  - Emergency responders would be prepared and expect to perform monitoring at site
  - Many existing monitoring capabilities
  - If release detected, plans enacted, exclusion zones established, notifications made, casualties handled accordingly
  - Monitoring for offsite releases and meteorological conditions
  - Population doses projected to be low given existing controls in place

Nuclear Weapon Detonation

- Assumed to be a single, low yield device (20 kT)
  - Blast – overpressurization, accelerated debris
  - Heat – intense fireball, ignite materials far from center
  - Initial radiation – prompt emission of high radiation levels (EMP)
  - Residual radiation – activation products and contamination, fallout dependant on environmental conditions
  - Crater formation – large amounts of ground displacement
  - Ground shock – disrupt utilities, damage structures

Explosion of a Nuclear Weapon

- Assume a 20 kT ground burst
  - 180 ft radius crater
  - Within ½ mile, 50% population fatalities from debris impact
  - Within 1.8 mile radius, 50% population fatalities from thermal burns
  - Within 1 mile radius, 50% population fatalities from immediate radiation exposures
  - Within 7.7 mile radius, 50% population fatalities from rad exposures in first hour

  - *For purposes of comparison, 40 acres is approximately a circle with a radius of approximately 750 ft*

Emergency Medical Response

- A significant challenge (Hiroshima 20 kT airburst)
  - 45,000 deaths first day, 91,000 injured.
  - of 45 hospitals, only 3 left standing
  - of 298 physicians, only 28 uninjured
  - of 1780 nurses, 1654 were casualties
- On-scene triage: wounds, burns, exposure, contamination
- Radiological assessment of patients with and without immediately observable injuries
- Decontamination
- Pharmacological protection for fallout?

Operational Topic

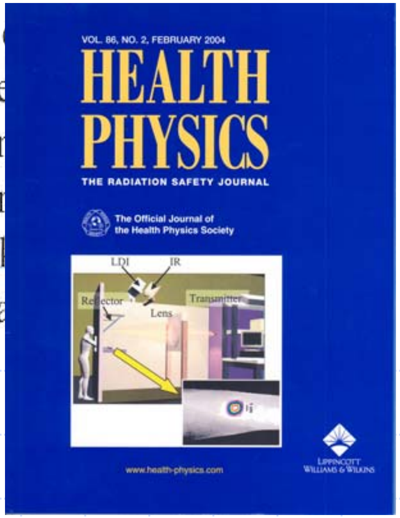
AN ANALYSIS OF 45 YEARS OF REPORTED OVEREXPOSURE INCIDENTS IN TEXAS, 1956 TO 2001

