A Report on the Effects of Radiation in Canines

Summary based on Published Experimental Data

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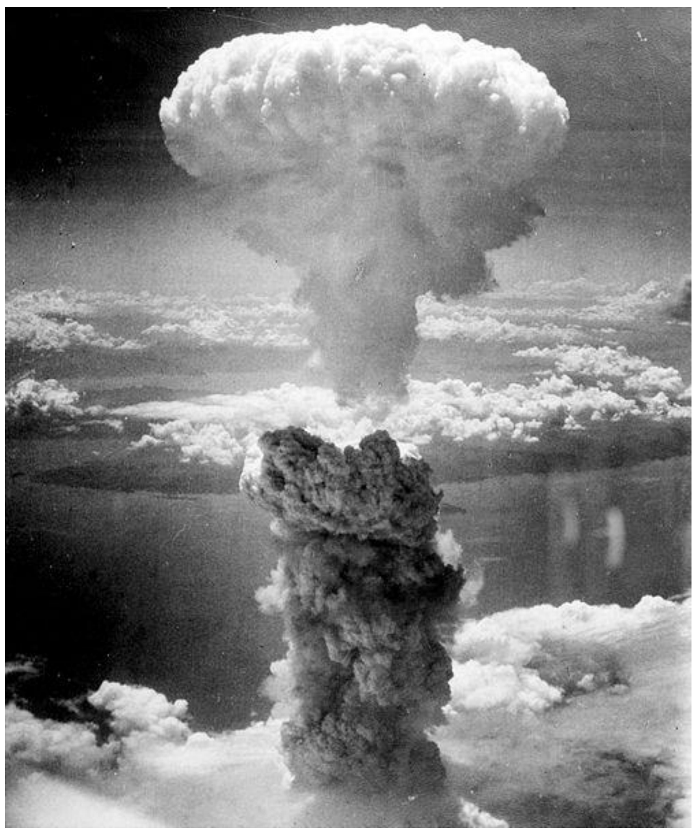

CONTENTS

* Front Cover: Atomic bombing of Nagasaki on August 9, 1945.

INTRODUCTION

This report is intended to summarize various points of scientific study with respect to the effects of radiation on the canine. Excerpts from ten papers are presented as a representative portion of currently available studies for review.

Most of these studies were conducted under controlled conditions with radiation effects produced from specific compounds. The exception to this is Report 10, *Acute Effects of Irradiation on People and Animals from Soviet Underground Nuclear Explosions.* This nuclear detonation experiment more closely resembles a potential field situation, and therefore the findings are of special interest.

Weapons of mass destruction, particularly a nuclear accident or terrorist event, are subjects that evoke tremendous emotional turmoil in the public sector. These substances have been studied in a scientific manner in order to promote safety both pre- and post-event based on factual data. Though search canines are technically a US&R tool, there is a human-animal bond that develops between handler and canine. They are a tool, but also a responsibility. This report attempts to allow for the decision to use search canines in a nuclear event to be based on scientific tenants, yet guided by that responsibility.

Respectfully Submitted,

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* Note: Excerpts highlighted in yellow are of particular interest

RADIATION MEASUREMENT EQUIVALENTS

Rad = radiation absorbed dose
Rem = roentgen equivalent man
R = Roentgen

1 rad ≈ 1 rem ≈ 1 R

Roentgen measures the energy produced by gamma radiation in a cubic centimeter of air

Gray (Gy) is the SI unit of absorbed radiation: 1 Gy = 100 rads ≈ 100 rem ≈ 100 R
1 cGy = centiGray = 0.01 Gy = 1 rad
1 mGy = milliGray = 0.001 Gy = 0.1 rad
10 mGy = 1 cGy = 0.01 Gy = 1 rad

Sievert (Sv) = the SI unit of dose equivalent
1 Sv = 1 Gy = 100 rads ≈ 100 rem ≈100 R

Becquerel (Bq) is the SI unit of radioactivity
1 Bq = 1 disintegration of a nucleus per second

Curie (Ci) = radiation given off by radium
1 Ci = radiation from 1 gram of radium which = 3.7 x 10^{10} Becquerels
This results in a dose rate of approximately 1 Rad/hour at 1 meter

Other Radiation Measurements Source: http://www.radmeters4u.com/#1b

1 terabecquerel (TBq)	~	27	curie (Ci)
1 gigabecquerel (GBq)	~	27	millicurie (mCi)
1 megabecquerel (MBq)	~	27	microcurie (µCi)
1 kilobecquerel (kBq)	~	27	nanocurie (nCi)
1 becquerel (Bq)	~	27	picocurie (pCi) = 1 dps
1 curie (Ci)	~	37	gigabecquerel (GBq)
1 millicurie (mCi)	~	37	megabecquerel (MBq)
1 microcurie	~	37	kilobecquerel (kBq)
1 nanocurie (nCi)	~	37	becquerel (Bq)
1 picocurie (pCi)	~	37	millibecquerel (mBq)
1 Gray (Gy)	=	100	rad (rad)
1 milligray (mGy)	=	100	millirad (mrad)
1 microgray (µGy)	=	100	microrad (µrad)
1 nanogray (nGy)	=	100	nanorad (nrad)
1 kilorad (krad)	=	10	gray (Gy)
1 rad (rad)	=	10	milligray (mGy)
1 millirad (mrad)	=	10	microgray (µGy)
1 microrad (µrad)	=	10	nanogray (nGy)
1 coulomb/kg (C/kg)	~	3876	roentgen (R)
1 millicoulomb/kg (mC/kg)	~	3876	milliroentgen (mR)
1 microcoulomb/kg (µC/kg)	~	3876	microroentgen (µR)
1 nanocoulomb/kg (nC/kg)	~	3876	nanoroentgen (nR)
1 kiloroentgen (kR)	~	258	millicoulomb/kg (mC/kg)
1 roentgen (R)	~	258	microcoulomb/kg (µC/kg)
1 milliroentgen (mR)	~	258	nanocoulomb/kg (nC/kg)
1 microroentgen (µR)	~	258	picocoulomb/kg (pC/kg)
1 sievert (Sv)	=	100	rem (rem)
1 millisievert (mSv)	=	100	millirem (mrem)
1 microsievert (µSv)	=	100	microrem (µrem)
1 kilorem (krem)	=	10	sievert (Sv)
1 rem (rem)	=	10	millisievert (mSv)
1 millirem (mrem)	=	10	microsievert (µSv)

Dosage (Source: http://hypertextbook.com/physics/modern/radiobiology/)

The amount of energy absorbed from a source of radiation by some material per mass is called the **absorbed dose (D)**. It is a quantity that applies to any source of radiation acting on any type of material, be it living or non-living. It only provides a first approximation to the biological damage of the radiation in a human.

