CHILDREN AND RADIATION

Children's Health and the Environment

WHO Training Package for the Health Sector

World Health Organization

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LEARNING OBJECTIVES
AFTER THIS PRESENTATION INDIVIDUALS WILL:

- Understand basic principles of radiation physics
- Identify the sources of radiation exposure
- Understand the range of potential health effects
- Understand the basic principles of radiation protection and their application in paediatric healthcare
- Be able to describe preventive strategies

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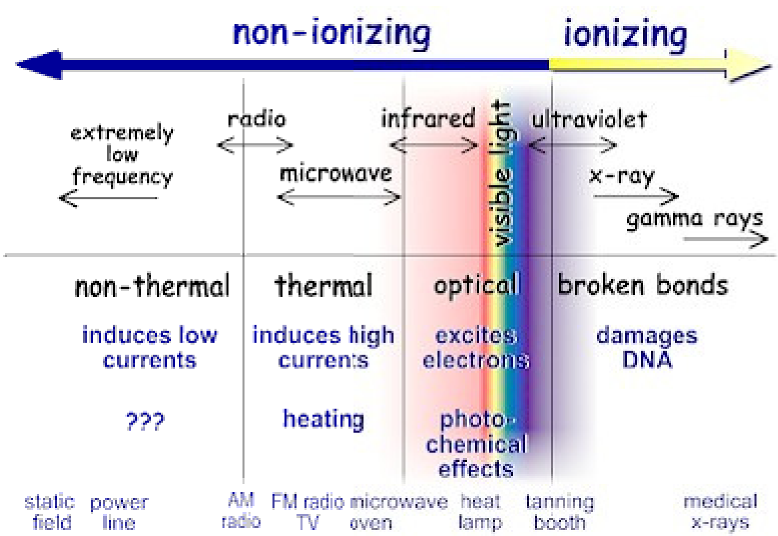
TYPES OF RADIATION



EPA 3

Radiation is energy that is radiated or transmitted in the form of waves or particles.

According to their frequency and energy, electromagnetic waves can be classified as either "ionizing radiation" (IR) or "non-ionizing radiation" (NIR).

Ionizing radiation (IR) has enough energy to remove electrons from atoms, thus creating ions. Its properties can be used for the production of energy, diagnosis and treatment of diseases, agricultural and manufacturing processes.

Non-ionizing radiation (NIR) is a general term for that part of the electromagnetic spectrum which has photon energies too weak to break atomic bonds. It includes ultraviolet (UV) radiation, visible light, infrared radiation, and electric and magnetic fields with diverse applications in communication, industry and medicine.

Image:

•*US Environmental Protection Agency, EPA. Ionizing and non-ionizing radiation. Available at: www.epa.gov/radiation/understand/index.html – accessed December 2009*

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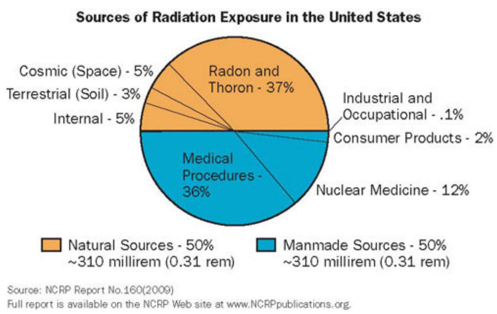
IONIZING RADIATION



U.S NRC

Electromagnetic radiation:

- X-rays (photons, no mass, no charge)
- Gamma rays (photons, no mass, no charge)

Particulated radiation:

- alpha radiation (two protons and two neutrons; positive charge)
- beta radiation (essentially electrons; negative charge)
- neutrons (no electrically charged)

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Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized.

There are two basic types of ionizing radiation: electromagnetic and particulated. Electromagnetic ionizing radiation such as X-rays and gamma rays has discrete packets of energy called "photons" that have neither mass nor electric charge. While X-rays come from the electronic part of the atom, gamma radiation originates in the nucleus. Electromagnetic ionizing radiation is used in pediatric healthcare for both imaging and cancer treatment.

Particulate radiation involves tiny fast-moving particles that have both energy and mass. Particulate radiation is primarily produced by disintegration of an unstable atom and the energy is carried by sub-atomic particles such as electrons, protons and neutrons. Beta and alpha radiation are examples of particulate radiation.

<<READ SLIDE>>

Ionizing radiation is a known carcinogen to which children are particularly vulnerable. Relevant exposures include pre- and postnatal irradiation for medical reasons, radon in the home, and accidental radiation releases. In some cases, children may receive higher doses than adults because of higher intake and accumulation. Furthermore, sensitivity to radiation is highest early in life. Although the mechanism of greater susceptibility is not well understood, it is likely to be linked to greater cell division in growing and developing tissues. In addition, a longer expected lifetime, with a resultant increased chance of repeated exposure and accumulated damage, also leads to higher cancer risk for children. Fetuses might be particularly sensitive to ionizing radiation, since their tissue cells are not only undergoing high rates of division, but are also differentiating into mature functional cells.

Reference:

•*Ionizing radiation, Part 1: X- and gamma-radiation, and neutrons.* Lyon, International Agency for Research on Cancer, 2000 (IARC Monographs on the Evaluation of the Carcinogenic Risk to Humans, Volume 75).

Image:

•U.S NRC (U.S. Nuclear Regularoty Commission) www.nrc.gov/reading-rm/basic-ref/glossary/exposure.html – Reprinted with permission of the National Council on Radiation Protection and Measurements, NCRPonline.org

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TYPES AND ROUTES OF EXPOSURE

Types of exposure

- External exposure
  - Whole body exposure
  - Partial body exposure
  - Localized exposure
- Internal exposure
  - Inhalation
  - Ingestion
  - Skin
  - Wounds
  - Parenteral
  - Transplacental

Routes of internal exposure

- Inhalation
  - Air
  - Water vapor
- Ingestion
  - Contaminated food or water
- Skin, wounds
  - Fall-out, external radioactive contamination
- Parenteral
  - Medical (nuclear medicine)
- Transplacental
  - Maternal contamination

Children can be exposed to radiation by a variety of routes.

<<READ SLIDE>>

UNITS OF MEASUREMENT

Absorbed dose
- **Gray (Gy): 1 Gy = 100 rads**

Equivalent dose
- **Absorbed dose X "radiation weighting factor" (Wr)**
- **Sievert (Sv): 1 Sv = 100 rems**

Effective dose
- **Equivalent dose X "tissue weighting factor" (Wt)**
- **Sievert (Sv) 1 Sv = 100 rems**

The absorbed dose is a measure of the amount of energy actually absorbed in a material, and is used for any type of radiation and any material. Gray (Gy) is the unit of measurement for absorbed dose in the International System of Units (SI). In the old system of units 1 Gy = 100 rads.

One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations Absorbed dose is often expressed in terms of fractions of a gray (e.g. centi-gray: cGy; milligray: mGy).

The equivalent dose is the product of the absorbed dose and a "radiation weighting factor" depending on the quality of the particular type of radiation (e.g. 1 for X-rays, gamma rays and beta particles, 20 for alpha radiation, between 1-10 for neutrons). This weighting factor relates the absorbed dose in human tissue to the effective biological damage of the radiation.