K. Maness,* R. J. Emery,* and D. Casserly†

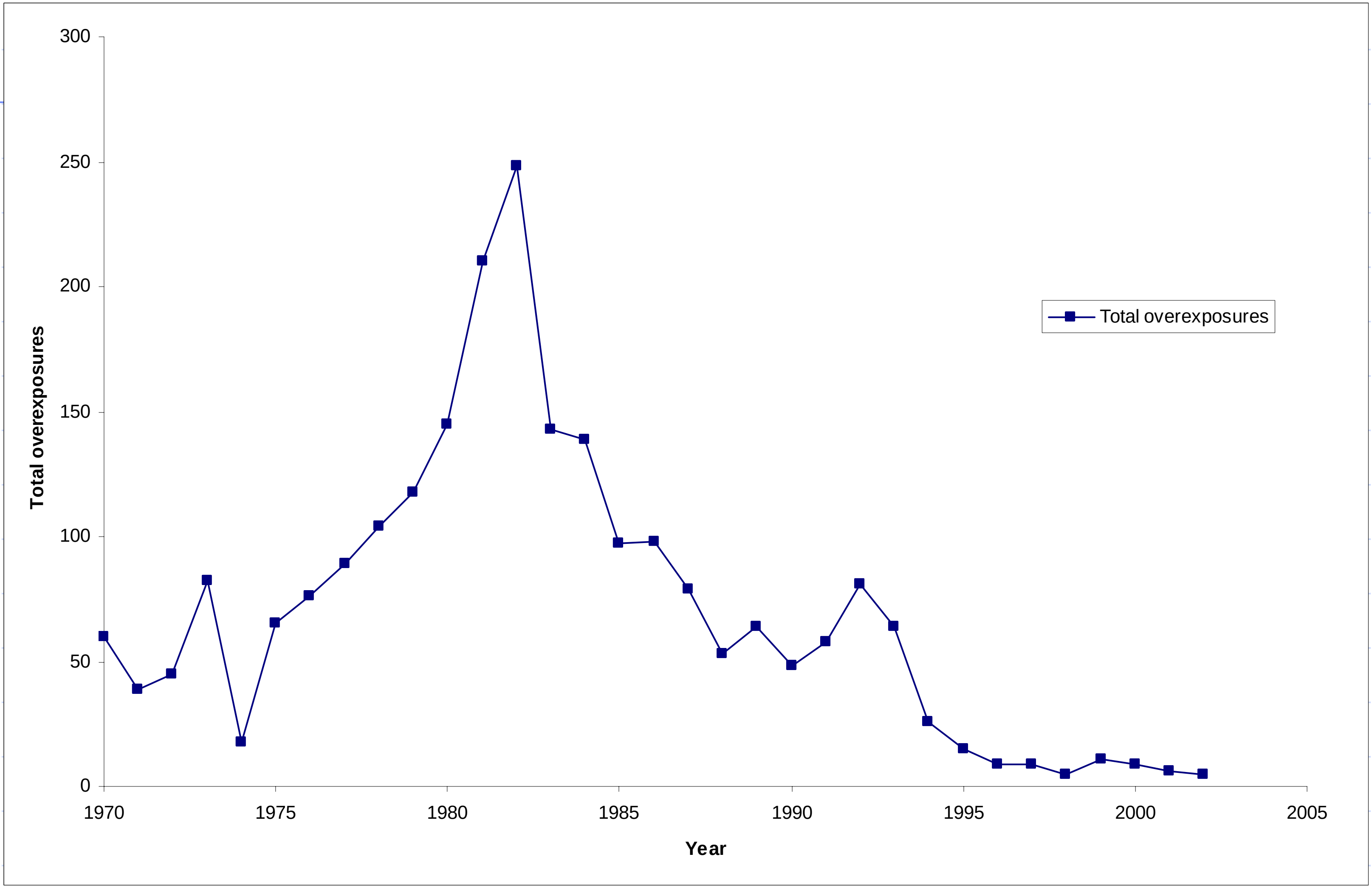
Abstract—Sources of ionizing radiation are commonly encountered in a wide variety of modern work settings. The controls in place to ensure the safe use of these sources have proven to be quite effective, as events involving occupational doses in excess of established limits are quite rare. Nonetheless, instances of doses in excess of established limits, commonly referred to as "overexposures," do occur, but the rarity of such events has resulted in a body of scientific knowledge that consists essentially of sporadic case reports. In this study,