Different forms of radiation with identical absorbed doses may differ in their effect on living things. Neutrons and alpha particles are harder on human tissues than are beta particles or gamma rays. To account for this variation, the absorbed dose is multiplied by a **radiation weighting factor (*Q*)** that varies according to the type of radiation. The product is called the **equivalent dose (*H*).**

Different tissues or organs receiving identical equivalent doses may differ in their response to radiation damage. Skin is durable stuff that is designed to take abuse and be discarded as it wears out. Bone marrow is much less durable and its loss affects the body as a whole since red blood cells are produced within it. To account for this variation, the equivalent dose is multiplied by a **tissue weighting factor (*Q*)** that varies according to the organ or tissue exposed. The product is called the **effective dose (*H*).**

In symbolic form, the relation between D the absorbed dose, H the equivalent or effective dose, and Q the weighting factor is $\boxed{H = QD}$

Radiation Weighting Factors (*Q*) for Equivalent Dose

radiation	weighting factor
alpha	20
beta	1
gamma & x rays	1
neutrons, thermal	2.5
neutrons, fast	0-20
heavy ions	> 20

Tissue Weighting Factors (*Q*) for Effective Dose

tissue/organ	weighting factor
bladder	0.05
bone surface	0.01
bone marrow	0.12
breast	0.05
colon	0.12
esophagus	0.05
gonads	0.20
liver	0.05
lung	0.12
skin	0.01
stomach	0.12
thyroid	0.05
everything else	0.05
whole body	1.00

These **quality factors (Q)** are an important factor when looking at any exposure to a mixed contaminant environment. It is one thing to evaluate external exposure limitations and associated whole-body dose, but internalization of certain radioactive materials can/does increase organ and whole-body dose dramatically. The above also allows the reader a perspective to later studies presented concerning intake of radioactive materials and effect.[a]

*NOTE: This table (page 5) demonstrates the internalization issue. Depending on the emitter inhaled and/or ingested, the biological significant dose can change greatly. Unlike the free air – absorbed dose transmission of 87%, organ dose may be up to a 1:20 factor for alpha emitters. The table allows one to convert from absorbed dose to biological equivalent dose (biological effect).[a]

Short Term Effects of Sudden Radiation Absorption

absorbed dose (Gy)	symptoms
<0.25	short term effects unlikely
0.25 - 1	nausea, temporary sterility
1 - 3	vomiting, diarrhea, rapid weight loss, temporary reduction in white blood cells
3 - 6	damage to bone marrow and digestive tract, sterility, cataracts, 50% mortality
10	severe radiation sickness, death within 30 days
100	unconsciousness or coma, death within several hours

Source: New Scientist, 18 March 2000, Hiroshima Peace Memorial Museum

Lethal Dose for Various Organisms (LD-50 = 50% mortality)

organism	LD-50 (Gy)
dogs, pigs	3
goats	3.5
humans	4
mice, monkeys	4.5
sheep	5.4
fish, shellfish	5.5 - 1000
cattle, rats, horses	6.3
rabbits	8
chickens	10
insects	> 50
turtles	150
bacteria, viruses	1000

organism	LD-90 (Gy)
cabbage, spinach	140

organism	LD-100 (GY)
onions	20
oats	33
barley, rye, wheat, corn	43
fruits, grasses	> 50
potatoes	120
tomatoes	150

Source: Todd's Atomic Dose Information

[a]: Personnal communication, Frederick M. Scudiery, CIV CSUD, February 2009

Report 1

Muggenburg BA, Guilmette RA, et al**. *Radiotoxicity of Inhaled (239)PuO(2) in Dogs*.** Radiation Research 2008 Dec;170(6): 736-57
www.ncbi.nlm.nih.gov/pubmed/19138039

Beagle dogs inhaled graded exposure levels of insoluble plutonium dioxide ((239)PuO(2)) aerosols in one of three monodisperse particle sizes at the Lovelace Respiratory Research Institute (LRRI) to study the life-span health effects of different degrees of alpha-particle dose non-uniformity in the lung. The primary non-carcinogenic effects seen were lymphopenia, atrophy and fibrosis of the thoracic lymph nodes, and radiation pneumonitis and pulmonary fibrosis. Radiation pneumonitis/ pulmonary fibrosis occurred from 105 days to more than 11 years after exposure, with the lowest associated alpha-particle dose being 5.9 Gy. The primary carcinogenic effects also occurred almost exclusively in the lung because of the short range of the alpha-particle emissions. The earliest lung cancer was observed at 1086 days after the inhalation exposure. The most common type seen was papillary adenocarcinoma followed by bronchioloalveolar carcinoma. These lung cancer results indicate that a more uniform distribution of alpha-particle dose within the lung has an equal or possibly greater risk of neoplasia than less uniform distributions of alpha-particle dose. The results are consistent with a linear relationship between dose and response, but these data do not directly address the response expected at low dose levels. No primary tumors were found in the tracheobronchial and mediastinal lymph nodes despite the high alpha-particle radiation doses to these lymph nodes, and no cases of leukemia were observed.

Report 2

Linsley G. ***Radiation and the Environment: Assessing effects on plants and animals*;** IAEA Bulletin, 39/1/1997; pages 17-20.

(Page 20)For the most sensitive animal species, mammals, there is little indication that dose rates of 400 microgray per hour to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (40-100 microgray per hour), the same statement could be made with respect to reproductive effects.

Report 3

www.betondweird.com/survival/1hrrads.html

LD-50 (lethal dose for 50% of exposed population) EXPOSURE DOSES FOR VARIOUS ANIMALS AND PLANTS

Organism	LD-50 in RADS
Dogs, pigs	300
Goats	350
MAN	400
Mice, monkeys	450
Sheep	540
Fish/shellfish	550 to 100,000
Cattle,rats,horses	630
Rabbits	800
Chickens	1000
Insects	5000+
Turtles	15000
Bacteria/viruses	100000

Report 4

Cockerham LG, Doyle TF, et al. ***Canine postradiation histamine levels and subsequent response to Compound 48/80***. Aviat Space Environ Med. 1984 Nov;55(11):1041-5.

Radiation-induced hypotension in the beagle is accompanied by increased intestinal blood flow (IBF) and hematocrit (HCT). This study was performed to correlate these radiation-induced changes with plasma histamine (PH) levels following radiation. The histamine (H) levels were monitored in the systemic arterial circulation (SA) and the hepatic portal vein (HPV) before and after radiation. To examine the effect of radiation on the mobilization of total body H stores, Compound 48/80 was given I.V., and H responses were monitored in both control and radiated animals. Data obtained indicated that 100 Gy, whole-body, gamma-radiation produced a decrease in systemic mean blood pressure (BP), an increase in IBF and an increase in HCT. Concurrently, the mean PH/SA values increased and the PH/HPV levels decreased. Compound 48/80 produced a marked increase in PH levels in both control and radiated animals; however, the levels found in the radiated animals were consistently lower than those in the controls, although not statistically different. This implies that H may mediate these observed intestinal responses and that the mobility of histamine is decreased in radiated animals.

Report 5

Cockerham LG, Doyle TF, et al**. *Acute post-irradiation canine intestinal blood flow*.** Int J Radiat Biol Relat Stud Phys Chem Med. 1984 Jan;45(1):65-72.