The effective dose is the product of the equivalent dose and a " tissue weigthing factor" which reflects different sensitivities to radiation of different organs and tissues in the human body. It is, in simple terms, the sum of the equivalent doses received by all tissues or organs, further weighted by the “tissue weighting factors”. Effective dose allows to express radiation detriment to the whole body as a summation of doses to different organs. The SI unit for the equivalent and effective dose is the sievert (Sv), where 1 Sv = 1 J/kg. In the old system of units 1 Sv = 100 rems.

HEALTH EFFECTS

- Deterministic
  - Dose-response relationship above threshold
  - Tissue destruction, cell loss
    - Acute radiation sickness
    - Developmental damage from early exposures
- Stochastic
  - Probabilistic
  - Non demonstrated threshold
  - Cells are modified but not killed
    - e.g. somatic cell transformation resulting in cancer

The biological effects of ionizing radiation are the combined result of *direct* absorption of energy at molecular level and the *indirect* oxidative damage produced by the reactive oxygen species ("free radicals") produced through a process called water radiolysis. (i.e. direct and indirect effects). Direct and indirect effects may lead to recognizable damage particularly when they affect molecules of biological importance. The DNA molecule is the principal target for the biological effects of ionizing radiation, including cell killing and mutations leading to non-lethal cell transformation.

Cellular damage from ionizing radiation depends on the type of radiation, the energy deposition rate, and the distribution through the tissue. Biological effects also depend on the radiosensitivity of the tissue exposed. Two kinds of effects of radiation on tissues are observed.

-*Deterministic effects* (or "tissue reactions") occur when a large number of cells have been damaged and as a result of that, the tissue structure or function is affected. These effects occur at doses above a certain threshold, with the frequency and the severity of effects increasing sharply above this threshold. To the extent that the organism is able to compensate for the loss of cells, the harm may be temporary. Examples of deterministic effects are nausea, diarrhoea, skin damage and sterility.

-*Stochastic effects* occur when cells are not killed, but are modified. Some of the changes may persist in daughter cells. Examples of stochastic effects are cancer in the individuals who have been exposed to radiation if the transformation occurred in a somatic cell, and hereditary diseases in descendants of individuals exposed, if the transformation occurred in a germ cell (i.e. oocytes or sperm cells) .

Ionizing radiation is a complete carcinogen since it can act to initiate, promote and progress cellular changes that lead to cancer. The dose of radiation received by an individual affects the probability of cancer, but not its aggressiveness. Radiation-induced cancer is indistinguishable from cancer from other causes. The probabilistic nature of this risk means that children have more time to accumulate exposures and damage, and more time after exposure to develop the disease.

Epidemiological evidence that low doses of radiation may induce cancer in humans is only available for doses higher than 100 mSv. A linear non-threshold (LNT) hypothesis is applied to calculate risks for lower radiation doses. There is no direct epidemiological evidence of radiation-induced hereditary effects in humans, although animal studies suggest that they might occur.

Emerging evidence suggests that radiation exposure may increase the risk of cardiovascular and possible other non-cancer diseases. However, the mechanisms involved are still unclear and further research is needed before considering this effect as part of the radiation detriment.

Reference:

•UNSCEAR (2006). Sources, effects and risks of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, NY. Available at: *www.unscear.org/unscear/en/publications/2006_1.html – accessed December 2009*

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EFFECTS OF WHOLE BODY EXPOSURE TO I.R.

Whole body dose (Gy)	Symptoms	Survival time
20	Damage to the cardiovascular and central nervous system	hours to a few days
8–20	Damage to the gut	about two weeks
3.5	Bone marrow damage	**LD50/60** (50% will die within 2 months if not treated)
0.5–3	Bone marrow damage causing transient reduction in the number of blood cells	All survive, but possible later damage or death (moderate-high probability of stochastic effects)
< 0.5	Stochastic effects may occur later in life	All survive, but possible later damage or death (low probability of stochastic effects)

This table summarizes (in a simplified way) the effects of acute whole body exposure to ionizing radiation (IR).

This values are presented as an example, but they have been estimated for an average population and dose would probably be lower for children.

As can be see, the severity is proportional to the absorbed dose.

LD: lethal dose

LD50/60 is the radiation dose which causes death in 50% of the individuals exposed within 60 days after exposure, without providing treatment (healthy adult, acute exposure, no tretment).

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RADIATION ASSOCIATED CANCERS

- Leukaemia
  - Association with exposure *in utero* to diagnostic x-ray
- Breast Cancer
  - Associated with early check x-ray
- Thyroid Cancer
  - 100 fold increase in children after Chernobyl incident
- Brain Cancer
  - Strongest association when exposure under 20 years of age

Epidemiological studies have shown that moderate and high dose exposure to ionizing radiation leads to an increased risk of cancer. Epidemiological evidence that low doses of radiation may induce cancer in humans is only available for doses higher than 100 mSv. Exposure in childhood, in particular, increases risk of leukaemia, breast and thyroid cancer. Age dependence for these cancers, which are among the diseases most readily induced by radiation, is complex, and generally tracks changes in background rates, i.e. increase in the risk due to radiation is proportional to the overall increase in cancer risk due to aging.

Leukaemia

Studies of survivors of atomic bomb explosions (Life Span Study / LSS) showed an increased risk in both incidence of leukaemia and associated mortality. Furthermore, the risk of leukaemia from radiation is higher than for other risk factors and occurs earlier than for solid cancers. Leukaemia risk is best described by non-linear fit; risk is higher for exposures that occur in childhood, but tends to begin to decrease 10–15 years after exposure. Most of the studies of radiotherapy and diagnostic irradiation confirm an increase in leukaemia risk at high doses.

The observed association between childhood leukaemia and *in utero* exposure to diagnostic X-rays has been interpreted as providing further support for the etiological role of ionizing radiation, despite methodological limitations of some of the studies.

Breast cancer

Breast cancer risk was associated with radiation exposure in the LSS cohort and among several medically exposed groups. The risk increases with dose linearly and is particularly high for those exposed at young ages. The risk of breast cancer was increased in women who were under 10 years of age at the time of the atomic bomb explosion – a time when girls have little or no breast tissue. Women who developed early-onset breast cancer might have been genetically susceptible to radiation. Similar results were observed in women exposed to ionizing radiation due to repeated fluoroscopy. Age at exposure strongly influenced the risk of radiation-induced breast cancer with young women being at highest risk. On the basis of these findings, it is recommended that breasts should be shielded when possible during diagnostic or therapeutic radiation.

Thyroid cancer

Thyroid gland tissue is highly susceptible to radiation during childhood. In the LSS cohort, a significant association was found between radiation dose and risk of thyroid cancer for those exposed before 19 years of age. Irradiation in childhood for benign conditions, as well as therapeutic exposure, can increase the risk of thyroid cancer. Risk is highest for children and decreases with increased age at exposure. The excess risk can be observed for many years after exposure and is highest 15–30 years after exposure. The most dramatic finding after the Chernobyl incident was a large increase in thyroid cancers in children. Some 2000 children have now been diagnosed with thyroid cancer, and in some locations where contamination was highest, as in the Gomel region, the incidence of this cancer increased over 100-fold.

Brain cancer

Ionizing radiation is related to brain tumours, although the relationship is weaker than for the cancers described above. Most brain tumours associated with ionizing radiation are benign. Japanese data show no association with brain cancers, but an increase in malignant brain tumours has been observed in patients who received radiotherapy. The evidence is strongest for those exposed before 20 years of age.

References:

•American Academy of Pediatrics. Risk of ionizing radiation exposure to children: a subject review. *Pediatrics*, 1998, 101:717-9.

