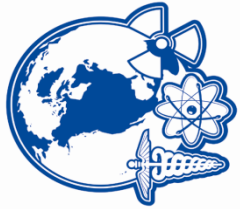


Radiation Exposure of the U. S. Population



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Kenneth R. Kase
*Sr. Vice President and
Chair of Scientific Committee 6-2*

Kenneth L. Miller, Dennis M. Quinn
Daniel J. Strom, Orhan H. Suleiman
Bruce R. Thomadsen, Marvin Rosenstein
Subcommittee Chairs & Staff

*Health Physics Society Annual Meeting
American Academy of Health Physics
July 2009*

Members of SC 6-2

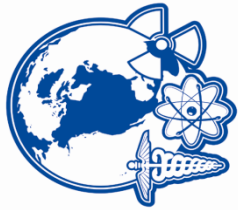
Natural Background

- ▣ Daniel J. Strom
- ▣ Alan Birchall
- ▣ Thomas B. Borak
- ▣ David J. Brenner
- ▣ Paul E. Goldhagen
- ▣ Keran O'Brien III
- ▣ Jerome S. Puskin
- ▣ *Thomas F. Gesell**
- ▣ *Anthony James**

Medical Patient

- ▣ Bruce R. Thomadsen
- ▣ Mythreyi Bhargavan
- ▣ Debbie B. Gilley
- ▣ Joel E. Gray
- ▣ Jill A. Lipoti
- ▣ Mahadevappa Mahesh
- ▣ John L. McCrohan
- ▣ Fred A. Mettler, Jr.
- ▣ Terry T. Yoshizumi

* *Consultants*



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Members of SC 6-2



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Consumer Products

- ▣ **Orhan H. Suleiman**
- ▣ Jennifer Goodman
- ▣ Raymond H. Johnson, Jr.
- ▣ Cheryl K. Rogers
- ▣ *Paul W. Frame**
- ▣ *Ronald L. Kathren**

Industrial Sources

- ▣ **Dennis M. Quinn**
- ▣ Ralph Andersen
- ▣ Regis A. Greenwood
- ▣ Cynthia G. Jones

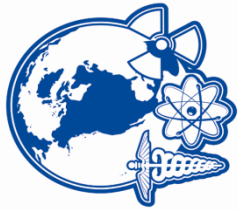
Occupational Exposure

- ▣ **Kenneth L. Miller**
- ▣ David J. Allard
- ▣ Kelly Classic
- ▣ Michael A. Lewandowski
- ▣ Kathleen L. Shingleton
- ▣ George J. Vargo

*Consultants

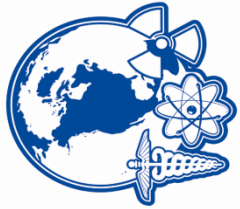
Outline

- ▣ Overview of Report
- ▣ Exposure from Ubiquitous Natural Background, including Radon
- ▣ Exposure to Patients from Medical Procedures
- ▣ Exposure from Consumer Products and Activities
- ▣ Exposure from Industrial, Security, Medical, Educational and Research Activities
- ▣ Occupational Exposure
- ▣ Summary



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Overview



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- ▣ NCRP Report No. 93: Exposure of the U.S. population to ionizing radiation as of the early 1980s.
- ▣ Population dose has increased because the population has increased, but
 - Individual dose has also increased from medical procedures to exposed individuals;
 - Individual and population doses from various other sources have changed.

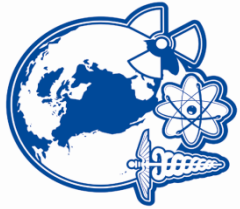
Overview



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- ▣ Results are presented as annual values for:
 - average effective dose to an individual in a group exposed to a specific source (E_{Exp}) (mSv);
 - collective effective dose (S) (person-Sv);
 - and effective dose per individual in the U.S. population (E_{US}) (mSv).
- ▣ Variation of dose and uncertainties in dose are discussed.
- ▣ Doses reported are not suitable for use in risk assessment.

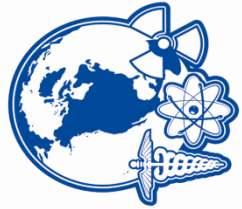
Ubiquitous Background



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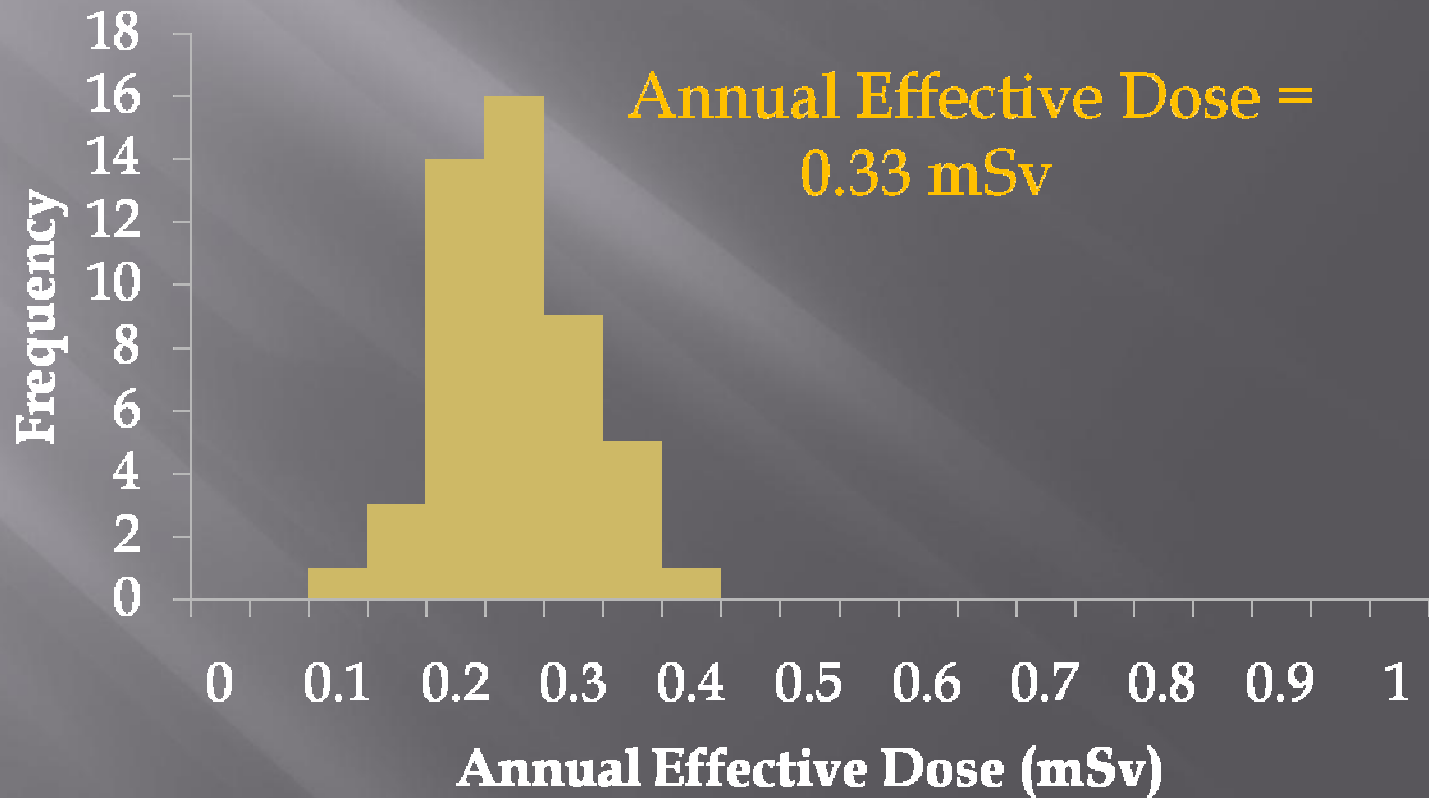
- ▣ Four subcategories grouped by the origin of the source:
 - external exposure from space radiation (solar particles and cosmic rays);
 - external exposure from terrestrial radiation (primarily from ^{40}K and the ^{238}U and ^{232}Th decay series);
 - internal exposure from inhalation of radon and its progeny;
 - and internal exposure from radionuclides in the body (primarily ^{40}K).

Space Radiation

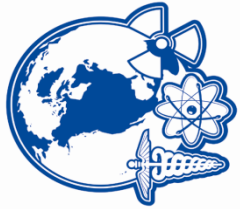


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Space Radiation in 99 Most Populated U. S. Cities