Radiation-induced early transient incapacitation (ETI) is accompanied by severe systemic hypotension, during which arterial blood pressure often decreases to less than 50 per cent of normal. One haemodynamic compensatory mechanism is increased peripheral resistance due to vasoconstriction. This vasoconstriction in the small intestine of dogs is disproportionately increased during haemorrhagic or endotoxic shock, and intestinal ischaemia is frequent. In an attempt to elucidate mechanisms underlying radiation-induced ETI and the gastrointestinal radiation syndrome, canine intestinal submucosal blood flow was measured by the hydrogen polarographic technique, both before and after exposure to gamma radiation. Systemic blood pressures, blood gases and haematocrits were determined simultaneously. Data obtained from 12 sham-irradiated dogs and 12 irradiated dogs indicated that 90 Gy, whole-body, gamma radiation produced a 31 per cent decrease in systemic mean blood pressure beginning within 20 min post-irradiation and lasting for at least 90 min. However, the intestinal submucosal blood flow did not decrease as anticipated, but it exhibited an actual post-irradiation increase. This increase in post-irradiation intestinal submucosal blood flow began within 5 min after irradiation and lasted for at least 90 min. Post-irradiation haematocrits were 10.5 per cent higher than those obtained before irradiation and those obtained from sham-irradiated subjects. Histopathological examination of ileal mucosa revealed significant pathologic lesions in some irradiated animals within two hours after exposure.

Report 6

Cockerham LG, Hampton JD, Doyle TF. ***Dose dependent radiation-induced hypotension in the canine.*** Life Sci. 1986 Oct 27;39(17):1543-7

Radiation-induced early transient incapacitation (ETI) is often accompanied by severe systemic hypotension. However, postradiation hypotension does not occur with equal frequency in all species and is not reported with consistency in the canine. In an attempt to clarify the differences in reported canine postradiation blood pressures, canine systemic blood pressures were determined both before and after exposure to gamma radiation of either 80 Gy or 100 Gy. Data obtained from six sham-radiated beagles and 12 radiated beagles indicated that 100 Gy, whole-body, gamma radiation produced a decrease in systemic mean blood pressure while 80 Gy, whole-body, gamma radiation did not. Analysis of this data could be consistent with a quantal response to a gamma radiation dose between 80 Gy and 100 Gy.

Report 7

Baum SJ, Alpen EL**. *Comparative effects of 50 KvP and 250 KvP X-rays on the dog*.** Naval Radiological Defense Lab, San Francisco, CA; Accession number AD0400635. http://handle.dtic.mil/100.2/AD400635

Abstract : The subject of relative biological effectiveness of various ionizing radiations has been difficult and vexing to handle meaningfully when tissue distribution of dose is not uniform. It has been suggested by some that problems relating to linear energy transfer in tissues should appropriately be divided into two components - that relating to macroscopic energy distribution and that relating to energy distribution in terms of individual ionizing events. We have evaluated principally the former effect by looking at the biological potency of a lower energy X-ray source (50 kvp) in the dog. Previously we have shown that no single dose parameter is adequate to express the biological potency of lower energy X-rays, although it was suggested that, to the extent that it was possible to measure it, the dose to the critical organ, usually bone marrow, would be the most significant. Further studies have been completed on dogs exposed to high doses of X radiation from a 50 kVp beryllium window generator. Doses of 4000 to 10,000 rad (air) at the potential midline of the subject have been shown to be as effective as doses of 200 to 300 rad of 250 kVp X rays. Hematological comparisons of the two radiations show close correlation with mortality and a relative potency factor of 1 for 30 the lower energy radiation. The lethal dose of 50 kVp X rays for the dog is 7500 r (air). Serious lesions of the skin were seen as a complicating factor at all doses in excess of 4000 r (air). Dosimetry was done in tissue equivalent ("Mix D") wax phantoms using the rotational exposure method which is routine in this Laboratory. Phantom depth dose measurements with miniature ion chambers and chemical dosimetry in agar gels yielded essentially identical values of 3% for midline tissue dose.

Report 8

Sorenson DK, Bond VP, et al. ***An effective therapeutic regimen for the hemopoietic phase of the acute radiation syndrome in dogs*****.** Radiation Research 1960 Nov 01; vol: 13; 669-85**.**

A therapeutic regimen consisting in administration of large amounts of fresh whole blood when indicated to control bleeding, the judicious use of antibiotics to control infection, and parenteral fluids to combat dehydration was successful in reducing the mortality from nine of ten untreated controls to two of ten in the treated group. The dogs were exposed to 400 r of h irradiation measured free in air at the position corresponding to the proximal skin surface. It was found easier to control hemorrhage by fresh whole-blood transfusion than to control infection with antibiotics. Regeneration of the bone marrow as reflected by peripheral counts commenced on approximately the twenty-third to the thirtieth day postirradiation. The leukocytes appeared several days earlier than the platelets in all dogs. The rate of regeneration was different in the treated dogs and was slower in the four smaller dogs. The pre-irradiation-platelet, leukocyte, and red-blood-cell levels were not reached at the end of 100 days in these four dogs. The greater degree of effect seen in smaller dogs is discussed in terms of the greater tissue, or absorbed dose received by these animals with a given air-exposure dose. (auth)

Report 9

Cerveny TJ, MacVittie TJ, Young RW**. *Acute Radiation Syndrome in Humans*.** Chapter 2 in Medical Consequences of Nuclear Warfare
http://www.bordeninstitute.army.mil/published_volumes/nuclearwarfare/chapter2/chapter2.pdf

Page 23
Influence of Radiation Quality and Exposure Geometry on LD_{50}

- Distribution of radiation dose (energy deposition) throughout the target tissue varies significantly with the energy and quality of radiation and with the geometry of the exposure. Figure 2-8 illustrates the effects of tissue depth on absorbed radiation dose from unilateral cobalt-60 and 1 MeV (million electron-volts) of mixed neutron-gamma radiations. To reconstruct the effects of an accidental exposure involving neutrons, we must consider the tissue depth of a large-animal model (such as the canine) and that of humans, relative to the absorption characteristics of these two different radiation types (gamma and neutron, 1 MeV).

- Equivalent doses of different types of radiation, or of the same type at different energy levels, do not produce equivalent biological effects. However, the relative biological effectiveness (RBE) of two types of radiation can be compared.

- A significant number of studies establish the LD_{50} for hematopoietic death in canines at approximately 2.60 Gy for 1,000 kVp (plate voltage in kiloelectron-volts) of cobalt-60 radiation, or 2,000 kVp of X radiation. For lower-energy X radiation (50-250 kVp), an average dose of 2.28 Gy would yield this LD_{50}. These values suggest an RBE of approximately 0.87 for radiation higher than the standard 250 kVp of X ray energy.

- Canine exposure to mixed-fission neutron-gamma radiation yields an LD_{50} value of 1.48 Gy (compared to a derived value of 2.60 Gy for cobalt-60). This results in an RBE of approximately 1.7. Using a neutron spectrum of similar energy, an LD_{50} of 2.03 Gy (compared to 2.80 Gy for 1 MVp of X radiation) was determined to have an RBE value of 1.38.