•Boice JD Jr, et al. Frequent chest X-ray fluoroscopy and breast cancer incidence among tuberculosis patients in Massachusetts. *Radiat Res*. 1991, 25(2):214-22.

•Brenner DJ, et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. *American journal of roentgenology,* 2001, 176(2):289-96.

•Coursey C., et al. Pediatric chest MDCT using tube current modulation: effect on radiation dose with breast shielding. *AJR Am J Roentgenol*. 2008, 190(1):W54-61.

•Land CE, et al. Early-onset breast cancer in A-bomb survivors. *Lancet*, 1993, 342(8865):237.

•Tilyou SM. NRC issues interim rule on medical use of radionuclides. *Journal of nuclear medicine*, 1990, 31(11):20A-21A.

•United Nations Scientific Committee on the Effects of Atomic Radiation. *Effects on Ionacing Radiation. Report to the General Assembly, with Scientific Annexes.* New York, United Nations, 2006, Volume I, Annex A . Available at *www.unscear.org/docs/reports/2006/07-82087_Report_2006_Web.pdf* – accessed December 2009.

HEAD CIRCUMFERENCE AND MENTAL RETARDATION

- Effects of ionizing radiation on the developing brain
- Prenatal exposure: highest risks gestational weeks 8-15
  - Dose-dependent relationship
  - Mental retardation
  - Reduced head circumference
  - Concern about CT scans in premature and sick term infants
    - 100 mGy per study

Fetal exposure to radiation has been associated with severe mental retardation in the LSS study. A dose-dependent relationship with reduced head circumference was reported. The risk depended on gestational age, and was most severe at 8–15 weeks of gestation, when the frequency of severe mental retardation in the LSS was 40% per Sv, decreasing to 10% per Sv when prenatal exposure occurred between weeks 16-25. No mental retardation was observed in children prenatally exposed to ionizing radiation after the week 25. This effects show a threshold between 100-200 mSv, depending on the gestational age.

As a result, it is recommended to avoid exposure to radiation of pregnant women as much as possible. If the procedure is necessary and justified, the protection should be optimized in order to reduce the fetal dose as much as reasonably achievable, according to the medical purpose.

Considering the effects of radiation in the developing brain, and taking into account that the central nervous system is still under development during the first three years of life, frequent radiological examinations over short periods should be avoided early in life, particularly when other imaging techniques are available. This is specially important for computerized tomography (CT) scans, because of the potentially high exposure of the head of an infant during such procedures (around 100 mGy),

Reference:

•Lee S, et al. Changes in the pattern of growth in stature related to prenatal exposure to ionizing radiation. *International radiation biology*, 1999, 75(11):1449-58.

MEDICAL EXPOSURES IN CHILDREN

- X-Rays, invaluable medical tool
  - Shield breasts when possible
  - Justify the procedure (appropriateness criteria/referral guidelines)
  - Minimize dose
  - Ensure necessity
- CT scans deliver higher doses
  - Alternative imaging for prematures and infants
  - Justify the procedures (appropriateness criteria/referral guidelines)
  - Minimize dose (low-dose protocols)

The radiation exposure from a single diagnostic procedure is usually small. However, many people undergo radiological examinations, some of them rather frequently, making these procedures the highest human-made source of radiation exposure. Because of the increased lifetime risk per unit dose for children, the potentially higher doses, and the increasing frequency of paediatric computerized tomography (CT) examinations, diagnostic procedures that use radiation can lead to a small, but non-negligible, increase in risk of cancer. While these procedures are undisputedly beneficial, the magnitude of exposure of children can often be reduced without significant loss of information.

An area of special concern is the unnecessary use of radiation imaging when clinical evaluation or other imaging modalities could provide an accurate diagnosis (*justification*). Methods for dose reduction should be applied to optimize protection, keeping the dose commensurate with the medical purpose (*optimization* of radiation protection). JUSTIFICATION and OPTIMIZATION are the two principles of radiation protection in medical exposures to ionizing radiation. From a radiological protection perspective, clear justification of radiological examinations for children and young adults is essential. In addition, dose protocols and techniques have to be adapted to children and young adult patients while providing the required diagnostic information, thus optimizing protection.

References:

•Brenner DJ, et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. *American journal of Roentgenology*, 2001, 176(2):289-96.

•International Commission on Radiological Protection (ICRP). *Radiation and your patient: a guide for medical practitioners*. Available at *www.icrp.org/docs/Rad_for_GP_for_web.pdf* - accessed December 2009

JUSTIFICATION OF PEDIATRIC CT

- **"Headache in young children in the emergency department: use of computed tomography".**
  Lateef TM et al. Pediatrics. 2009,124(1):e12-17.
- **"Clinical predictors of pneumonia among children with wheezing".**
  Mathews B. et al. Pediatrics. 2009,124(1):e29-36.

The risks of CT are usually small and the risk-benefit balance favors the benefit when CT is used appropriately. However, this risk/benefit balance does no more favor the benefit when pediatric CT scans are performed without a clear clinical indication or when patients receive a higher dose than necessary because adult CT settings are used for children.

Two studies indicate that radiologic imaging is often unnecessary in children who present to the Emergency Department (ED) with headache or wheezing.

-Investigators retrospectively reviewed the records of 364 children (age range, 2–5 years) who presented to one Emergency Department in Washington DC with a chief complaint of headache. Initial history and physical exam showed that 84% of children had headaches that were secondary to an apparent acute illness (usually viral, respiratory, or febrile), trauma, or a known underlying condition (e.g. ventriculo-peritoneal shunt, brain tumor, or chronic non-neurological disease). Among the remaining 58 children with primary headache, 16 underwent head computed tomography (CT) scans; only 1 child had an abnormal finding (brainstem glioma), and this child's history had details suggestive of intracranial pathology. Among children with primary headache who had follow-up information available, no neurological conditions were subsequently discovered (mean follow-up, 28 months).

-In a second study, investigators studied a prospective cohort of 526 patients (age range, 0–21 years) who presented to one ED in Boston with wheezing and who underwent chest radiography for possible pneumonia. Only 5% of children had radiographically confirmed pneumonia as determined by radiologists. Fifteen percent of the cohort received antibiotics for pneumonia, and 36% were hospitalized. Fever (38℃) was significantly associated with increased risk for radiographic pneumonia (positive likelihood ratio, 2.03). The incidence of radiographic pneumonia in children who did not have fever was very low (2%). Oxygen saturation <92% was associated with radiographic pneumonia (positive LR, 3.06), especially in children younger than 2 years. Focal findings on chest exam, respiratory distress, and chest radiographs obtained for first-time wheezing were not associated with radiographic pneumonia. Lack of fever was the only finding on history or exam that helped identify children in whom chest radiography was even less likely to show pneumonia.

Comment: Head CT scans are expensive, carry some long-term risk associated with radiation exposure, and, in this study, did not contribute to the diagnosis of pathology in children without suspicious findings on history or physical exam, even in young children. Similarly, the utility of chest radiography for diagnosing pneumonia in children with wheezing is low, especially in children without fever. Moreover, many consider pneumonia a clinical, not radiographic, diagnosis.

In these two common ED situations, careful history and physical exam can obviate the need for these radiologic tests.

References:

•Lateef TM et al. Headache in young children in the emergency department: Use of computed tomography. *Pediatrics.* 2009; 124:e12.

•Mathews B et al. Clinical predictors of pneumonia among children with wheezing. *Pediatrics* 2009. 124:e29.