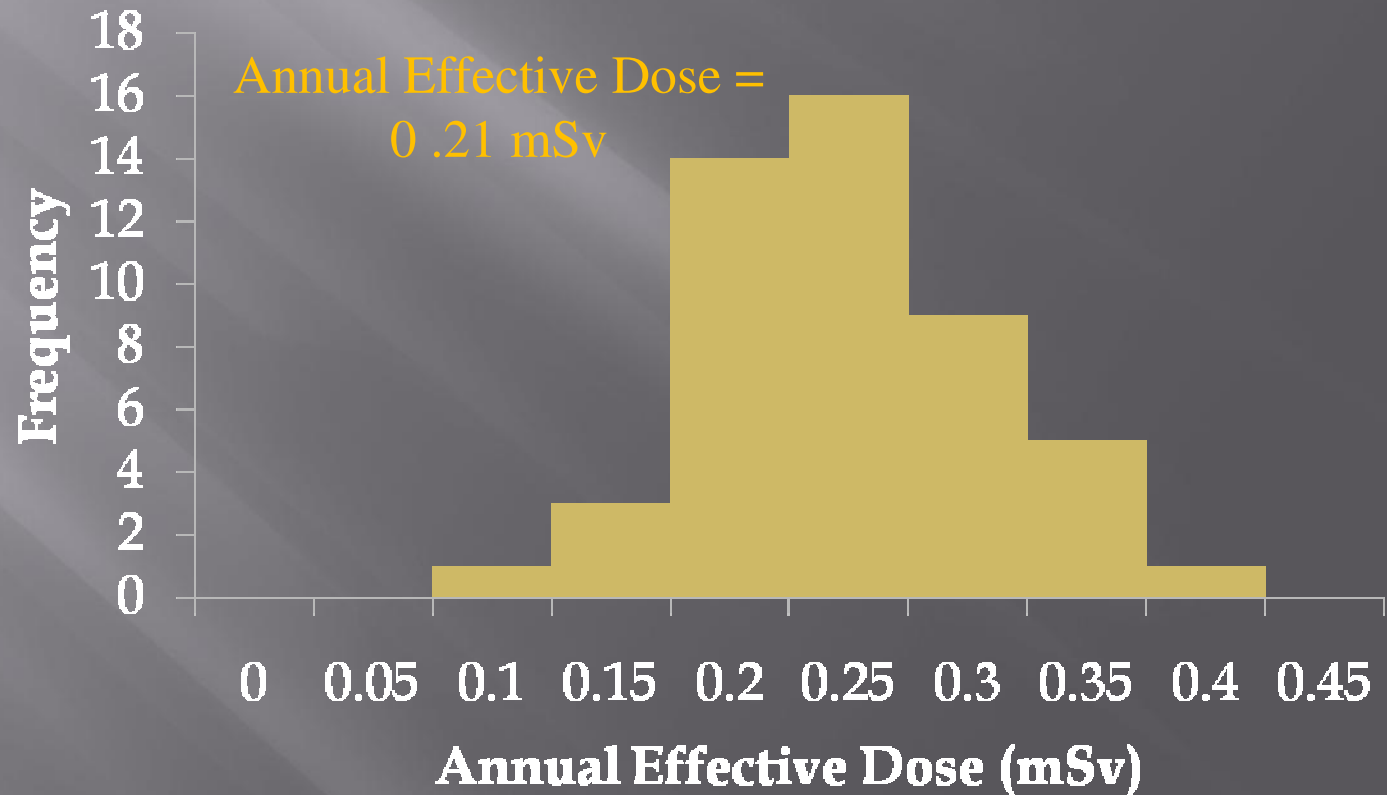


Terrestrial Radiation

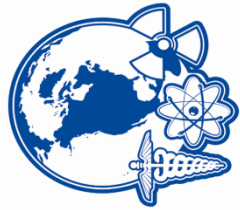


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Terrestrial Radiation in 49 States (excluding Hawaii)



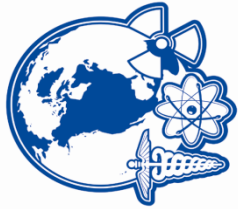
Measured Radon Concentrations



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Concentration (Bq m ⁻³)	University of Pittsburgh		LBNL		EPA	
	(States)	(Counties)	(States)	(Counties)	(Regions)	(Residences)
Arithmetic mean	59.8	65.5	56.6	59.1	49.5	46.3
Standard deviation	25.4	37.8	31.6	39.4	25.2	
Standard error of the mean						4.4
Minimum	22.1	9.7	13.1	6.3	21.1	
Maximum	116	237	141	266	95.8	
Number	46	1,601	49	3,079	10	5,694

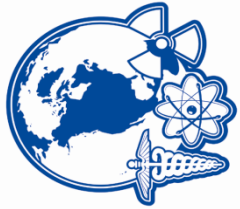
Radon Dose



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- ▣ For indoor exposure an average concentration in U.S. residences of **46.3 Bq m⁻³** is used.
- ▣ The average annual potential alpha energy exposure is estimated to be **0.207 WLM**.
- ▣ Over 40 calculations of dose conversion coefficients show a lognormal distribution with an arithmetic mean of **10 mSv WLM⁻¹** and a standard deviation of **5 mSv WLM⁻¹**.
- ▣ The average adult in the United States receives an annual effective dose to the bronchial epithelium of **2.07 mSv**

Radon Dose



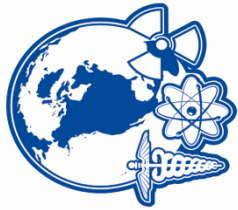
|N|C|R|R|P|

- ▣ Annual Effective Dose:
 - From Rn-222 decay products = 2.07 mSv
 - From Rn-222 gas = 0.05 mSv
 - From Rn-220 gas & decay products = 0.16 mSv

- ▣ Total Annual Effective Dose from radon

2.3 mSv

Internally Deposited Radionuclides

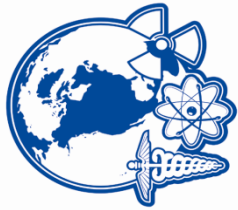


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- ▣ Annual Effective Dose from K-40
 - Males – 0.149 (0.069 – 0.243) mSv
 - Females – 0.123 (0.067 – 0.203) mSv
 - Avg., male & female – 0.136 mSv
- ▣ Annual Effective Dose from Th-232, U-238
 - Avg., male & female – 0.127 (0.050 – 0.138) mSv
 - Infants – 0.132 mSv; children – 0.114 mSv
- ▣ Others (C-14, Rb-87) – 0.01 mSv
- ▣ Total Annual Effective Dose

0.28 mSv

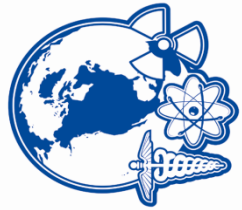
Ubiquitous Background



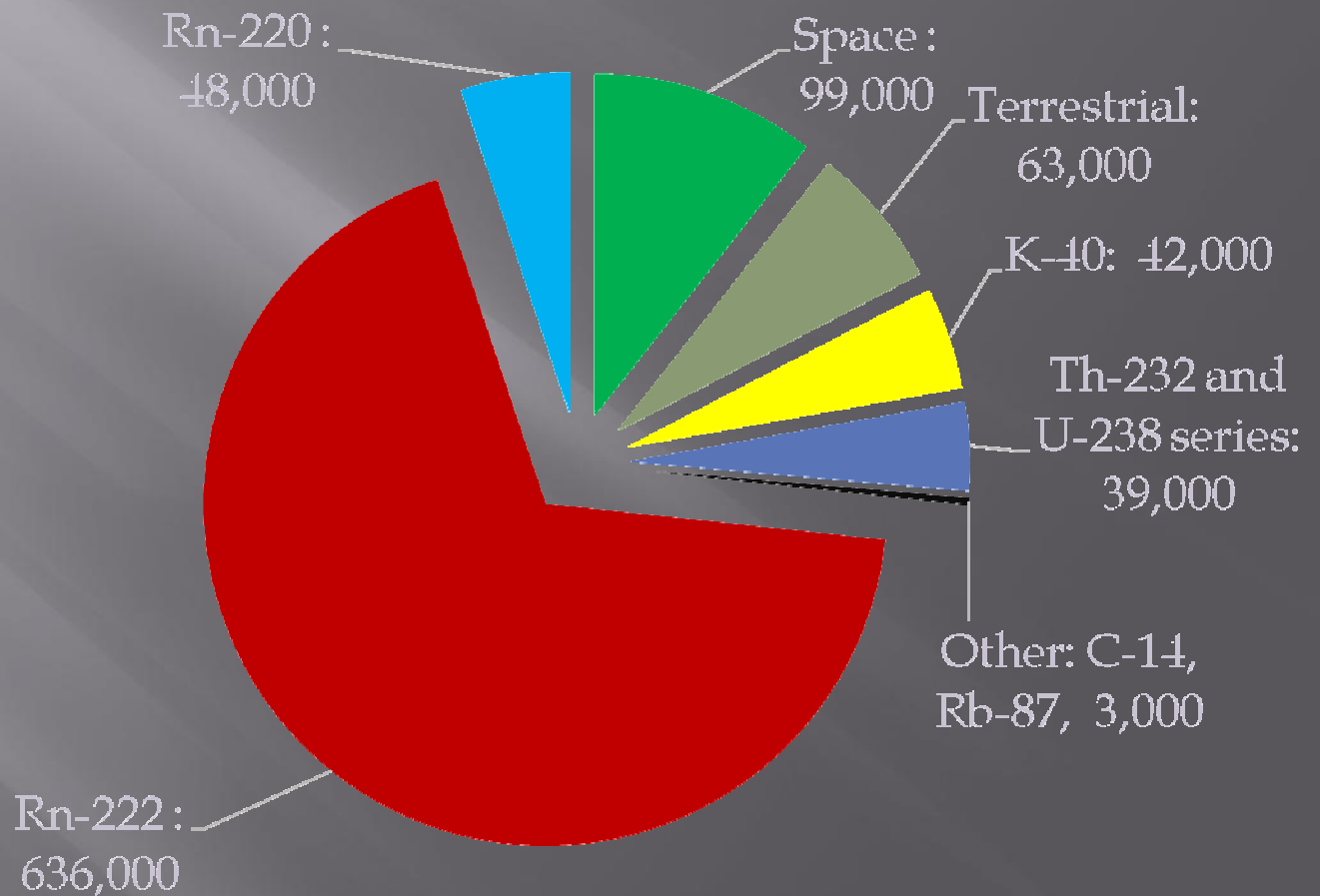
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Source	AM	SD	Percentiles	
	(mSv)	(mSv)	2.5	97.5
Space	0.33	0.08	0.20	0.52
Terrestrial	0.21	0.06	0.12	0.35
Radon-222	2.12	3.99	0.09	11.1
Radon -220	0.16	0.31	0.007	0.80
Internal - K-40	0.14	0.02	0.11	0.21
Internal - U & Th	0.13	0.007	0.11	0.14
Internal - Others (C-14, Rb-87)	0.01			
TOTAL	3.10	3.61	0.94	12.1