- A radiation dose delivered to hematopoietic stem cells in bone marrow is the most damaging to the organism. Therefore, unilateral exposure with either gamma or neutron radiation will result in non-uniform dose distribution, whereas bilateral or rotational whole-body neutron exposure will have a greater RBE. Unilateral exposure usually occurs in accidents or warfare. Exposure to any type of unilateral radiation can result in lower doses to stem-cell populations that are distant from the source, with a consequent rise in the LD_{50} value

Page 23-24

Influence of Trauma on LD_{50}

- The combination of radiation exposure and trauma produces a set of circumstances not encountered by most military and civilian physicians. In combined injury, two (or more) injuries that are sublethal or minimally lethal when occurring alone will act synergistically, resulting in much greater mortality than the simple sum of both injuries would have produced. The mechanisms responsible for combined-injury sequelae are unknown, but they can significantly increase the consequences of radiation exposure across the entire dose-response curve. It must be emphasized that the survival of a patient following exposure in the hematopoietic dose range requires (a) a minimum critical number of surviving stem cells to regenerate a competent host defense system, (b) the functional competence of surviving cells composing the specific and nonspecific immune system, or (c) effective replacement or substitution therapy during the critical postexposure cytopenic phase. Trauma alone, depending on its intensity, may effectively depress host resistance to infection. When imposed on a radiation-injured system, it can be lethal. In most instances, trauma symptoms will either mask or exacerbate the first reliable signs of radiation injury. This will cloud the situation if one is relying on biological dosimetry and prodromal symptoms for estimation of dose. In addition, the choice of treatment in these cases should include consideration of not only the patient's initial status but also the condition that will exist 7-21 days later when the radiation effects are seen.

- An open skin wound (combined injury) markedly increases the chances of infection. The immediate closure of wounds has been recommended. Mortality in mice from exposure to 5.1 Gy of gamma radiation alone rose from 25% to 90% when combined with open dorsal skin wounds occurring 2 days after exposure. If wounds were immediately closed, mortality decreased to 18%. Closing of the skin wound obviously affected the mechanism of pathogenesis.

- In combined injuries, burns produce the most significant synergistic increases in mortality. The dog, pig, rat, and guinea pig have been studied as animal models. **Table 2-3** summarizes this synergistic effect on the lethality of combined radiation and trauma. As little as 0.25 Gy, combined with a burn of 20% body surface area, increased mortality in dogs from 12% to 20%.

TABLE 2-3
COMBINED EFFECTS OF WHOLE-BODY RADIATION AND BURNS ON VARIOUS ANIMAL MODELS*

Subjects	Percent Lethality
Dog	
20% burns	12
100 R exposure	0
20% burns + 100 R	73
Pig	
10%-15% burns	0
400 R exposure	20
10%-15% burns + 400 R	90
Rat	
31%-35% burns	50
250 R exposure	0
500 R exposure	20
15%-31% burns + 100 R	65
31%-35% burns + 250 R	95
31%-35% burns + 500 R	100
Guinea Pig	
1.5% burns	9
250 R exposure	11
1.5% burns + 250 R	38

*Significant increases in mortality occur when radiation is superimposed on concomitant conventional trauma.

Page 25-26

Effects of Clinical-Support Therapy on LD_{50} Dose-Effect Curve

Modification of survival throughout the LD_{50} dose range is achievable using a simple regimen of clinical support to replace or substitute the depleted functional cells after stem-cell destruction. In the cases of large-animal models (monkey, canine, and swine) and the human, therapy is directed at replacing the functions of the granulocytes and platelets. Experimental work performed more than 20 years ago showed the efficacy of supportive care centered on systemic antibiotics and transfusions of fresh platelets. Several canine studies indicated that antibiotics, singly or in combination, were successful in reducing mortality in the LD_{50} range. Combination antibiotics, in conjunction with fresh whole-blood transfusions and parenteral fluids, have been effective in controlling dehydration and thereby reducing mortality. Reports that hemorrhage is easier to control than infection may be traced to the fact that several types of opportunistic pathogens are capable of overwhelming a compromised host.

In an attempt to determine the lowest dose at which spontaneous regeneration would not occur, the dose range was extended in a later animal study from 4.0 to 5.5 Gy, well into 100% lethality (LD_{100}). The dose of 4.2 Gy resulted in an LD_{100}. Survival was significantly increased with good clinical support. This support consisted of (a) several antibiotics (penicillin G, dihydrostreptomycin, and tetracycline) administered at the onset of fever (8-13 days after exposure) and continued until fever subsided for 3-4 days and white cell count was greater than $1,000/mm^3$; (b) the infusion of fresh platelet-rich plasma from 50 ml of blood, given when blood platelet levels were below $5,000/mm^3$ (10-12 days after exposure); and (c) fluid therapy (isotonic saline or 5% dextrose) given during the period of anorexia. Soft food was usually given during this period to entice the animals to eat. The success with these regimens supports the hypothesis that infection and hemorrhage are the main contributors to lethal consequences of radiation exposure in the hematopoietic subsyndrome range. Controlling infection during the critical granulocytopenic and thrombocytopenic phase is the limiting factor in successful treatment.

These studies have been extended over a dose range that is capable of determining the shift in LD_{50} that is due to treatment. Figure 2-9 shows the shift in the canine LD_{50} from 2.60 Gy to approximately 3.39 Gy measured as midline tissue dose. This results in a dose reduction factor of 1.3. The treatment regimen was essentially the same as above, with the addition of the newer antibiotics, gentamicin and claforan (cephotaxime-$S0_4$). These collective data indicate that modest clinical care consisting of the infusion of fluids, antibiotics, and fresh platelets is capable of shifting the LD_{50} by a factor of 1.5. A more intensive regimen of support, including use of a sterile barrier and selective decontamination of intestinal bacteria, should allow an even greater shift in the LD_{50}. It must be emphasized that the practical application of these concepts requires that the damage to the stem-cell system be reversible; that is, the surviving fraction of hematopoietic stem cells must be capable of spontaneous regeneration.

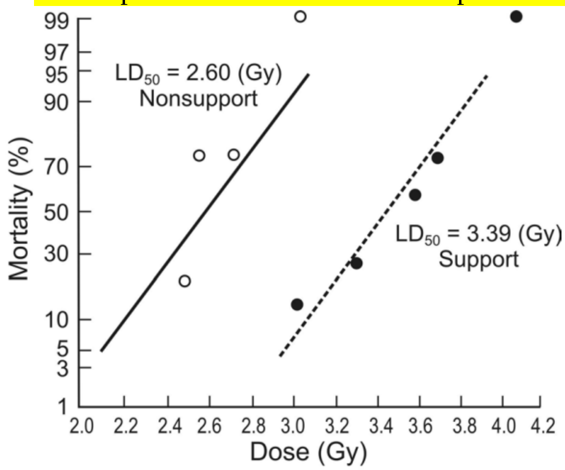

Figure 2-9. Effect of clinical support therapy on LD_{50}. Parenteral fluids, platelets, and antibiotics to control infection during critical nadirs in granulocyte and platelet counts provide the basis for successful treatment.