REFERRAL GUIDELINES

- Population radiation dose could be reduced by around 30% just applying referral criteria for justification of medical exposures.
- Referral guidelines/ appropriateness criteria: practical tools for justification of radiological procedures.
- Special recommendations for the use of radiological procedures in children.
- Communication between pediatricians and radiologists.
- Consider other modalities which do not use ionizing radiation (e.g. ultrasound or magnetic resonance imaging).

In some countries, healthcare costs and population radiation dose could be reduced by around 30% just applying referral criteria for justification of medical exposures.

In terms of risk reduction, the highest impact of the application of such referral criteria would be observed in the field of pediatric health care.

Referral guidelines and appropriateness criteria are practical tools for justification of radiological procedures.

These guidelines contain special recommendations for the use of radiological procedures in children. Communication between pediatric health care providers and radiologists is essential and radiologists should review reasons and be available for consultation when indications are uncertain. When appropriate, consider other modalities such as ultrasound or magnetic resonance imaging, which do not use ionizing radiation.

Children and Radiation

Image Courtesy of the American Roentgen Ray Society

The Image Gently campaign is an educational and awareness campaign conducted by the Alliance for Radiation Safety in Pediatric Imaging, a 13-member organization consisting of leading medical societies, agencies, and regulatory groups that have joined forces to impact patient care and change practice. It is designed to increase awareness of CT doses to children.

The four key points are:

- Reduce or "child-size" the amount of radiation used;
- Scan only when necessary;
- Scan only the indicated region;
- Scan once; multiphase scanning is usually not necessary in children.

References:

•Evidence-Based Imaging in Pediatrics: Optimizing Imaging in Pediatric Patient Care. Medina L. et al, eds. 1st edition. 2010

•Goske MJ, et al. The 'Image Gently' campaign: increasing CT radiation dose awareness through a national education and awareness program. *Pediatr Radiol*. 2008;38(3):265-9

Image:

•*Image Courtesy of the American Roentgen Ray Society. Available at www.ajronline.org/cgi/content/full/190/2/273/FIG1*

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RADON

- Radon 222 is a radioactive gas released from soil and rocks during natural decay of Uranium and Thorium
- Considered second leading cause of lung cancer, may enhance risk of cancer in smokers
- Geology of the area can predict potential high levels in soil and water
- Radon concentrations indoors depend on construction aspects: building materials; cracks or pores in concrete floor and walls; floor-wall joints; loose pipe penetration; air pressure of a house lower than the surrounding soil, and others
- Highest level in basements and ground floor
- Exposure can also be from water vapor during showering, cooking

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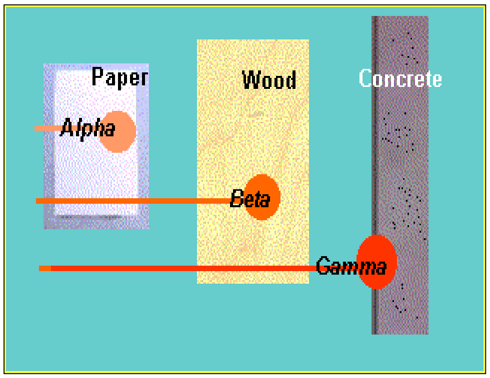
Radon is a radioactive gas that comes from the soil. Exposure to radon gas is the second leading cause of lung cancer (after smoking). Scientific evidence suggests that 3-14% of lung cancers are due to exposure to indoor radon.
Radon is produced from the natural breakdown of the uranium found in most rocks and soils. As it further breaks down, radon emits atomic particles. These particles are in the air we breathe. Once inhaled, they can be deposited in our lungs. The energy associated with these particles can alter cell DNA, thus increasing the risk of lung cancer.

Radon usually does not present a health risk outdoors because it is diluted in the open air. Radon can, however, build up to dangerous levels inside a house. Radon can enter your new house through cracks or openings in the foundation. The differences in air pressure between the inside of a building and the soil around it also play an important role in radon entry. If the air pressure of a house is greater than the soil beneath it, radon will remain outside. However, if the air pressure of a house is lower than the surrounding soil (which is usually the case), the house will act as a vacuum, sucking radon gas inside. Because radon comes from the soil, the geology of an area can help to predict the potential for elevated indoor radon levels.

Reference:

•World Health Organization. WHO Handbook on Indoor Radon: A Public Health Perspective .*WHO, Geneva, 2009*. Available at *www.who.int/ionizing_radiation/env/radon/en/index1.html* - accessed December 2009

PROTECTION FROM IONIZING RADIATION



EPA

- Time
  - Decrease exposure time
- Distance
  - Increase distance from source
- Shielding
  - Introduce shielding
- Develop norms and standards
  - Inspection and enforcement

Effects of radiation can be decreased by decreasing exposure time, increasing distance from source or introducing shielding. Standards have been developed for industrial and medical applications.

References:

•IAEA Safety Standards Series. Radiological protection for medical exposure to ionizing radiation. Co-sponsored by IAEA, PAHO and WHO. Safety Guide No. RS-G-1.5. Available at *www-pub.iaea.org/MTCD/publications/PDF/Pub1117_scr.pdf* - accessed December 2009

•Safety Series. International Basic Safety Standards (BSS) for Protection against Ionizing Radiation and for the Safety of Radiation Sources. Co-sponsored by IAEA, WHO, PAHO, ILO, FAO and NEA/OECD (1996). Safety Series N° 15. Available at *www-pub.iaea.org/MTCD/publications/PDF/SS-115-Web/Start.pdf* - accessed December 2009

Image:

•EPA. Radiation protection. Available at www.epa.gov/radiation – accessed December 2009.

ACUTE RADIATION SYNDROME

- Complex combination of signs and symptoms following acute whole body irradiation.
- Threshold > 1 Gray
- Four clinical phases:
  - prodromal
  - latent
  - manifest illness
  - recovery

The acute radiation syndrome (ARS) occurs after whole-body or significant partial-body irradiation, typically at a dose of > 1Gy. ARS varies in nature and severity, depending upon: (a) absorbed dose measured (b) dose rate, (c) dose distribution, and (d) individual susceptibility. Several clinical syndromes may occur individually or in combination: hematopoietic, cutaneous, gastrointestinal and neurovascular syndromes. ARS follows a clinical course that includes a prodromal phase (48-72 hours after exposure), a latent phase (a brief time period wherein symptoms improve) and a phase of manifest illness (some weeks). The severity of clinical signs and symptoms of ARS correlates with radiation dose. In severe cases ARS may result in death.

References:

•Mettler FA, Jr., Voelz GL. Major radiation exposure--what to expect and how to respond. *N Engl J Med*. 2002;346:1554-61.

•Military Medical Operations. Armed Forces Radiobiology Research Institute**.** Medical Management of Radiological Casualties. Handbook. 2nd ed. Bethesda, USA. Available at *www.afrri.usuhs.mil/outreach/pdf/2edmmrchandbook.pdf* – accessed December 2009.

•TMT Handbook - Triage, Monitoring and Treatment of people in the event of malevolent use of radiation. Available at *www.tmthandbook.org* – accessed December 2009.