INTRODUCTION

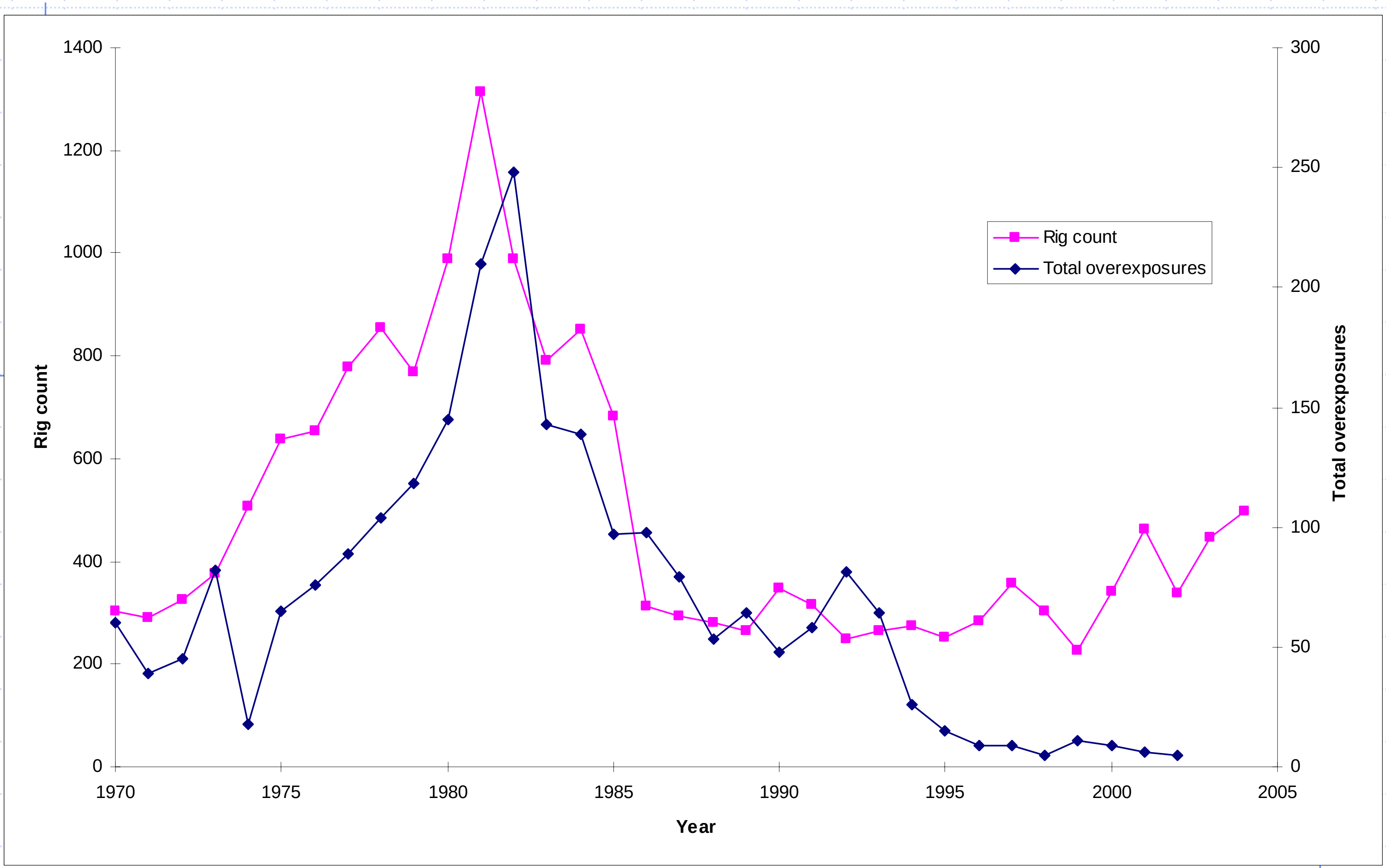
SOURCES OF ionizing radiation
wide variety of modern work se
is used in industrial settings in
medical settings for treatment an
quality control applications. Li
reactions such as combustion a



Total overexposures in Texas, 1970 to 2002



Rig count 1970 to 2004 and Total overexposures 1970 to 2002, in Texas



Summary

- Radiation overexposures are relatively rare events, but do happen
- Medical intervention decisions are based on dose estimations
- To estimate dose, basic information is needed
- The initial estimation need not be extremely accurate
- Remember to always check for contamination – both inside and out
- Given possibility of domestic terrorism, now is the time to begin reviewing response capabilities and procedures –especially the worried well issue
- Keep a watch on rig count – at least in Texas, overexposures are linked to this metric
- Help is out there – so keep the contact information readily accessible

Web References/Resources

- Center for Defense Information available at www.cdi.org/terrorism
- Office of Technology Assessment: *The Effects of Nuclear War*, May 1979, available at www.wws.princeton.edu/cgi-bin/byteser.prl/~ota/disk3/1979/7906/790604.PDF
- Armed Forces Radiobiology Research Institute, available at www.afrri.usuhs.mil
- Texas Division of Emergency Management at www.txdps.state.tx.us/dem/
- Texas Department of Health Bureau of Radiation Control at www.tdh.state.tx.us/ech/rad
- Health Physics Society at www.hps.org
- South Texas Chapter of the Health Physics Society at www.stc-hps.org
- Texas Public Health Training Center at www.txphtrainingcenter.org

Text References/Resources

- NCRP Report No. 138 *Management of Terrorist Events Involving Radioactive Materials,* October 2001. available at www.ncrp.com
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