Exposure Geometry: Heterogeneous Partial-Body and Nonuniform Exposure (Page 26-27)

A series of experiments using canines further illustrated the protective effects of partial-body shielding. Large-animal models can not only illustrate the relationships between tissue depth and dose, but can also approximate the non-uniform effects of exposure for more reliable extrapolation to the human radiation response. Shielding the lower body indicated an approximately sevenfold increase in LD_{50}. One report emphasized that considerable hematopoietic tissue may be spared by non-uniform exposures to cobalt-60 gamma radiation. Results indicated that the greater the dose gradient and the more non-uniform the exposure, the greater the survival of stem cells that are capable of repopulation.

These canine experiments illustrate the complexity of determining the dose received during an accidental exposure. Accidental whole-body irradiation will most likely not be strictly unilateral, due to backscatter and reflection of the radiation. It is also possible that some body regions may be shielded. These factors, as well as the anatomical position of the exposed subjects, can either increase or decrease the total dose received. Shielding and non-uniform dose distribution can therefore differ markedly in how much hematopoietic tissue they spare. The biological response of marrow stem and progenitor cells to radiation is exponential in nature.

Report 10

Gusev BI, Kurakina NN, Strelnikov AV**. *Acute Effects of Irradiation on People and Animals from Soviet Underground Nuclear Explosions.*** DTRA01-03-D-0022; September 2007; Defense Threat Reduction Agency, DTRA-TR-07-39

ABSTRACT
We studied the mechanisms and features of the formation of the response reactions in humans and in animals to the effects of radiation factors imposed on them from experimental nuclear explosions. It was established that, as a result of short-term exposure of testing participants and the populace to a low-lying radioactive nuclear explosion cloud in 1968, with an overall external gamma irradiation of from 170 to 260 mGy (17.0-26.0 rad), and an internal contamination from freshly produced radioactive fission products in the 296 to 740 MBq (8 to 20 mCi) range, radiation reactions were expressed to varying degrees.

Page 3-4
Test on January 15, 1965
On January 15, 1965, at the confluence of the Ashisu and Chagan Rivers, a thermonuclear device with a yield of roughly 100-140 kt was detonated at a scaled depth of 41 $m/kt^{1/3.4}$. A radioactive cloud formed to an altitude of up to 4.5 km, and a crater formed with a diameter of 408 m and depth of 100 m. The height of the soil was 42 m, the width 412 m. The velocity cloud was 40 km/hr.

After the explosion measurements of levels of gamma irradiation were taken on the open territory and in enclosed areas along the territory of the radioactive track. Radioactive gasses leaked out of the crater for several days. It was established that the doses of external irradiation caused by the effects of the radioactive gas streams reached considerable values outside the zone of the radioactive track. When the gas stream passes through population points, we observe the effect of sorption of radioactive materials on the surfaces or rooms and all contents. Given this condition, ventilating the rooms has practically no effect on reducing the gamma level backround. Clothing is contaminated, especially fur clothing and hair.

Page 6
Test of May 31, 1974
In May of 1974, a subsequent underground nuclear explosion was conducted at the Semipalatinsk nuclear test site. Yield was 150 kt, cloud velocity 45.0 km/hr.

Page 19
To compare the results of the investigations, conducted on the experimenters and the populace during the time the radiation factors from the underground nuclear explosions affected the subjects, an experiment was also conducted on animals. The purpose of this investigation was to study the clinical-morphological features of combined radiation injuries in 25 dogs and 108 rats after staying on the ground at the moment of passage of the low-lying radioactive cloud from the nuclear explosion accompanied with an ejection of soil.

The animals, placed 0.4-1.0 km from the explosion center, were covered by the radioactive cloud within the first 3.5-7 minutes. In the subsequent 4 hours (before removing the animals), additional irradiation and contamination was possible due to the gas plumes which exited out of the explosion cavity. To prevent ingestion the dogs were fitted with muzzles.

The doses of external gamma irradiation recorded by the IFK film dosimeters, which were attached to the dogs' collars, registered 120-180 R at a distance of 0.4 km, and 38-90 R at a distance of 1 km.
It was more difficult to determine the quantity of radioactive material entering into the body through the respiratory organs, since a significant number of these radionuclides have a short half-life and many isotopes were gaseous in form. The quantity of radioactive material which entered into the body was determined by calculation using the air concentration, lung ventilation volume, and duration of being held inside the lungs. Roughly, at a distance of 0.4 km, close to 20 mCi (740 MBq) of radioactive fission products could have entered the dogs' bodies, and at a distance of 1.0 km, close to 10 mCi (370 MBq).

Page 26

Clinical-Morphological Changes in Animals Subjected to Radiation

Of the 13 dogs at 0.4 km mark receiving irradiation doses of 1.42, 1.50, and 1.80 Gy:

Radiation Injury:

- 3 developed a severe level (Degree III) of acute radiation injury; fatal at 21-28 days
- 5 developed medium level (Degree II) radiation illness
- 5 developed mild level (Degree I) radiation illness

Leukocyte counts

- Prior to test leukocyte counts ranged 10-12 $x10^9$/liter
- Degree III injury dog leukocytes decreased to 0.4-0.7 $x10^9$/liter at the height of their illness, with an average count of 2-3 $x10^9$/liter
- Degree I injury dog leukocytes decreased down to 3-4 $x10^9$/liter

Of the 12 dogs at the 1.0 km mark:

- 8 developed mild (Degree I) radiation illness
- Leukopenia occurred at the end of the 1st week to 4.7 $x10^9$/liter (+/- 0.5 $x10^9$/liter)
- Second leukopenia wave at end of the 3rd week to 5.4 $x10^9$/liter (+/- 0.7 $x10^9$/liter)
- Individual animals had leukocyte reductions to 3.1-3.2 $x10^9$/liter

The 3 deceased dogs (0.4 km mark, Degree III radiation injury) had acute radiation sickness with manifestations of hemorrhagic syndrome

- Hemorrhage of subcutaneous tissue, epicardium, all lung lobes, mesentery, serous and mucous membranes of small and large intestine, and other internal organs
- Necrosis of the palatine tonsils
- Focal hemorrhagic pneumonia

Four sacrificed dogs (one from 0.4 km, 3 from 1.0 km)

- Thyroid necrobiotic changes; necrosis and desquamation of follicular epithelium
- Fibrinous hemorrhagic pneumonia with multiple foci of hemorrhage and necrosis
- Focal renal hemorrhages
- Hepatic cell necrobiosis, edema, centrolobular hepatic cord atrophy, and deranged lobular architecture
- Cellular element destruction and manifest edema in spleen, bone marrow, and lymph nodes

The 23% fatality rate (3 of 13) of the dogs at the 0.4 km mark is roughly equivalent to the effect of unilateral general gamma irradiation at a dose of 4.00 Gy. If we consider that the effect of irradiation from all sides delivered by the radioactive cloud could be roughly 1.5 times higher

than that from unilateral irradiation, then in this case the effect of the internal irradiation turned out to be equivalent to a dose of 1.75 Gy. In other words, the contribution of the external and internal radiation components to the overall injury could be considered roughly equal.
In the dogs that died with severe radiation illness we noted clinically a reduction in mobility and a moderate reduction in appetite during the beginning of the illness. As the illness climaxed, loose black colored stool appeared, and the body temperature increased up to 40.3 to 40.7 degrees (normal range 37-40 degrees C). We noted as well necrotic ulcerous changes in the mucous membranes of the mouth. The dynamics of the blood indices in these dogs were typical for severe acute radiation injury and were characterized by a significant depression of hematopoiesis right up to the analysis of the hematopoietic organs.