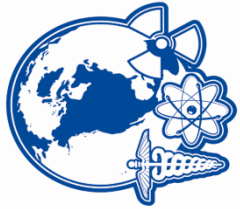
Population Dose (person-Sv) from Sources of Ubiquitous Background Radiation



NCRP



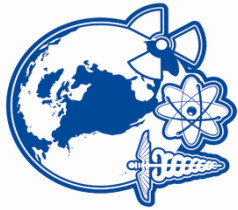
Medical Exposure of Patients



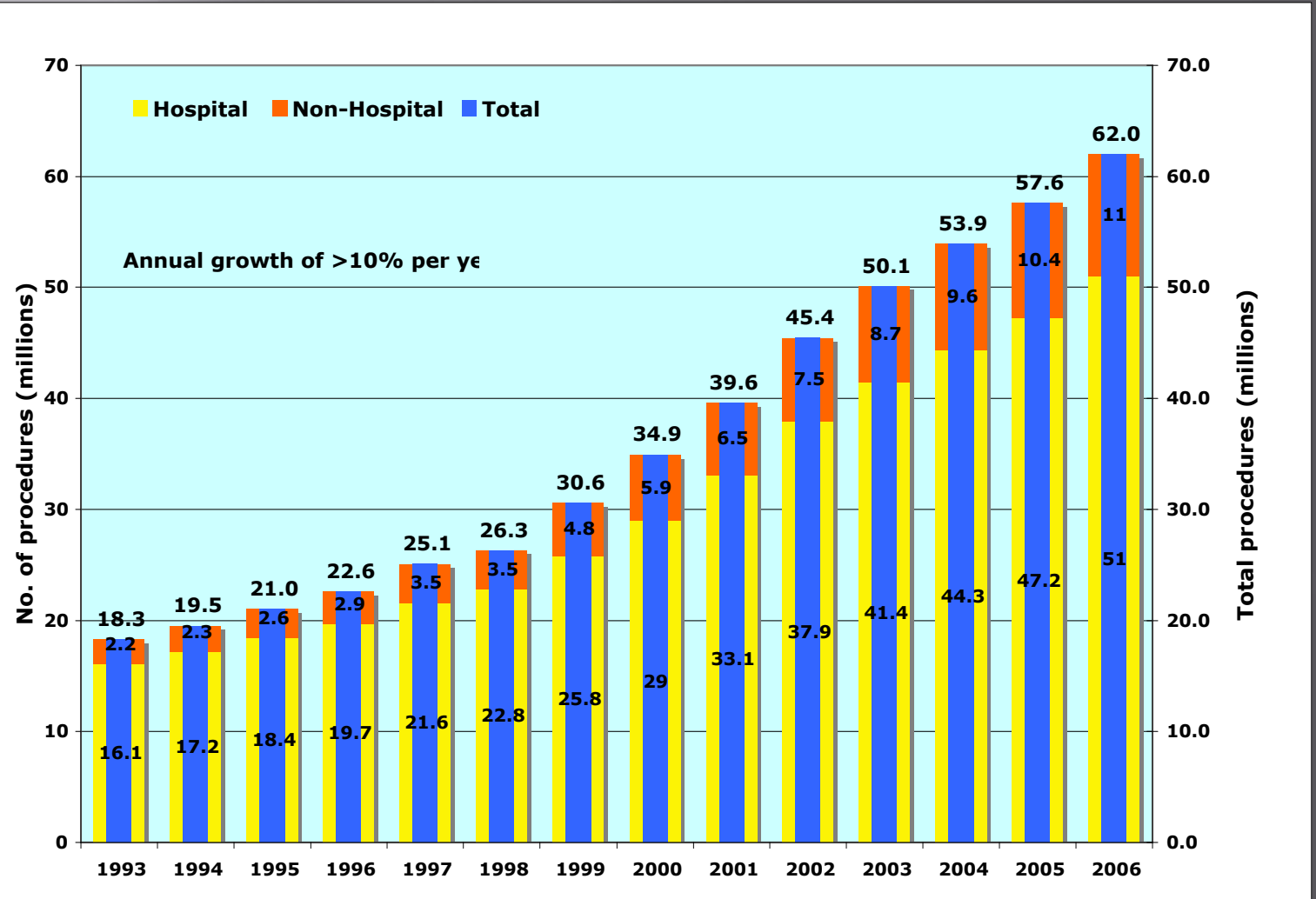
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- ▣ Five subcategories grouped by type of medical modality:
 - computed tomography;
 - conventional radiography and fluoroscopy;
 - interventional fluoroscopy;
 - nuclear medicine; and
 - Radiotherapy (results were not included in the total because of unique considerations).

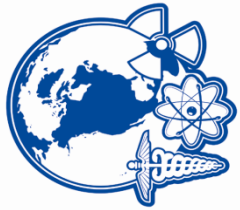
Computed Tomography



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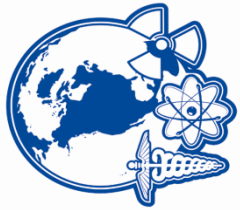
Computed Tomography



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Category	Range of Effective Dose (mSv)	Effective Dose per Scan (mSv)
Head	0.9 - 4	2
Abdomen & pelvis	3 - 25	10
Extremity	0.1 - 1	0.1
Virtual colonography	5 - 15	10
Whole-body screening	5 - 15	10
Calcium scoring	1 - 12	2
Angiography - Head	1 - 10	5
Angiography - Heart	5 - 32	20
Other	1 - 10	5

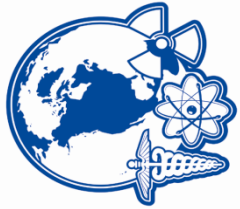
Computed Tomography



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Categories	Scans (%)	S (person-Sv)	S (%)
Head	28.4	38,044	8.7
Chest	15.9	74,326	17.0
Abdomen/pelvis	31.7	212,538	48.6
Extremity	5.2	515	0.1
Angio - Heart	3.4	46,000	10.5
Angio - Head	3.0	10,000	2.3
Spine	6.2	41,369	9.5
Interventional	3.4	230	0.5
Cardiac	0.5	6,000	1.4
Others	2.5	8,500	2.0

Computed Tomography

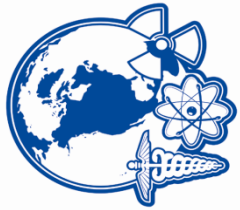


|N|C|R|P|
|N|C|R|P|

- ▣ Total Annual Collective Effective Dose (S):

437,500 person Sv

Conventional Radiography and Fluoroscopy



NCRP

Examination	E per Exam (mSv)	No. Exams (÷ 1000)	S (person-Sv)	S (%)
Chest	0.1	128,944	12,894	12.8
Breast	0.18 (0.42)	34,500	6,210 (14,490)	6.2
Cervical Spine	0.2	5,800	1,160	1.2
Thoracic Spine	1.0	2,590	2,590	2.6
Lumbar Spine	1.5	11,197	16,796	16.7
Upper GI	6.0	4,044	24,264	24.1
Abdomen	0.7	14,964	10,475	10.4
Barium Enema	8.0	656	5,248	5.2
IVP	3.0	1,180	3,540	3.5
Pelvis & Hip	0.6 - 0.7	19,963	13,156	13.1
Other exams	0.005 - 1.7	58,131	1,613	0.7
Dental	0.005 (0.21)	500,000	2,528 (10,500)	2.8

Conventional Radiography and Fluoroscopy



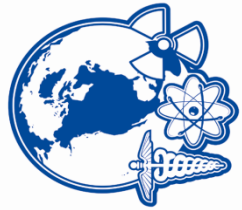
N|C|R|P
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- ▣ Annual Collective Effective Dose (S) :

100,500 person Sv

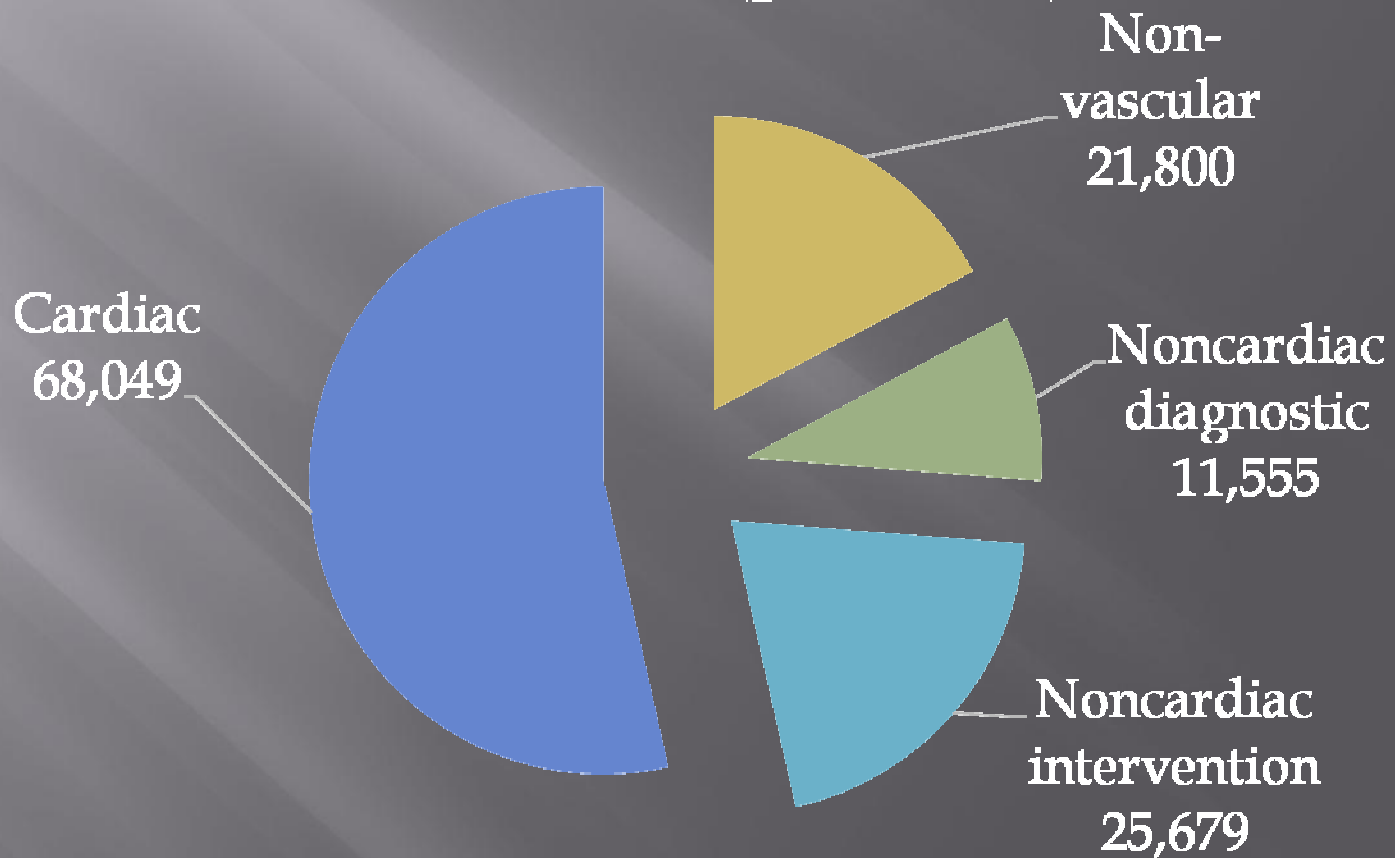
(116,800 person-Sv using ICRP 2007 weighting factors for breast and dental exposures)