Children and Radiation

FOUR CLINICAL PHASES

- **Prodromal**
  - Lasts 2 to 4 days
  - Gastrointestinal symptoms
  - Erythema
- **Latent period**
  - Lasts for approximately 1 to 2.5 weeks
- **Manifest illness phase**
  - Period when overt illness develops
- **Recovery phase or death**
  - May take weeks or months

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- Prodromal phase: occurs in the first 48 to 72 hours and is characterized by nausea, vomiting, diarrhea, intestinal cramps, salivation, and dehydration. Fatigue, weakness, apathy, fever, and hypotension are the result of neurovascular dysfunction. At doses below about 5 Gy it lasts 2 to 4 days. Latent critical cell populations (leukocytes, platelets) are decreasing as a result of bone marrow insult.

- Latent phase is longest preceding bone marrow depression of the hematopoietic syndrome (varies between 2 and 6 weeks). Prior to the gastrointestinal syndrome, the latent period lasts from a few days to a week. Preceding the neurovascular syndrome, the latent period is shortest, lasting only a few hours. These times are exceedingly variable and may be modified by the presence of other disease or injury.

- Manifest phase presents with the clinical symptoms associated with the major organ system injured (bone marrow, intestinal, neurovascular).
Within the acute radiation syndrome is included: hematopoietic syndrome, gastrointestinal syndrome, neurovascular syndrome, and cutaneous syndrome.
- Mortality is increased because of bleeding diathesis complications, prolonged wound healing, and increased risk of sepsis.

Radiation-induced multi-organ dysfunction (MODS) and failure (MOF) refers to progressive dysfunction of two or more organ systems over time. Radiation-associated MODS develops in part, as a consequence of a systemic inflammatory response syndrome (SIRS).

References:

•Fliedner TM et al. Proceedings of the advanced research workshop on radiation-induced multi-organ involvement and failure: A challenge for pathogenetic, diagnostic, and therapeutic approaches and research. Ulm, Germany, November 2003. *British Institute of Radiology*. 2003.

•Gourmelon P et al. Involvement of the central nervous system in radiation-induced multi-organ dysfunction and/or failure. *BJR* Suppl. 2005, 27:62-8.

CASE EXAMPLE

- 6 year old girl comes to a public health clinic with severe nausea and vomiting
  - Previously in good health
  - No remarkable findings on physical exam

Questions to ASK in the history

- Who? (family and friends also ill)
- What? (no fever, diarrhea or bloody stools)
- When? (started 1 day ago)
- Why? (playing with blue powder)
- Where? (at junkyard and home)

Differential diagnosis

- *Staphylococcus aureus* (preformed toxins)
- *Bacillus cereus* (emetic toxin)
- Heavy metals (copper, tin, cadmium, iron, zinc)
- Natural toxins (vomitoxin)
- ???

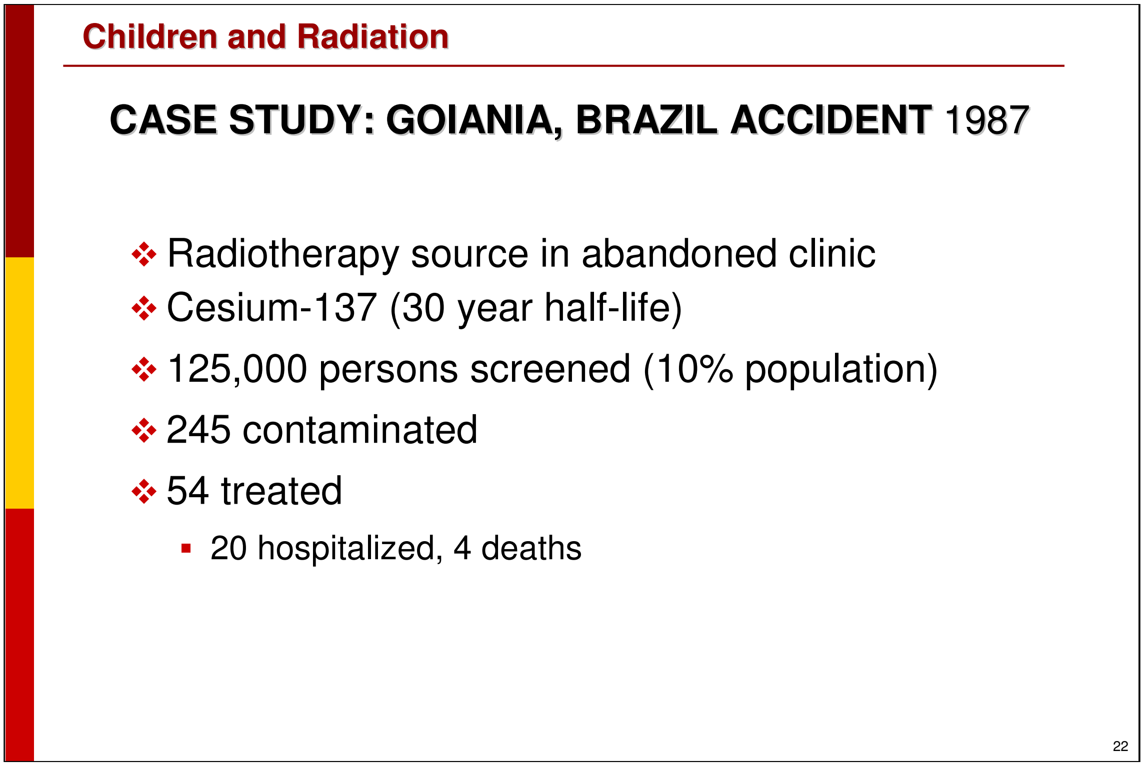
Detailed history

- Uncle was a junkyard dealer, open a lead canister about a week earlier
- Luminous blue powder was in canister
- Child rubbed blue powder on her body so that she glowed and sparkled
- She also ate a sandwich tainted with blue powder from her hands

Diagnosis

Acute radiation syndrome due to internal exposure to "blue powder"

(Cesium-137)



Case study: accidental leakage of Cesium-137 in Goiania, Brazil, in 1987

In September of 1987, scavengers dismantled a metal canister from a radiotherapy machine at an abandoned Cancer Clinic in Goiania, Brazil. Five days later a junkyard worker pried open the lead canister to reveal a pretty blue, glowing dust: radioactive cesium-137. In the following days, scores of Goianian citizens were exposed to the radioactive substance. In a nuclear disaster second only to Chernobyl, the city of Goiania had one of the largest radioactive leaks on its hands and for a few days, they knew nothing about it.

History

In the early 1980's, "three doctors had owned the private downtown [Cancer] clinic...when they left [in 1985], the doctors simply abandoned the radiotherapy machine and left the building to deteriorate without windows or doors". Two years later, the canister containing cesium-137 was found by scavengers. Accounts differ as to who found the canister and how it was opened. However, once the canister was pried open releasing its radioactive contents, tragedy ensued.

Children and Radiation

TREATMENT OF RADIOACTIVE CONTAMINATION

Immediate concerns in radioactive contamination:

1. External decontamination procedures:
   - Remove patient's clothing
   - Wash patient with detergent and water (or have patient take a shower)
2. Measure contamination
3. Evaluate internal contamination and treat (if indicated) with the appropriate decorporating drug

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Treat conventional injuries first - ABCs etc.:

-Initial care should always prioritize conventional injuries (life-threatening conditions) focusing on managing the airway and ensuring adequate ventilation and hemodynamic stability.

-Since radiation does not cause immediate life-threatening risks, serious conventional combined injuries (e.g. burns, wounds, trauma) will take priority over concerns about irradiation and contamination. Radiation injuries can be treated later, once the patient has been clinically stabilized.

- If the clinical condition of the patient is not critical, the first action will be to treat radioactive contamination (following procedures including strict radiation protection measures to prevent contamination to be spread).