At the 1.0 km mark, the effect of the radiation reaction in dogs could be roughly estimated at an equivalent dose of 2.00-2.50 Gy of unilateral gamma irradiation, though the exposure doses actually registered were 0.40-0.90 Gy.

In animals who suffered mild and moderate radiation illness, the depth of the reduction in the blood indices during the time periods was more significantly expressed than could be expected from the external irradiation doses on the order of 1.50 Gy. The depth of hematological changes in the animals at this distance (1.0 km) corresponded to that for doses of unilateral external gamma irradiation on the order of 2.50 Gy.

Hence, the results of our experiment indicate that in conditions of a low-lying radioactive venting cloud resulting from an underground nuclear explosion with the ejection of soil, internal irradiation determines to a significant extent the level of intensity of the radiation injury.

In our experience, when dogs are located in the track of radioactive venting cloud from an underground nuclear explosion, the animals were subjected to combined effects of external beta and gamma irradiation and also internal contamination from fission products of the nuclear explosion.

The following features of radiation injury in the study animals, as compared to radiation illness caused by only external irradiation in such doses, should be noted:

- The intensity of the progression of the radiation illness does not correspond to the dose of external irradiation actually received
- There are large differences in the levels of intensity of illness in different animals placed the same distance form the explosion, despite little difference in doses of external beta and gamma irradiation
- There is slower restoration of hematological indices in animals who suffered from mild and moderate radiation illness

Exacerbation of the radiation injury intensity at relatively low doses of external beta and gamma irradiation is caused by the internal contamination from fission products of the underground nuclear explosion.

DISCUSSION

Clinical Emergence of Three Phases of Illness

The profound clinical and hematological changes that appeared in these animal, accompanied by the appearance of ulcerous-necrotic injuries of the mucous membranes of the mouth, the emergence of hemorrhagic colitis, increased body temperature of up to 40.7 degrees centigrade, and total aplasia of the hematopoietic centers during these time periods, indicated a significant disparity from the effects normally expected from the dose of overall external gamma irradiation actually measured. According to the data in the literature, the integrated biological effects of combined radiation action, based on the severity of the clinical and hematological changes observed during the peak of illness, corresponded to an external gamma irradiation dose of 3.50-4.00 Gy. That is two to three times greater than the dose recorded by the dosimeter devices.

Hematological Changes

In both humans and test animals in our report, the restoration of hematopoiesis occurred significantly more slowly, as compared to the duration of repair processes after external gamma radiation. In humans with 220 +/- 30 mGy external gamma irradiation doses, the blood picture was not normalized seven months after exposure, and in animals it was not normalized even 1.5 years after the effect.

The Role of Individual Radiation Factors of the Cloud Vented from an Underground Nuclear Explosion in Producing Injury

When both humans and the test animals were under the radioactive cloud, they were subjected to external beta and gamma irradiation combined with internal contamination by radioactive materials. When evaluating the role of various factors in the formation of an integrated biological effect, we must consider as well the higher effectiveness of simultaneous irradiation from all sides.

External Beta Irradiation

We saw a trend toward increasing severity of radiation illness only with the additional effect of overall external beta irradiation. In our experimental cases, the external beta irradiation of humans was predominantly local (face, neck, wrists, and hands), since the test participants were wearing winter clothing at the time the explosion cloud passed by. As for the animals, they were covered by blankets, which could also have a definite protective effect.

Destructive changes in the skin were also lacking in the animals from the "Telkem-1" test. This data confirmed that the beta irradiation doses for humans and large lab animals were relatively low. Thus, it is hardly likely that external beta irradiation could have made a significant contribution in strengthening the effectiveness of combined radiation action. It is also unlikely since in the cases of higher doses of beta irradiation in the Marshall Islands residents, no significant enhancing effect on the level of intensity of radiation was noted.

Internal Irradiation

Four mCi (148 MBq) of radioactive fission products entered the bodies of humans and dogs; this could have been only via aerosol inhalation. Given this, it was established that the aerosol fraction concentration of radioisotopes in inhaled air comprised 20-25% of the overall activity. Consequently, the total amount of radioactive materials which entered into the body could have been at maximum only roughly 20 mCi (740MBq). According to current opinion, the minimum amount of radioactive materials up to one hour old required to cause radiation injury is 75 mCi (2.8 GBq). It is also known that we observe a more severe course of combined radiation injuries from single exposures only when there are high doses of external and internal irradiation (close to the LD_{50}).

It is fully possible that the remaining unexplained part of the biological effects was caused in the conditions set forth, that is by internal irradiation. This situation permits us to establish that when one remains under a low-lying venting cloud from an underground nuclear explosion, the role of internal contamination from radioactive materials can greatly aggravate the integrated biological effect. The danger from internal irradiation in such cases becomes comparable to that of external gamma irradiation.

REPORT DATA SUMMARY

Report 1

Alpha-particle dose 5.9 Gy (590 rad ≈ 590 rem ≈ 590 R)
*Note: If this (5.9 Gy) were whole body radiation, it would be a lethal dose. Plus, alpha radiation is 20x more ionizing than gamma.[b]
Non-carcinogenic effects:

- Lymphopenia
- Atrophy, fibrosis thoracic lymph nodes
- Radiation pneumonitis, pulmonary fibrosis 105 days post-exposure to >11 years

Carcinogenic effects:

- Adenocarcinoma
- Bronchioalveolar carcinoma
- Earliest found at 1,086 days (3 years) post-exposure

Report 2
400 microgray/hour chronic irradiation dose (10 milligray/day, or 1 rad ≈ 1 rem ≈ 1 R /day)

- Little indication this would seriously affect mortality in the population

40-100 microgray per hour (dose rates up to an order of less magnitude)

- Little indication this would seriously affect reproductive effects

Report 3
300 rads (3 Gy, ≈ 300 rem ≈ 300R)

- Canine LD-50 (lethal dose for 50% of exposed population)

Report 4
100 Gy Whole-body gamma radiation (10,000 rads ≈ 10,000 rem ≈ 10,000 R)
*Note: This is a very high level of radiation, approximately 33x LD_{50}s! [a]