Interventional Fluoroscopy

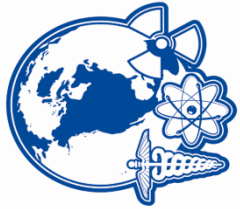


NICRP

Interventional Fluoroscopy Annual S (person-Sv)



Interventional Fluoroscopy

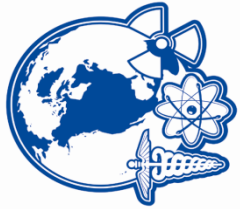


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|N|C|R|P

- ▣ Total number of procedures:
16,735,650
- ▣ Annual Collective Effective Dose (S):

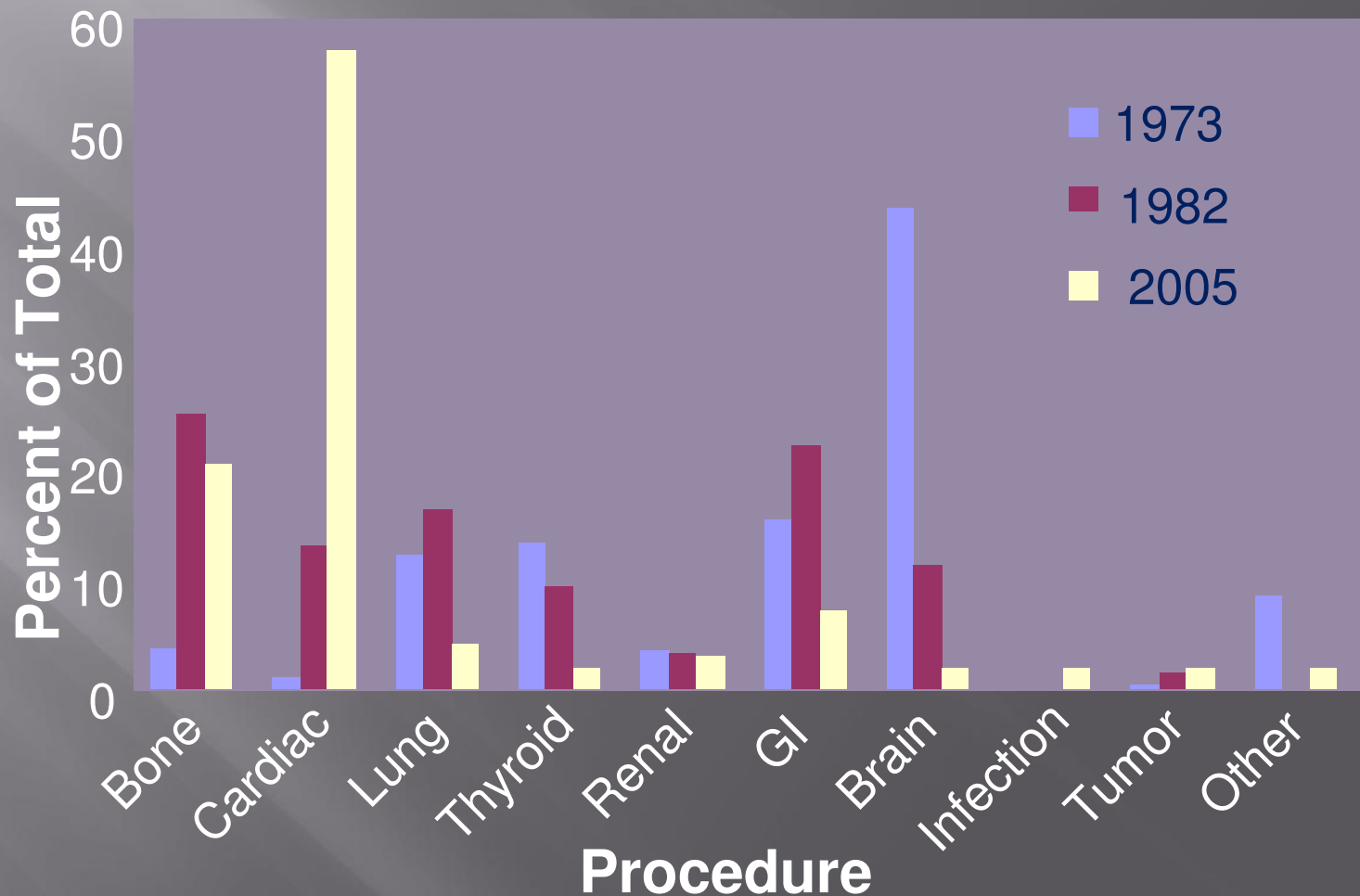
128,400 person-Sv

Nuclear Medicine

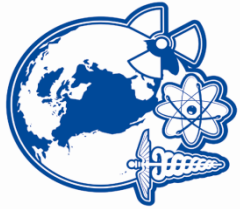


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Change in Nuclear Medicine Procedures