- Complete all surgical procedures for irradiated patients within 36 hours of exposure - no quick patches.

- Cytokine marrow resuscitation: begin as early as possible

- If several patients arrive to the hospital, a conventional triage based on clinical conditions will be conducted, identifying levels of priority according to the level of urgency for medical intervention. Then, the radiological triage is aimed to direct patients to the most appropriate level of medical assistance according to the severity of the radiation injury.

Reference:

•TMT Handbook - Triage, Monitoring and Treatment of people in the event of malevolent use of radiation. Available at *www.tmthandbook.org* – accessed December 2009.

PRUSSIAN BLUE ADMINISTRATION

- 46 persons received Prussian Blue
  - Ion exchange chemical, reduces Cesium-137 biological half-time to < 30% previous value
- Dosage related to internal burden
  - For children initial dose 1-1.5 g/day then 3 g/day for up to 3 weeks

In the particular case of the Goiania accident the treatment for internal contaminated patients was oral administration of Prussian Blue, specifically indicated for contamination with Cesium.

For internal contamination with other radionuclides, the therapeutic approach will be different.

Principles of internal contamination treatment are provided in elsewhere (see references) and specialized assistance should be required (e.g. radiotoxicologists).

So far, clinical evidence about use of decorporating and blocking agents for treating internal radioactive contamination is limited. Few agents that have been proven to be effective, such as:

1) Potassium iodide is effective for thyroid blocking in nuclear or radiological emergencies involving release of radioactive isotopes of iodine

2) Diethylene triamine pentaacetic acid (DTPA) is a as a chelating agent to treat internal contamination from radioactive materials such as americium, plutonium, californium, curium, and berkelium.

3) Prussian blue is effective for treating internal contamination with radioactive cesium.

Children are particularly susceptible to thyroid cancer from radiation exposure. Immediate administration of potassium Iodine after a nuclear event can decrease the thyroid uptake of radioactive iodine and therefore decrease the risk of thyroid cancer. This procedure is called iodine thyroid blocking (ITB). It should be emphasized that ITB is indicated ONLY if the emergency involves the release of radioactive isotopes of iodine but it is not not effective in any other situation of internal or external exposure.

Reference:

•Etzel RA, ed. Pediatric Environmental Health. 2nd ed. American Academy of Pediatrics Committee on Environmental Health.; *Elk Grove Village, IL: American Academy of Pediatrics,* 2003.

TREATMENT OF ARS

- According to the severity:
  - Supportive care
  - Cytokines/growth factors
  - Stem cell transplantation

- Daily blood cell counts for 6 days and weekly for 2 months.

The therapeutic strategy for ARS (Acute Radiation Syndrome) is proposed according to the clinical status of the patient.

In this context, patient management can be:

•Outpatient clinical monitoring;

•Hospitalisation for curative treatment;

•Hospitalisation with prediction of MOF.

According to the severity of ARS the treatment will include:

•Supportive care;

•Cytokines/growth factors;

•Stem cell transplantation.

At least daily blood cell counts for 6 days and weekly for 2 months, blood component therapy as necessary, symptomatic treatment of GI damage, reverse isolation.

An international group of experts, coordinated by the Belgian Nuclear Research Centre, has prepared a handbook of information that can be used by clinicians and public health officials in the event of a malevolent act involving radiation. It is called the TMT Handbook and it is available online.

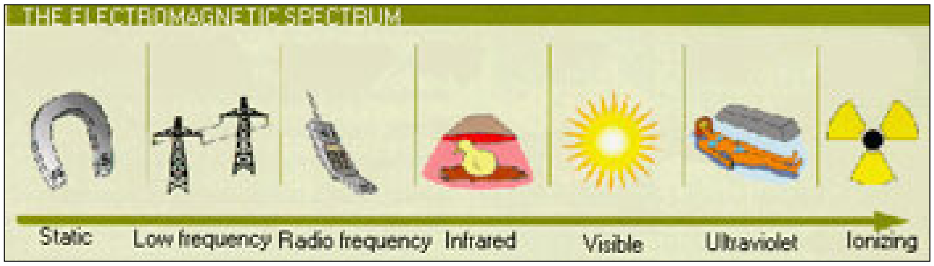
Reference:

•TMT Handbook: Triage, Monitoring and Treatment of people exposed to ionising radiation following a malevolent act. Osteras, Norway: Norwegian Radiation Protection Authority, 2009. Available at *www.tmthandbook.org/index.php?option=com_frontpage&Itemid=1* – accessed December 2009

WHAT IF THE CLINICIAN HAD NOT MADE THE RIGHT DIAGNOSIS?

- The radioactivity would have continued to contaminate the population
- More people may have died

ULTRAVIOLET RADIATION



WHO

- UVA (315-400 nm)
  - Less damaging, concern for long-term exposure
- UVB (280-315 nm)
  - Damages skin and eyes, causes sunburn, implicated in skin cancer
- UVC (100-280 nm)
  - Absorbed in upper atmosphere

Ultraviolet (UV) radiation is part of the electromagnetic spectrum emitted by the sun and exists in the junction between ionizing and non-ionizing radiation. Whereas UVC rays are absorbed by the atmospheric ozone, most radiation in the UVA range and about 10% in the UVB range reach the Earth's surface. Both UVA and UVB are of major importance to human health.

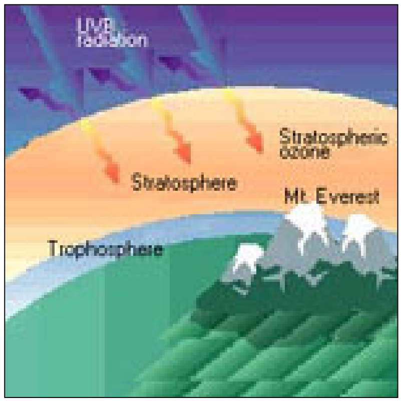
Reference:

•WHO International Programme on Chemical Safety. *Environmental Health Criteria 160 Ultraviolet Radiation.* Available at *www.inchem.org/documents/ehc/ehc/ehc160.htm* – accessed December 2009

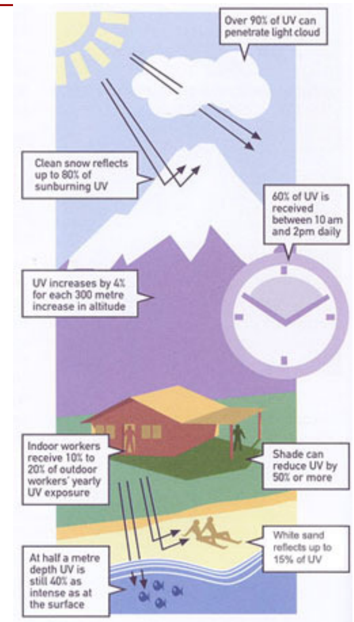
Image:

•*WHO.* Available at *www.who.int/uv/uv_and_health/en/ - accessed December 2009*

ATMOSPHERE FILTERS UV



WHO



WHO

Sun height—the higher the sun in the sky, the higher the UV radiation level. Thus UV radiation varies with time of day and time of year, with maximum levels occurring when the sun is at its maximum elevation, at around midday (solar noon) during the summer months.

Latitude—the closer the equator, the higher the UV radiation levels.

Cloud cover— UV radiation levels are highest under cloudless skies. Even with cloud cover, UV radiation levels can be high due to the scattering of UV radiation by water molecules and fine particles in the atmosphere.