- Decrease in systemic mean blood pressure (BP)
- Increase in intestinal blood flow (IBF)
- Increase in hematocrit (HCT) (percent red blood cells)
- Mean plasma histamine (PH)/systemic arterial circulation (SA) values increased
- Plasma histamine (PH)/ hepatic portal vein (HPV) levels decreased

Report 5
Radiation-induced early transient incapacitation (ETI) is accompanied by severe systemic hypotension, during which arterial blood pressure often decreases to less than 50 % of normal.
90 Gy Whole-body gamma radiation (9,000 rads ≈ 9,000 rem ≈ 9,000 R)
*Note: This is a very high level of radiation, approximately 30x LD_{50}s. [b]

- Produced a 31 per cent decrease in systemic mean blood pressure beginning within 20 min post-irradiation and lasting for at least 90 min.
- Significant pathological lesions in the ileal mucosa within 2 hours after exposure

Report 6
Radiation-induced early transient incapacitation (ETI) is often accompanied by severe systemic hypotension. **100 Gy Whole-body gamma radiation (10,000 rads ≈ 10,000 rem ≈ 10,000 R)**
*Note: Again, with these high levels, both handler and canine would receive lethal doses. [a]

- Decrease in systemic mean blood pressure

[b]: Personnal communication Gary Eifried, SAIC, Chief Technical Officer, EAI, February 2009

Report 7

Doses of **4,000 to 10,000 rad (air)** at the potential midline of the subject have been shown to be as effective as doses of 200 to 300 rad of 250 kVp X-rays.

- Hematological comparisons of the two radiations show close correlation with mortality and a relative potency factor of 1 for 30 the lower energy radiation.
- **Lethal dose of 50 kVp X-rays for dogs is 7500 r (air) (≈ 7500 rem ≈ 7500 R, 75 Gy)**
- **Serious lesions of the skin were seen as a complicating factor at all doses in excess of 4000 r (air) (≈ 4000 rem ≈ 4000 R, 40 Gy).**

Report 8

400 R (≈ 400 rem ≈ 400 rad, 4 Gy) of h irradiation measured free in air at the position corresponding to the proximal skin surface

- Fatal in 9 of 10 untreated controls
- Fatal in 2 of ten treated controls (see treatment below)
- The pre-irradiation-platelet, leukocyte, and red-blood-cell levels were not reached at the end of 100 days in the four smaller dogs

The therapeutic regimen consisted of administration of large amounts of fresh whole blood when indicated to control bleeding, the judicious use of antibiotics to control infection, and parenteral fluids to combat dehydration

Report 9

LD_{50} for hematopoietic death in canines

- **1.48 Gy (148 rad ≈ 148 rem ≈ 148 R) for mixed-fission neutron-gamma radiation**
- **2.28 Gy (228 rad ≈ 228 rem ≈ 228 R) for 50-250 kVp X-rays**
- **2.60 Gy (260 rad ≈ 260 rem ≈ 260 R) for 1,000 kVp cobalt-60 or 2,000 kVp X-rays**

*Note: Unilateral exposure usually occurs in accidents or warfare. Exposure to any type of unilateral radiation can result in lower doses to stem-cell populations that are distant from the source, with a consequent rise in the LD_{50} value

Influence of Trauma on LD_{50}

- As little as **0.25 Gy (25 rad ≈ 25 rem ≈ 25R),** combined with a burn of 20% body surface area, increased mortality in dogs from 12% to 20%.
- **1.0 Gy (100 rads ≈ 100 rem ≈ 100 R)** combined with a burn of 20% body surface area, increased mortality in dogs from 12% to 73%

Effects of Clinical-Support Therapy on LD_{50} Dose-Effect Curve

- Dose of **4.2 Gy (420 rad ≈ 420 rem ≈ 420 R)** resulted in an **LD_{100}**

  Modest clinical care consisting of the infusion of fluids, antibiotics, and fresh platelets is capable of shifting the LD_{50} by a factor of 1.5:

- *Untreated* canine **LD_{50} was 2.60 Gy (260 rad ≈ 260 rem ≈ 260 R)**
- *Treated* canine **LD_{50} was 3.39 Gy (339 rad ≈ 339 rem ≈ 339 R in the**
- Shielding the lower body indicated an approximately sevenfold increase in LD_{50}

*Note: Accidental whole-body irradiation will most likely not be strictly unilateral, due to backscatter and reflection of the radiation. Some body regions may be shielded. These factors, as well as the anatomical position of the exposed subjects, can either increase or decrease the total dose received. Shielding and non-uniform dose distribution can therefore differ markedly in how much hematopoietic tissue they spare.

Report 10

Gusev BI, Kurakina NN, Strelnikov AV**. *Acute Effects of Irradiation on People and Animals from Soviet Underground Nuclear Explosions.*** DTRA01-03-D-0022; September 2007; Defense Threat Reduction Agency, DTRA-TR-07-39

Abstract and Test Notes
The effect of sorption of radioactive materials on the surfaces or rooms and all content

- Ventilating the rooms has practically no effect on reducing the gamma level backround
- Clothing is contaminated, especially fur clothing, and hair

External gamma irradiation recorded by the IFK film dosimeters attached to the dogs' collars

- **10-180 R (≈ 10-180 rad ≈ 10-180 rem, 0.1-1.8 Gy) at a distance of 0.4 km**
- **38-90 R (≈ 38-90 rad ≈ 38-90 rem, 0.38-0.9 Gy) at a distance of 1 km**

Internal: radioactive material entering into the body through the respiratory organs

- **20 mCi (740 MBq) at a distance of 0.4 km**
- **10 mCi (370 MBq) at a distance of 1.0 km**

Clinical-Morphological Changes in Animals Subjected to Radiation

13 dogs at 0.4 km mark with **doses of 1.42, 1.50, and 1.80 Gy (142, 150, 180 rad ≈ rem ≈ R)**:

- 3 developed a severe level (Degree III) of acute radiation injury; fatal at 21-28 days
    - All had signs of hemorrhagic syndrome (details previously described on page 13)
- 5 developed medium level (Degree II) radiation illness
- 5 developed mild level (Degree I) radiation illness
- All developed significant leukopenia (decreased white blood cell counts)
- The **23% fatality rate** (3 of 13) of the dogs is roughly equivalent to the effect of unilateral general gamma irradiation at a dose of **4.00 Gy (400 rads ≈ 400 rem, ≈ 400R).**

Of the 12 dogs at the 1.0 km mark

- 8 developed mild (Degree I) radiation illness
- Significant leukopenia (decreased white blood cell counts)
- These effects are consistent with **2.00-2.50 Gy (200-250 rad ≈ rem ≈ R) of unilateral gamma irradiation even though registered exposure doses were 0.40-0.90 Gy (40-90 rad ≈ rem ≈ R)**

Four sacrificed dogs (one from 0.4 km, 3 from 1.0 km)

- Multi-organ necrosis, hemorrhage, and fibrosis
    - Thyroid, lungs, kidney, liver
- Cellular destruction and edema in spleen, bone marrow, lymph nodes