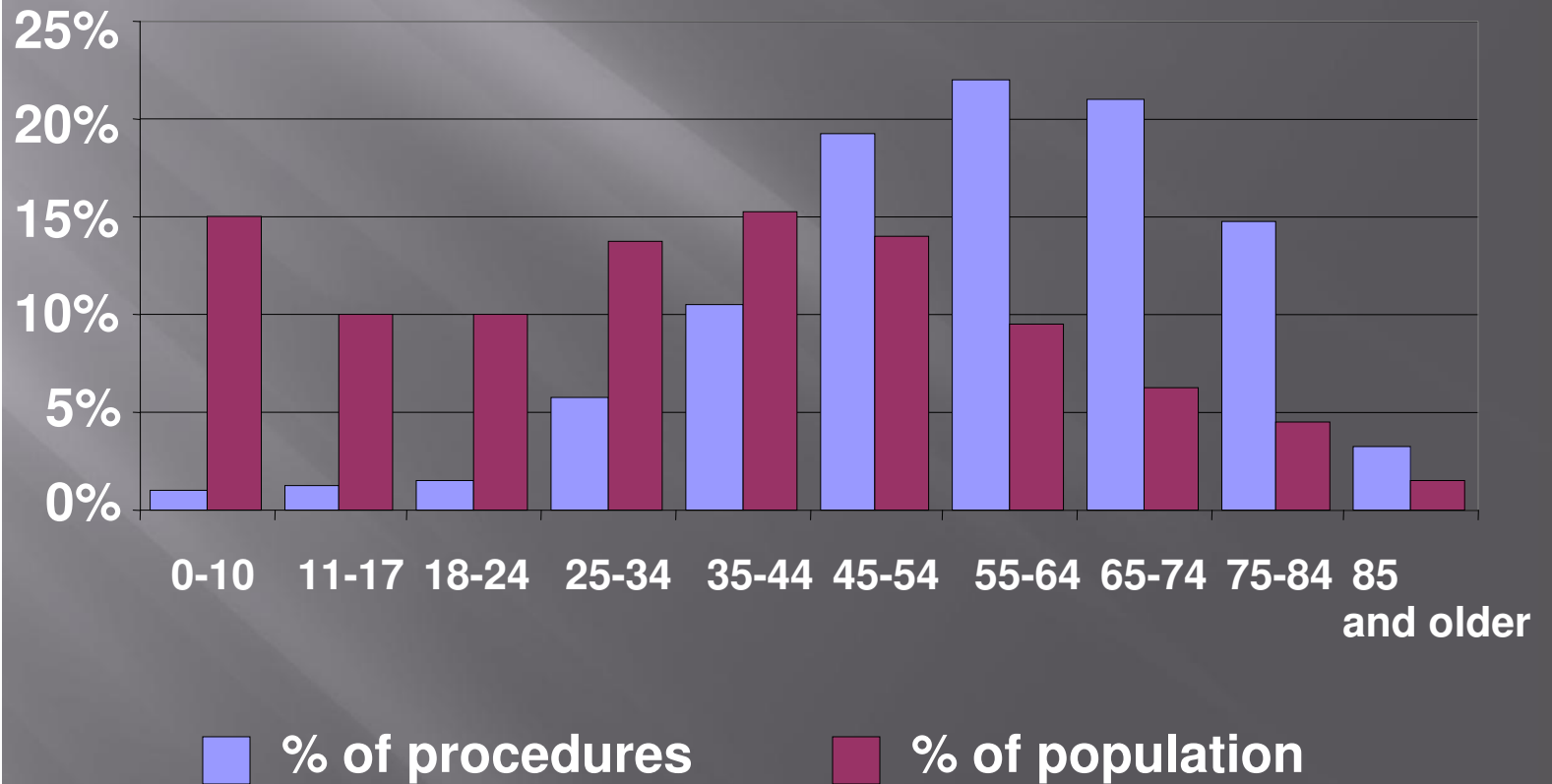


Nuclear Medicine



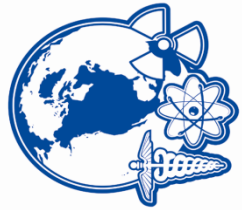
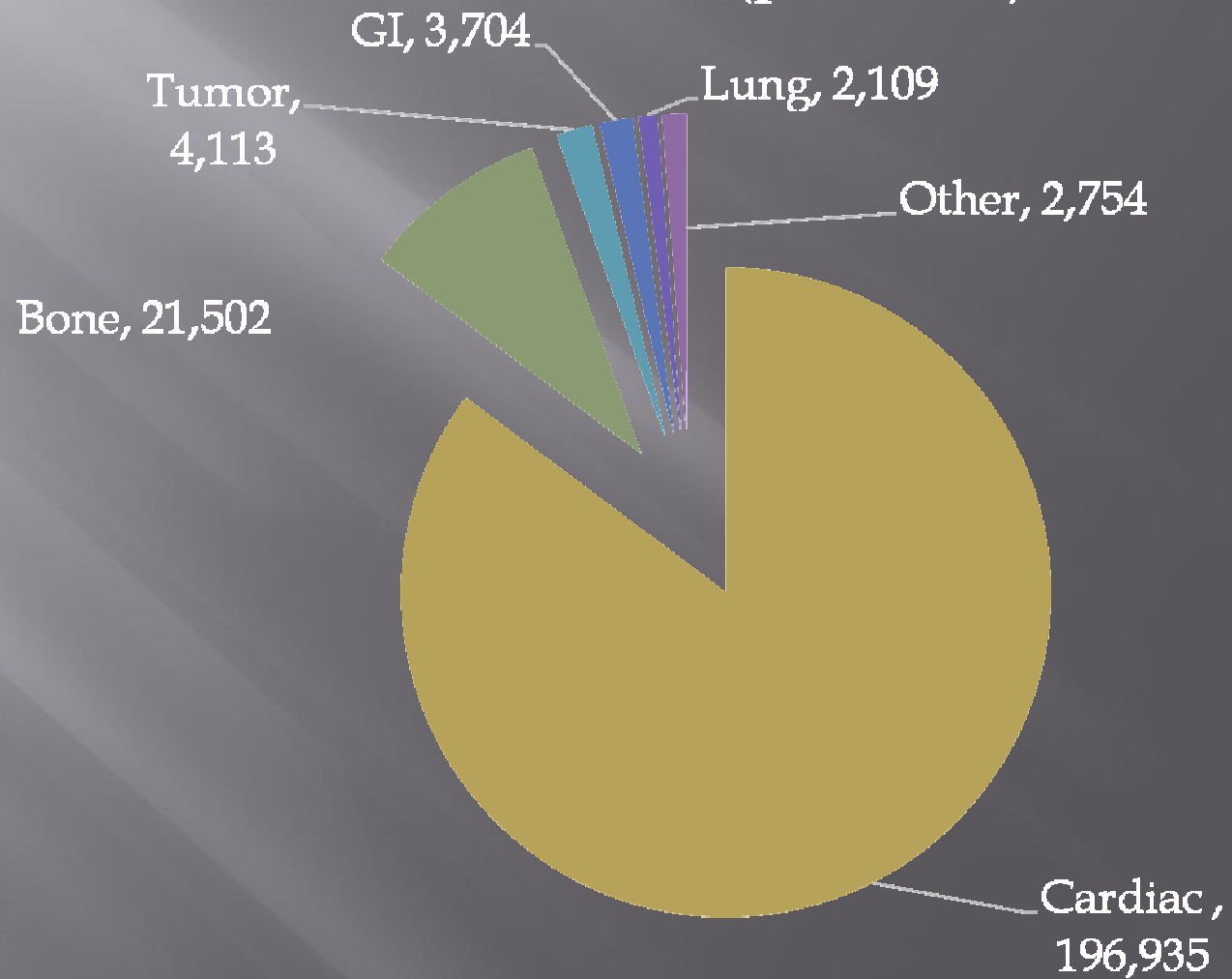
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Nuclear medicine: Age distribution, 2003
Relative to the US population age distribution



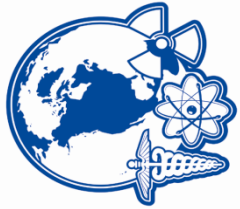
Nuclear Medicine

Annual S (person-Sv)



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Nuclear Medicine



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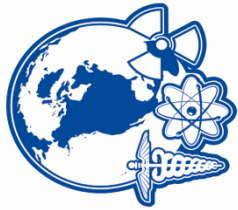
- ▣ Total number of procedures:

18,100,000

- ▣ Annual Collective Effective Dose:

231,000 person-Sv

Radiation Therapy



NCRP

Treatment Site	No. Patients	Effective Dose (mSv)	S (person-Sv)
Breast	212,558	337	71,632
Prostate	197,865	949	187,774
Lung	134,196	187	25,095
Head & Neck	69,547	319	22,185
Colorectal	57,792	258	14,910
Gynecological	52,895	240	12,695
Brain Metastasis	48,977	29	1,420
Brain Primary	39,181	59	2,312
GI	35,263	233	8,216
Lymphoma, Leukemia	23,509	333	7,828

Radiation Therapy



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- ▣ Total number of patients:

872,000

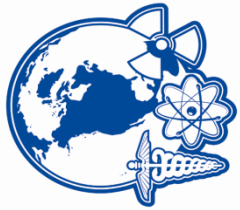
- ▣ Annual collective effective dose:

354,000 person-Sv

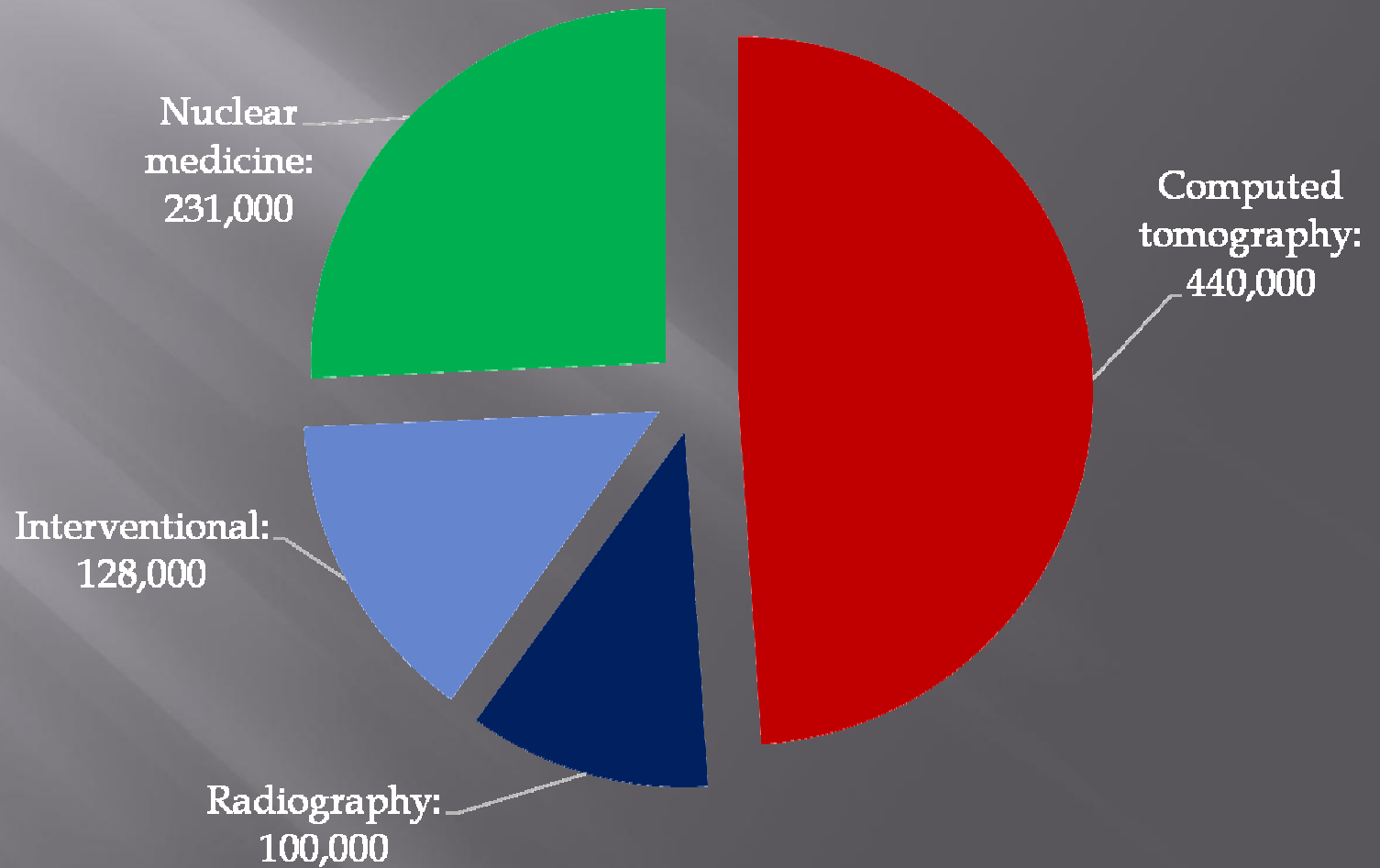
- ▣ Effective dose per patient:

406 mSv

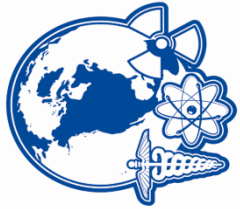
Population Dose (person-Sv) from Medical Exposure of Patients



NICRP



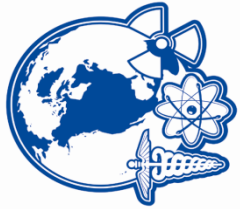
Consumer Products & Activities



NIEHS

- ▣ Eight subcategories grouped by the origin of the source:
 - cigarette smoking,
 - building materials,
 - commercial air travel,
 - mining and agriculture,
 - combustion of fossil fuels,
 - domestic water supplies,
 - highway and road construction materials, and
 - glass and ceramics.