Altitude—at higher altitudes, a thinner atmosphere filters less UV radiation. With every 1000 metres increase in altitude, UV levels increase by 10% to 12%.

Ozone—ozone absorbs some of the UV radiation that would otherwise reach the Earth's surface. Ozone levels vary over the year and even across the day.

Ground reflection—UV radiation is reflected or scattered to varying extents by different surfaces, e.g. snow can reflect as much as 80% of UV radiation, dry beach sand about 15%, and sea foam about 25%.

Depletion of the ozone layer is likely to aggravate existing health effects caused by exposure to UV radiation, as stratospheric ozone is a particularly effective UV radiation absorber. As the ozone layer becomes thinner, the protective filter provided by the atmosphere is progressively reduced. Consequently, human beings and the environment are exposed to higher UV radiation levels, and especially higher UVB levels that have the greatest impact on human health, animals, marine organisms and plant life.

Computational models predict that a 10% decrease in stratospheric ozone could cause an additional 300,000 non-melanoma and 4500 melanoma skin cancers and between 1.6 and 1.75 million more cases of cataracts worldwide every year.

Images:

•*WHO.* Available at *www.who.int/uv/uv_and_health/en/ - accessed December 2009*

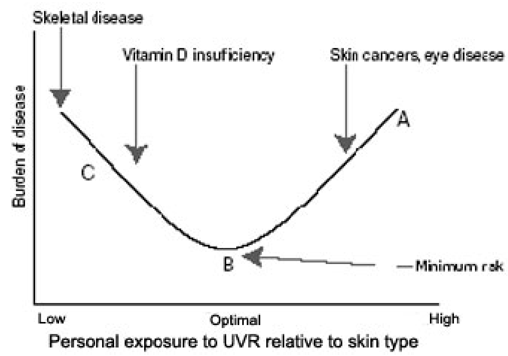
Children and Radiation

NOT TOO MUCH, NOT TOO LITTLE

- ❖ Growing bones need Vitamin D
  - UV is required

BUT

- ❖ Over-exposure in childhood
  - Increases health risks
  - Melanoma rising in children



WHO

Small amounts of UV are beneficial for people and essential in the production of vitamin D. UV radiation is also used to treat several diseases, including rickets, psoriasis, eczema and jaundice. This takes place under medical supervision and the benefits of treatment versus the risks of UV radiation exposure are a matter of clinical judgement.

Prolonged human exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye and immune system. Sunburn (erythema) is the best-known acute effect of excessive UV radiation exposure. Over the longer term, UV radiation induces degenerative changes in cells of the skin, fibrous tissue and blood vessels leading to premature skin aging, photodermatoses and actinic keratoses. Another long-term effect is an inflammatory reaction of the eye. In the most serious cases, skin cancer and cataracts can occur.

It is a popular misconception that only fair-skinned people need to be concerned about overexposure to the sun. Darker skin has more protective melanin pigment, and the incidence of skin cancer is lower in dark-skinned people. Nevertheless, skin cancers do occur with this group and unfortunately they are often detected at a later, more dangerous stage. The risk of UV radiation-related health effects on the eye and immune system is independent of skin type.

Reference:

•*WHO.* Available at *www.who.int/uv/uv_and_health/en/ - accessed December 2009*

WHO IS AT RISK?

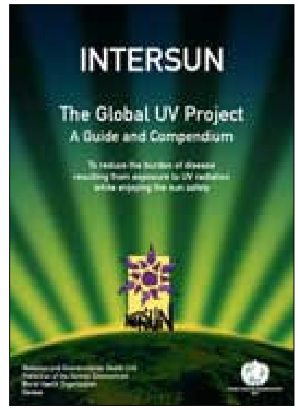
- Lighter natural skin color
- Family history of skin cancer
- Personal history of skin cancer
- Constant exposure to the sun through work and play
- **A history of sunburns early in life**
- Skin that burns, freckles, gets red easily, or becomes painful in the sun
- Blue or green eyes
- Blond or red hair
- Certain types and a large number of moles

Exposure to the sun's ultraviolet (UV) rays appears to be the most important environmental factor in developing skin cancer. This makes skin cancer a largely preventable disease when sun protective practices and behaviors are consistently applied and utilized. The number of skin cancer cases has increased in the United States and elsewhere. Since 1981, the incidence of melanoma has increased a little less than 3 percent per year in the USA. Melanoma is the most common cancer among people 25 to 29 years old.

Reference:

•CDC (Centers for Diseases Control). Skin cancer. Available at *www.cdc.gov/cancer/skin/chooseyourcover/* - accessed December 2009

REDUCING RISK



WHO

- InterSun
  www.who.int/uv/intersunprogramme/en/
- Sunwise Program
  www.epa.gov/sunwise/index.html
- Slip-Slap-Slop Campaign
  www.cancer.org.au/cancersmartlifestyle/SunSmart/Campaignsandevents/SlipSlopSlapSeekSlide.htm

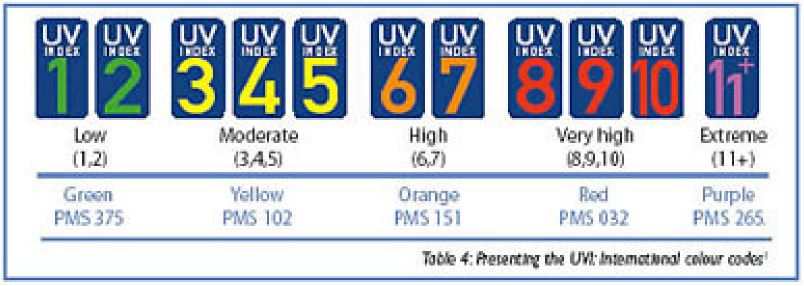
As the epidemic of melanoma and skin cancers has grown, effective public awareness programs have been developed to educate populations at risk about reducing exposure and therefore risk of sun related skin cancers. Here are a few well developed campaigns.

Intersun: At the United Nations Conference on Environment and Development (UNCED) in 1992 it was declared under Agenda 21 that there should be activities on the effects of UV radiation. Specifically, to provide information, practical advice and sound scientific predictions on the health impact and environmental effects of UV exposure; to encourage countries to take action to reduce UV-induced health risks, and; to provide guidance to national authorities and other agencies about effective sun awareness programmes.

REDUCING RISK OF SKIN CANCERS

- Sun avoidance (peak hours)
  - UV index
- Protective structures
  - Shaded playgrounds
- Protective clothing
  - Hats, sun glasses, tight weave clothes
- Sunscreens
- Do not use tanning beds

UV INDEX



WHO

0 to 2 You can safely ***enjoy being outside****!*

3 to 7 Seek shade during midday hours!
Slip on a shirt, ***Slap*** on hat, ***Slop*** on sunscreen!

8 + ***Avoid being outside*** during midday hours!
Make sure you seek shade!
Shirt, sunscreen and hat are a must!

The UV Index (UVI) is a measure of the level of UV radiation.

The values of the index range from zero upward - the higher the UVI, the greater the potential for damage to the skin and eye, and the less time it takes for harm to occur.

The UVI is an important vehicle to alert people about the need to use sun protection.

Image:

•WHO UV Index. Available at www.who.int/uv/intersunprogramme/activities/uv_index/en/ - accessed December 2009.

WHAT ABOUT SUNSCREENS?