<u>THEREFORE NOTE</u>

- The **intensity of the progression of the radiation illness does not correspond to the dose** of external irradiation actually received
- There are **large differences in the levels of intensity of illness in different animals** placed the same distance form the explosion, despite little difference in doses of external beta and gamma irradiation
- There is **slower restoration of hematological indices** in animals who suffered from mild and moderate radiation illness
- **Exacerbation** of the radiation injury intensity at relatively low doses of external beta and gamma irradiation is **caused by the internal contamination** from fission products of the underground nuclear explosion.
- Integrated **biological effects** of combined radiation action, based on the severity of the clinical and hematological changes observed during the peak of illness, **corresponded to an external gamma irradiation dose of 3.50-4.00 Gy. That is two to three times greater than the dose recorded by the dosimeter devices.**
- 220 +/- 30 mGy external gamma irradiation doses, the blood picture was not normalized in animals even 1.5 years after the effect
- The animals covered by blankets would have had a definite protective effect from beta irradiation; it is **hardly likely that external beta irradiation could have made a significant contribution** in strengthening the effectiveness of combined radiation action.
- Four mCi (148 MBq) of radioactive fission products entered the bodies of humans and dogs; this could have been only via **aerosol inhalation**
- It is fully possible that the remaining unexplained part of the biological effects was caused in the conditions set forth, that is by internal irradiation; **the role of internal contamination from radioactive materials can greatly aggravate the integrated biological effect.** The danger from internal irradiation in such cases becomes comparable to that of external gamma irradiation.

CONCLUSIONS

Canines appear to be at a range of 20% to 70% more sensitive to the effects of radiation when compared to humans. In addition to these measured doses there would be inhalation and ingestion levels that a search canine would acquire due to inability to utilize personal protective equipment (PPE) and perform their search function.

Radiation exposure significantly lowers leukocytes (white blood cells) which the body utilizes to fight infection. Even minor trauma, specifically skin wounds, greatly decreases survival due to the development of overwhelming infection. Search canines are particularly susceptible to wounding because they work without PPE. A study of morbidity of canines deployed to work at the World Trade Center building collapses revealed 35% suffered cuts and abrasions.

The nature of canine search, in addition to air scenting, requires working low to the ground where particulate matter settles. If surfaces contain fission fragments or activation products, canine sniffing may cause suspension of these materials as a dust, increasing the efficiency of direct intake.[a] It was by the inhalation route and subsequent transfer across the lung-blood barrier that allowed for the inclusion of ingestion as a body entry in the Russian nuclear testing.

Radioactive materials were observed to be collected in highest concentration by fur clothing and hair. The entire canine body is therefore a high collective surface for radioactive substances. Placing a muzzle on a working dog to prevent ingestion (from self-licking) decreases their scenting ability, as scenting occurs through both the nasal passages and the oral cavity. A basket muzzle allows the canine to open their mouth, but also to lick their face, defeating the purpose.

Canines may be asked to search areas that are not accessible for measuring radiation levels. This presents potential high-dose exposure and should be avoided if at all possible. Using advanced technological devices to access areas for radiation level measurements would allow for better assessment so as to avoid undue high radiation exposure. Per the ‘zoned approach to response’, page 24, lines 28-29 of the *Planning Guidance for Response to a Nuclear Detonation*, response teams should not enter affected areas without first confirming the level of radioactivity in the area they are entering. This should apply to the canines as well.

On the other hand, it is somewhat risky to extrapolate from the high dose studies (multiple LD_{50s}) to the lower dose rates in which humans would reasonably work, due to the ability of the body to repair lower dose damage. In humans, the first blood changes can be seen about 25 rad, initial (mild and reversible) visible symptoms at 75-100 rad. It is expected that canines would show a similar pattern but with higher sensitivity.[b] (see last paragraph, page 23).

Another consideration is that if we take the case of a person buried in rubble at an initial dose rate of 20 rad/hr, the victim would receive a lethal dose in something greater than 20 hours. So it seems like the chance of finding a viable victim is pretty slim at that level, considering when the canine team would be there, begin search etc. On the other hand, if the rate was 2 rad/hr, the victim could die from exposure, dehydration etc. before receiving a lethal dose. If the dog searched for 10 hours to find him, the dog would receive a dose somewhat less than 20 rad (due to the fact that radiation from fallout decays by a factor of 10 every 7 hours, which would make a big difference in the dose rate and dose over time).[b]

[a]: Personnal communication, Frederick M. Scudiery, CIV CSUD, HP DTRA at DNWS; February 2009
[b]: Personnal communication Gary Eifried, SAIC, Chief Technical Officer, EAI, February 2009
[d.] Dr. Cynthia Otto, PA TF-1, Morbidity study of canines treated at the World Trade Center Disaster, 2002

National Council on Radiation Protection and Measurements (http://www.ncrponline.org/, NCRP) Commentary #19 *Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism*, redefines areas based on dose rate and contamination rates. This document will most likely become law in the future providing a uniform national standard. One can base or estimate operational exposure to response personnel and maybe even their search dogs. If we can estimate this then we can control or limit exposure. The humans will have active monitoring instruments (pager-s, EPDs, etc). So by controlling the real-time human total dose, we can control the animal dose to at least external exposure. The internal issue still presents a problem and may not be able to be controlled. [a]

Based on human studies for survival, (Table 1.3, page 23, of the *Planning Guidance for Response to a Nuclear Detonation*) canines could only be exposed to 20-70 rads (≈ 20-70 rem ≈ 20-70 R, 0.2-0.7 Gy) of irradiation and have a high chance of survival. Anything higher and they begin to exhibit illness that would terminate their use for search. However these values do not account for inhalation and ingestion, and therefore may be artificially higher than can be safely recommended based on the data presented in this report.

Also in the *Planning Guidance for Response to a Nuclear Detonation*, page 33 lines 10-12, if lifesaving emergency responder doses approach or exceed 50 rem (0.5 Sv) emergency responders must be made aware of both the acute and the chronic (cancer) risks of such exposure. In keeping with this recommendation, handlers and other decision makers should be aware that a corresponding exposure of concern for the canine would be 10-35 rem (0.1- 0.35 Sv).

In canines, mild symptoms can occur at doses as low as 30 rad (≈ 30 rem, ≈ 30 R, 0.3 Gy). Acute radiation syndrome can occur when the following situations occur: doses are high, usually exceeding 70 rad (≈ 70 rem, ≈ 70 R. 0.7 Gy), the radiation is penetrating (gamma rays), a large portion of the body receives the dose, and the dose is delivered over a short period of time.[c]

Should search canines be used in a radiological event, decontamination protocols are to be followed in order to decrease continues exposure to the canine as well as protect and prevent further contamination of personnel and the environment.

[a]: Personnal communication, Frederick M. Scudiery, CIV CSUD, Health Physicist, Defense Threat Reduction Agency, Defense Nuclear Weapons School; February 2009

[b]: Personnal communication Gary Eifried, SAIC, Chief Technical Officer, EAI, SAIC; February 2009

[c]. Wingfield WE, et al. Veterinary Disaster Medicine. Wiley-Blackwell, 2009; page 143