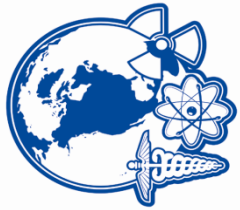
Consumer Products & Activities



NCRP

- ▣ Potential sources that are not discussed further in this Report (refer to NCRP, 1987d, Table 5.1) include:
 - Dental prostheses
 - Ophthalmic glass
 - Luminous watches and clocks
 - Gas and aerosol (smoke) detectors
 - Electron tubes
 - Thorium products (including gas mantles and welding rods).

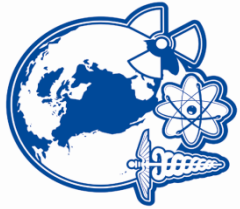
Cigarette Smoking



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Annual effective dose (μSv) for one cigarette per day .						Reference
^{226}Ra	^{228}Ra	^{210}Pb	^{210}Po	Range	Avg	
1.3-6.7	0.6-3.3	1.7-4.3	1.7-4.3	5.0-13.3	8.3	Papastefanou
				6.0-20	8.0	Prerez et al
		3.5	1.7			Skwarzec et al
				7.5-25	16.3	Desideri et al
				20-35	27.5	Khater et al
					30	Guilmette
					—	
					18	Overall Avg

Cigarette Smoking

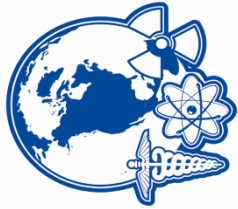


NIC|RIP

Annual collective effective dose

	Cigarettes (per day)	Avg E per Smoker (mSv)	Smokers (millions)	Σ (person-Sv)
Men	18	0.32 (0.09 – 0.6)	25	8,100 (2,250 – 15,000)
Women	15	0.27 (0.08 – 0.5)	20	5,400 (1,600 – 10,000)
Total				13,500 (~14,000)

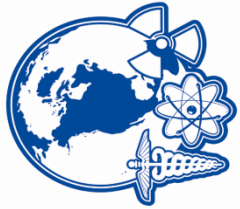
Building Materials



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- ▣ Analyzed the dose from the use of coal combustion products in buildings – similar to dose from brick & masonry
- ▣ Assumed that the radiation dose to individuals living in brick and masonry buildings has not changed since the estimates made in the 1980s
- ▣ Assumed that 50 % of population lives in brick and masonry buildings
- ▣ Use of zircon glazed tiles and fixtures, granite countertops, desktops, wall and floor tiles, and marble could add a small additional collective dose

Building Materials



NIEHS

- ▣ Annual collective effective dose:

10,500 person-Sv

Commercial Air Travel

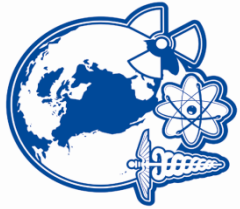


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- ▣ Domestic:
 - 660.7 million passengers
 - Average dose rate - 3.30 μSv per air hour (SD = 1.81 $\mu\text{Sv}/\text{h}$)
 - Average air time - 2.84 h.

- ▣ International:
 - 84.8 million passengers on U. S. carriers
 - Average dose rate - 5.21 μSv per air hour (SD = 0.94 $\mu\text{Sv}/\text{h}$)
 - Average air time - 9.35 h.

Commercial Air Travel

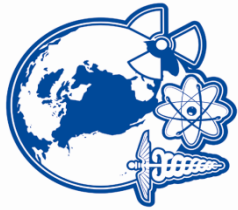


|N|C|R|P|
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- ▣ Annual collective effective dose:

10,300 person-Sv

Other Sources

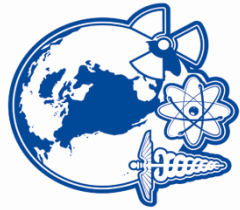


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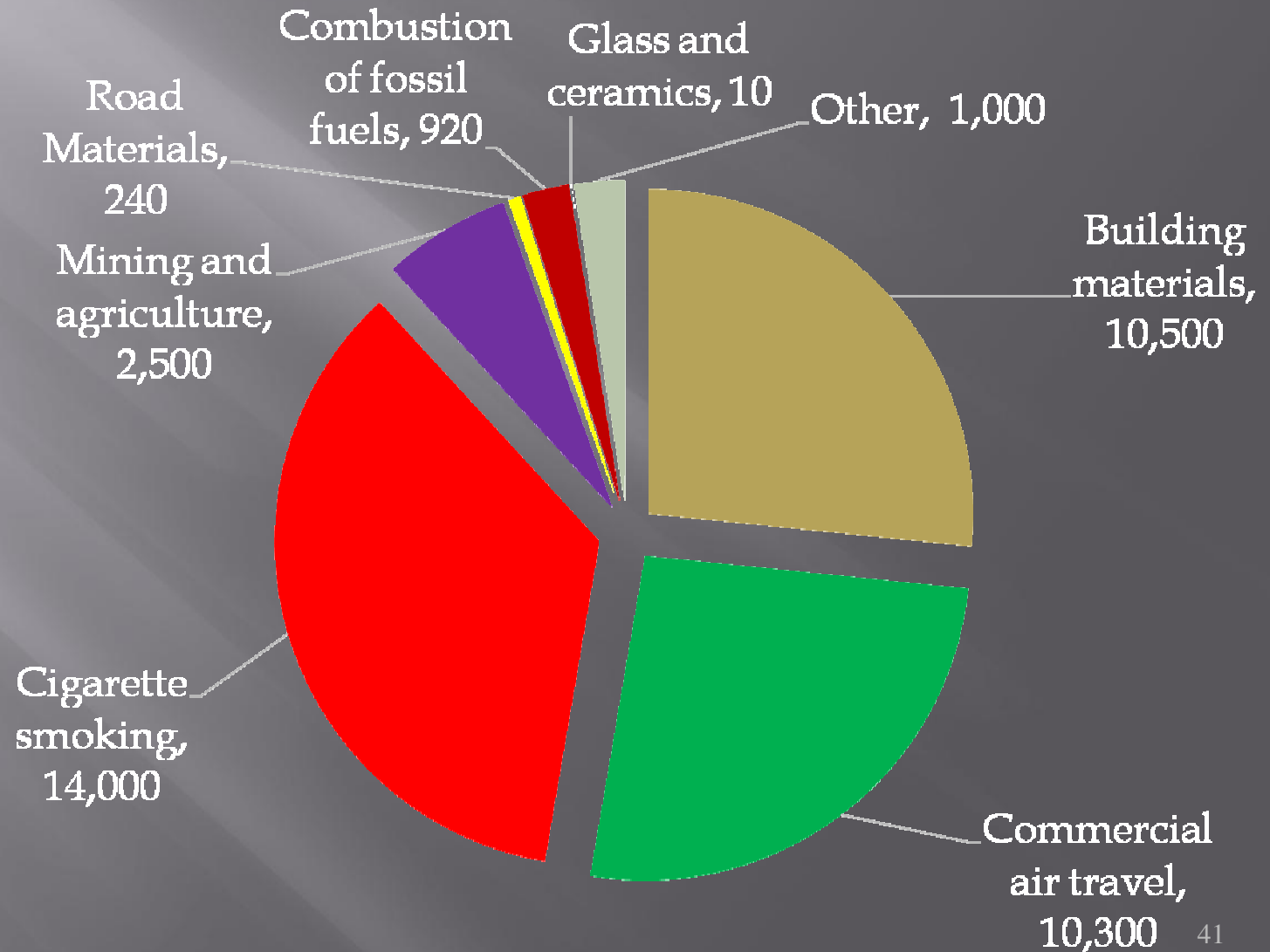
Source	Exposed (millions)	\underline{E}_{Exp} (μSv)	\underline{S} (person-Sv)
Mining and agriculture	250	10	2,500
Combustion of fossil fuels			
Natural gas cooking	155	4	620
Coal	300	1	300
Road construction materials	6	40	240
Glass and ceramics			<10
Other sources			<u>1,000</u>
Total			39,000

Other Sources include: dental prostheses, ophthalmic glass, luminous watches and clocks, gas and aerosol (smoke) detectors, electron tubes, and thorium products (including gas mantles and welding rods).