Do NOT to expose babies to the sun

If necessary:

- Apply sunscreen generously 30 minutes before going outdoors.
  - Sun Protection Factor (SPF) of 15 or higher
  - both UVA and UVB protection
  - Barrier and chemical forms
- Reapply during the day
- Sunscreen is not meant to allow your kids to spend more time in the sun
- American Academy of Pediatrics now advises that sunscreen use on babies less than 6 months old is not harmful on small areas of a baby's skin

Do NOT expose babies to the sun.

If necessary, follow the advice below.

Sunscreen may be easy, but it doesn't protect your child's skin completely. Try combining sunscreen with other "Choose Your Cover" options to prevent UV damage.

Sunscreen comes in a variety of forms — lotions, sprays, wipes, or gels. Be sure to choose one made especially for kids with:

-Sun Protection Factor (SPF) of 15 or higher

-both UVA and UVB protection

-or most effective protection, apply sunscreen generously 30 minutes before going outdoors. And, don't forget to protect ears, noses, lips, and the tops of feet which often go unprotected.

Take sunscreen with you to reapply during the day, especially after your child swims or exercises. This applies to "waterproof" and "water resistant" products as well.

Keep in mind, sunscreen is not meant to allow your kids to spend more time in the sun than they would otherwise. Sunscreen reduces damage from UV radiation, it doesn't eliminate it.

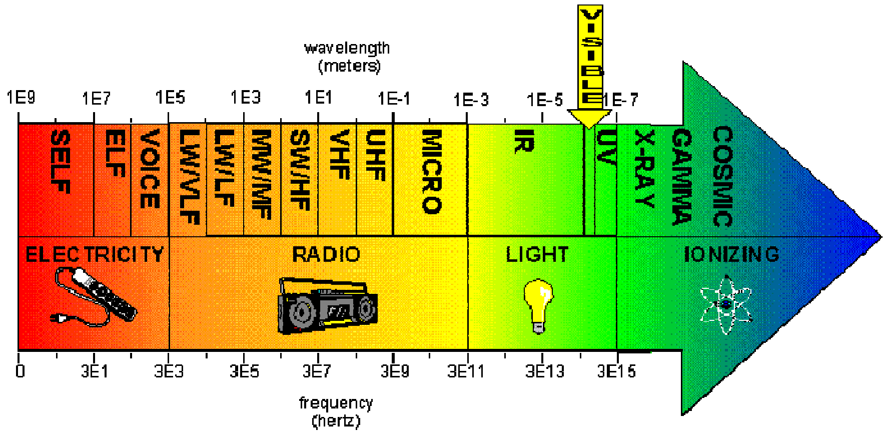
The American Academy of Pediatrics now advises that sunscreen use on babies less than 6 months old is not harmful on small areas of a baby's skin, such as the face and back of the hands. But your baby's best defense against sunburn is avoiding the sun or staying in the shade.

Reference:

•CDC (Centers for Diseases Control). Skin cancer. Available at *www.cdc.gov/cancer/skin/chooseyourcover/* - accessed December 2009

Children and Radiation

NON-IONIZING RADIATION



Utah Department of Environmental Quality

Non-ionizing radiation is electromagnetic radiation that does not have sufficient energy to remove electrons from the outer shells of atoms. Types of non-ionizing radiation are: ultraviolet (UV), visible light, infrared (IR), microwave, radio (and television), and extremely low frequency (ELF, sometimes referred to as EMF or ELF-EMF). Non-ionizing radiation is produced by a wide variety of products in the home and in the workplace, from lasers to power lines, tanning beds to household appliances, cellular phones to ham radios.

Image:

•*Utah Department of Environmental Quality. Available at www.radiationcontrol.utah.gov/DRC_nion.htm – accessed December 2009.*

Children and Radiation

MORE RESEARCH NEEDED ON EMFS

- EMFs ubiquitous in modern life
- Concern about childhood exposures
  - Cell phones
  - TV and computer monitors
  - High tension electrical wires
- No consistent findings of adverse health effects

WHO

Electromagnetic radiation has been around since the birth of the universe; light is its most familiar form. Electric and magnetic fields are part of the spectrum of electromagnetic radiation which extends from static electric and magnetic fields, through radiofrequency and infrared radiation, to X-rays.

A complete training program in this area is available at WHO at www.who.int/peh-emf/about/Training/en/

Additional information is available at

•Health Protection Agency. Radiation. Available at *www.hpa.org.uk/webw/HPAweb&Page&HPAwebContentAreaLanding/Page/1153822623782* – accessed December 2009.

•NIEHS (National Institue of Environmental Health Sciences). Electric and Magnetic Fields. Available at *www.niehs.nih.gov/health/topics/agents/emf/* - accessed December 2009

ELECTROMAGNETIC RADIATION

- Exposure assessment is poor (as sources are many)
- Extremely low frequency (ELF) magnetic fields (mostly from electricity) are considered a "possible carcinogen" based on epidemiologic studies of childhood leukaemia (IARC, 2002, WHO 2007)
- Radiofrequency (RF) fields are being studied with particular attention to potential increased sensitivity of children

Two meta-analyses have shown a **doubling** in rates of childhood leukemia in relation to residential exposure to EMFs (Ahlbom et al., 2000; Greenberg et al., 2000).

WHO (2007) states "epidemiological data…shows an association between ELF magnetic field exposure and an increased risk of childhood leukemia."

References:

•Ahlbom A. et al. A pooled analysis of magnetic fields and childhood leukaemia. *Br J Cancer.* 2000; 83(5): 692–698.

•Greenland S. et al. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Childhood Leukemia-EMF Study Group. *Epidemiology*. 2000, 11(6):624-34.

•WHO. Electromagnetic fields and public health: extremely low frequency fields and cancer fact Sheet. Available at: *www.who.int/mediacentre/factsheets/fs263/en/* - accessed December 2009

Ongoing RF research on children

•**MOBI-KIDS** (13 countries)
- 10-24 year olds
- 5 year study involving 13 countries (including Israel)

•**HPA Wi-Fi study** (United Kingdom)
- Exposure of children from Wi-Fi networks
- To be finalized by 2010

•**MobilEe** (Germany)
- Mobile phone use and well-being
- 8-17 years old

•**MoRPhEUS** (Australia)
- Mobile phone use and cognitive development
- Phase 1: currently being finalized, for 11-14 years olds
- Phase 2: starting in 2009, for 9-10 years olds

•**CEFALO** (Denmark, Sweden, Switzerland, United Kingdom)
- Case-control study of brain tumour risk among children and adolescents (7-19 year olds)

Children and Radiation

Children's exposure can be different ......

- Behaviour
- Timing of exposure
- Duration of exposure

Children's anatomy and physiology is different .....

- Head size (% of brain exposed)
- Skull thickness
- Ear elasticity
- Dielectric properties

When they reach adulthood, today's children will have a much higher cumulative exposure to RF than today's adults

Children and Radiation

World Health Organization

- WHO Fact Sheet 193 (2000)

  "Present scientific information does not indicate the need for any special precautions for use of mobile phones. If individuals are concerned, they might choose to limit their own or their children's RF exposure by limiting the length of calls, or using 'hands-free' devices to keep mobile phones away from the head and body."
- Research on the effects of mobile phone use on children remains a high priority on its research agenda
- Little data is currently available for that age group

ICNIRP and IEEE exposure guidelines

- In their current RF exposure guidelines, no differentiation between children and adults

ICNIRP: International Commission on Non-Ionizing Radiation Protection

IEEE: Institute of Electrical and Electronics Engineers

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