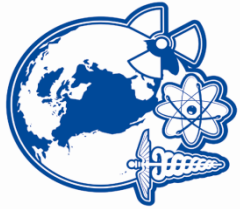
Population Dose (person-Sv) from Exposure to Consumer Products & Activities



NICRP



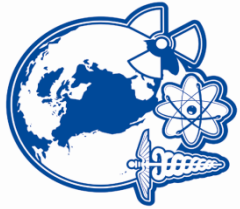
Industrial, Security, Medical, Educational and Research Activities



N|C|R|R|P

- ▣ Six subcategories grouped by activity and associated type of source:
 - nuclear medicine patients;
 - nuclear power generation;
 - industrial, medical, educational and research activities;
 - DOE installations;
 - decommissioning and radioactive waste;
 - security imaging systems.

Nuclear Medicine Patients

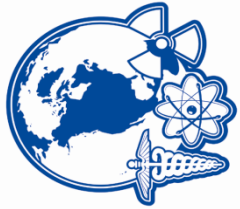


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- ▣ Procedures performed: **8 million**
- ▣ Persons (family and coworkers) exposed during each procedure: **4**
- ▣ Effective dose per procedure (NCRP Report No. 124, 1996): **10 μ Sv**
- ▣ Annual collective effective dose:

720 person-Sv

Nuclear Power Generation

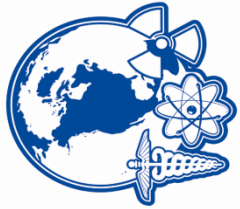


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Annual collective H_E to the regional population normalized to a 1 GWe reactor operating at full capacity 80 % of the time

<u>Facility</u>	<u>Annual Collective H_E (person-Sv)</u>
Mining	0.94
Milling	0.25
Conversion	0.0003
Enrichment	0.0001
Fabrication	0.00004
Nuclear Power Plants	0.048
Transportation	0.125
Total per 0.8 GW _e	1.36

Nuclear Power Generation



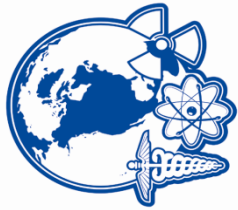
N|C|R|P

- ▣ Operating nuclear power plants in the U S: **104**
- ▣ Installed capacity: **100 Gwe**
- ▣ Capacity factor: **89.6 %**
- ▣ Power generation: **90 GWe**

- ▣ Annual collective effective dose:

153 person-Sv

Industrial, Medical, Educational and Research Activities



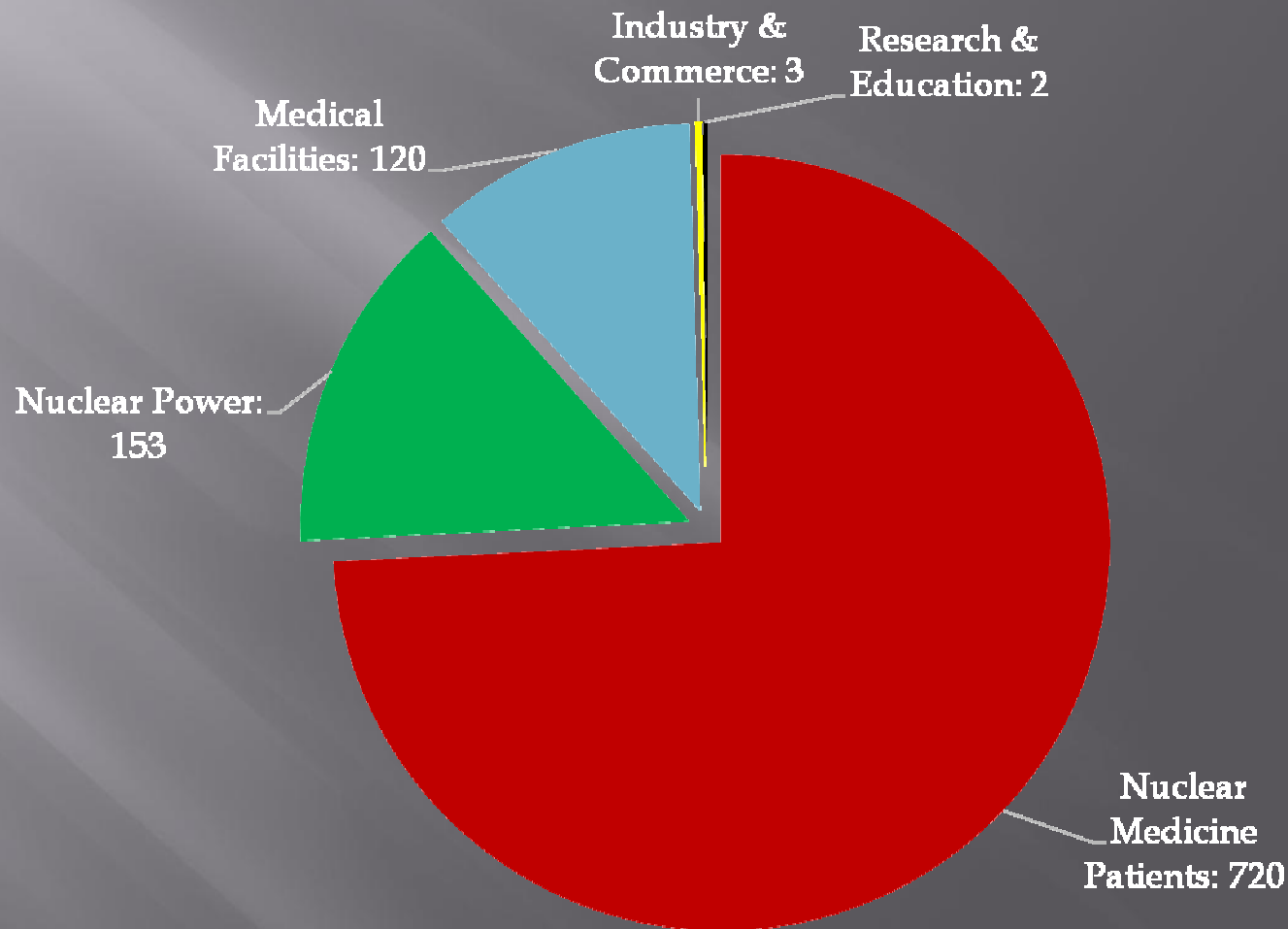
N|C|R|P|E|H

Source	Estimate of Exposed Population	Avg. Dose per Person (mSv)	Collective Effective Dose (person-Sv)
Medical - Occupational	740,000	0.8	550
Public	74,000,000	0.0016	120
Industry and Commerce - Occupational	130,000	0.8	110
Public	1,300,000	0.002	3
Education and Research - Occupational	84,000	0.7	60
Public	840,000	0.0018	2
Total <u>S</u>			125

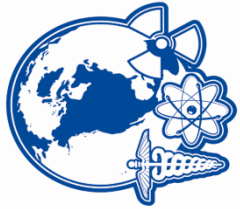
Population Dose (person-Sv) from Industrial, Security, Medical, Educational and Research Activities



NICRP



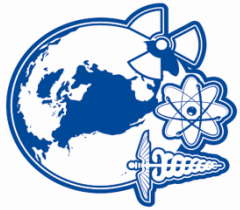
Occupational Exposure



N|C|R|P
N|C|R|P
N|C|R|P
N|C|R|P

- ▣ Six subcategories grouped by the nature of employment and associated type of source:
 - medical;
 - aviation;
 - commercial nuclear power;
 - industry and commerce;
 - education and research; and
 - government, DOE and military.

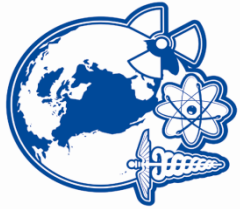
Medical



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Numbers of Workers and Doses	2003	2004	2005	2006
Monitored workers	1,957,088	2,220,861	2,352,976	2,519,693
Workers with recordable dose	690,661	735,400	693,941	735,347
Collective effective dose (person-Sv)	508	559	546	549
Average effective dose (mSv)	0.74	0.76	0.79	0.75

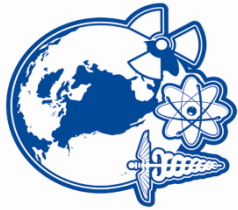
Aviation



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Numbers of Workers and Doses	2003	2004	2005	2006
Monitored airline crew	0	0	0	0
Number of airline crew	177,000	180,000	176,000	173,000
Collective effective dose (person-Sv)	543	553	540	531
Average effective dose (mSv)	3.07	3.07	3.07	3.07

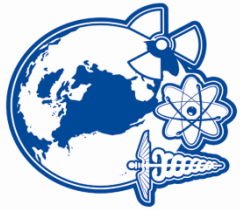
Commercial Nuclear Power



N|C|R|P
N|C|R|P
N|C|R|P

Numbers of Workers and Doses	2003	2004	2005	2006
Monitored workers	109,990	110,290	114,344	116,354
Workers with recordable dose	55,967	52,873	57,566	58,788
Collective effective dose (person-Sv)	120	104	115	110
Average effective dose (mSv)	2.14	1.97	2.00	1.87

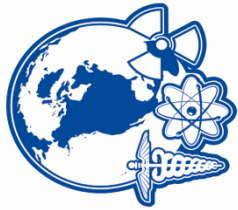
Industry and Commerce



NRC

Numbers of Workers and Doses	2003	2004	2005	2006
Monitored workers	360,069	556,325	579,864	505,369
Workers with recordable dose	112,671	133,926	125,257	134,105
Collective effective dose (person-Sv)	98	114	117	109
Average effective dose (mSv)	0.87	0.85	0.93	0.81

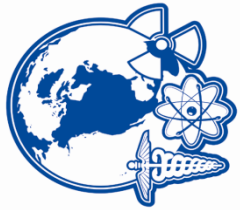
Education and Research



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Numbers of Workers and Doses	2003	2004	2005	2006
Monitored workers	351,309	504,948	514,267	437,007
Workers with recordable dose	79,901	88,125	81,732	83,700
Collective effective dose (person-Sv)	43	73	51	60
Average effective dose (mSv)	0.54	0.83	0.62	0.72

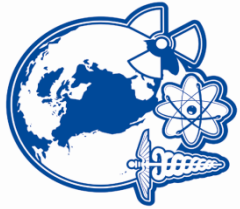
Government, DOE and Military



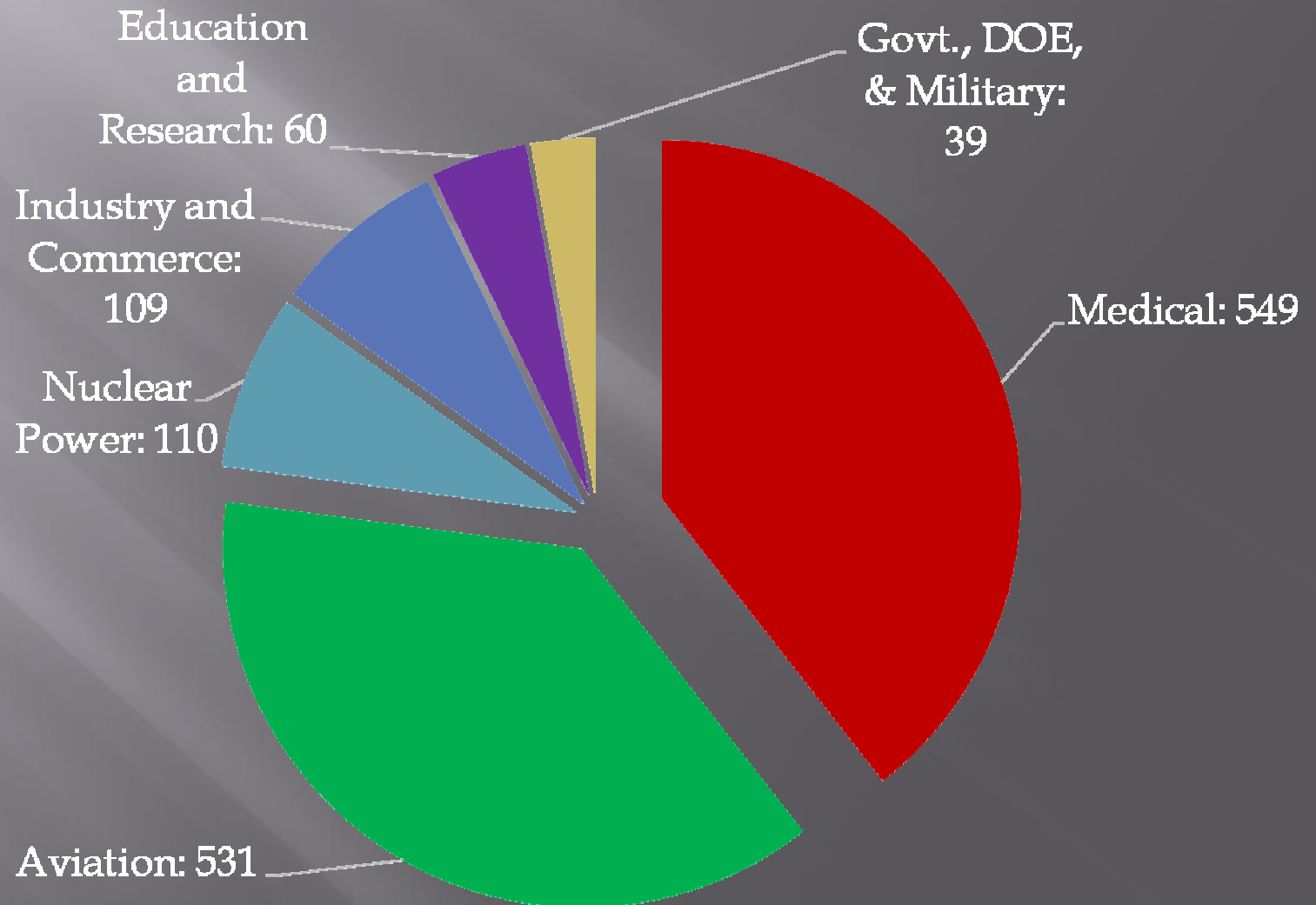
**N
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Numbers of Workers and Doses	2003	2004	2005	2006
Monitored workers	265,870	289,979	301,498	284,192
Workers with recordable dose	36,559	36,788	33,934	30,591
Collective effective dose (person-Sv)	44	49	38	39
Average effective dose (mSv)	0.66	0.73	0.50	0.59

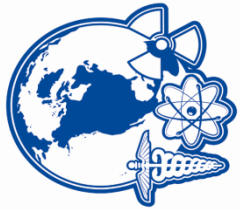
Population Dose (person-Sv) from Occupational Exposure



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N|C|R|P
N|C|R|P



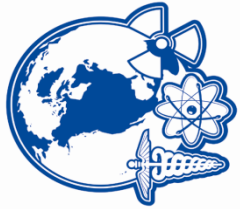
Radiation Exposures to U.S. Population in 2006



N|C|R|P
N|C|R|P
N|C|R|P
N|C|R|P

Exposure Category	S (person-Sv)	E_{US} (mSv)	E_{Exp} (mSv)
Background	933,000	3.11	0.94 - 12.1
Medical	899,000	3.00	
Consumer, etc.	39,000	0.13	0.001 - 0.4
Industrial, etc.	1,000	0.003	0.001 - 0.01
Occupational	1,400	0.005	<1 - 30

Radiation Exposure to U.S. Population in 2006



N|C|R|E|H

- ▣ Collective Effective Dose

1,870,000 person-Sv

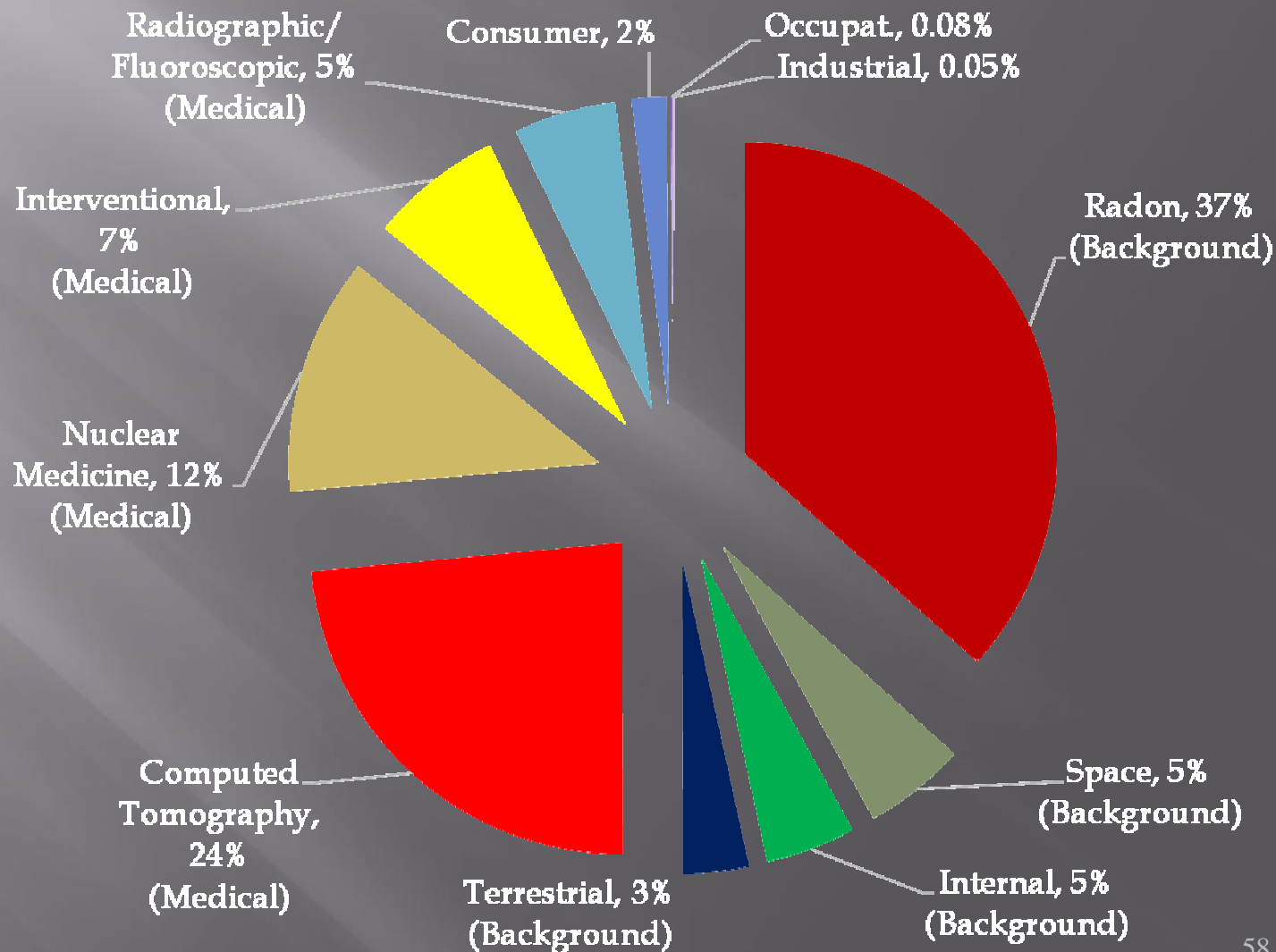
- ▣ Individual Effective Dose

6.2 mSv

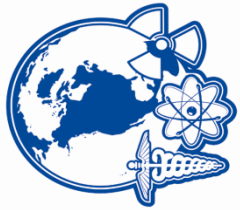
Radiation Exposure to U.S. Population in 2006



NCRP



Radiation Exposure to U.S. Population in 2006



N|C|R|R|P
N|C|R|R|P
N|C|R|R|P

