Introduction

• The beneficial uses of radiation in medicine, agriculture, industry and energy production have resulted in the improvement of the quality of life in our societies.

• However, activities involving ionizing radiation may produce harmful effects if they are not carried out under an appropriate regulatory control. Therefore, there is a need to establish a legal framework supporting regulatory programs that ensure the implementation of appropriate measures of radiation protection.

• Radiation protection is a cross-cutting discipline.
Background

- Photon emission (Gamma, X-rays)
- Particle emission (alpha, beta)

External exposure
Internal exposure
Contamination

Absorption
Penetration, Partly absorption
Marginal Penetration of skin

Ref.: BfS/Germany
Radioactivity

Henri Becquerel 1852-1908  Marie Curie 1867-1934

In 1903, Bequerel shared the Nobel Prize in Physics with Pierre and Marie Curie "in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity".

X-ray

X-rays were discovered by Wilhelm Conrad Röntgen 8 Nov 1895
X-ray

• The **first medical use** of x-rays was reported on
  
  23 Jan 1896
  
  (only 76 days later)

  when x-rays were used to locate the piece of a knife in
  the backbone of a drunken sailor, who was paralyzed
  until the fragment was removed.*

  • Radiobiology for the Radiologist (6th ed.)
    • E.J. Hall, A.J. Giaccia
    A more recent x-ray of a knife

X-ray

• The **first unnecessary exposure** took place **several weeks earlier**
The first unnecessary exposure took place several weeks earlier - soon followed by many more.

**Exposure pathways**

**Ionizing Radiation is in our daily life:**
- natural radiation
- man made radiation

**What is low?**
- It can be very costly to consider every dose level explicitly
- Dose levels below ‘regulatory concern’?
- A potential starting point are doses from natural background which are inevitable and one can assume organisms have adapted to them.
Effects of Ionizing Radiation

What can radiation do?

**Deterministic effects**
- death, skin burns, cataract, infertility

**Stochastic effects**
- cancer, genetic effects

Effects of Ionizing Radiation

Radiation

Energy absorbed by cells

Transformation of cells

Stochastic effects

Death of cells

Deterministic effects
Effects of Ionizing Radiation

**Stochastic Effects**
- may arise from any dose;
- have no known threshold;
- have a long latency period;
- have a probability of occurrence depending on the radiation dose.

**Deterministic Effects**
- are the result of high doses;
- have a threshold before they appear;
- appear early (and/or late);
- have a severity of harm depending on the dose.

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**Deterministic Effects - Example**

- Burn from very high dose interventional x-ray procedures
- Elbow injury from irradiator accident

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Stochastic Effects – Limits of knowledge

“For most tumour types in experimental animals and in man a significant increase in risk is only detectable at doses above about 100 mGy.”

UNSCEAR 2000

The need for protection applies to all dose levels!!

- It is generally assumed that even very small doses of ionizing radiation can potentially be harmful (linear no threshold hypothesis)
- Therefore, persons must be protected from ionizing radiation at all dose levels
OBJECTIVES OF RADIATION PROTECTION

- **PREVENTION** of deterministic effect
- **LIMITING** the probability of stochastic effect

Primary aim of radiation protection

Protection for people and environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may associated with such exposure

Model/System for protecting humans and environment against radiation
Paradigm to be maintained

Effects of radiation

Recommendations for protection

Essential principles (moral obligation)

Essential requirements (legal obligation)

The System of Radiological Protection

Biology: deterministic & stochastic effects

Units: activity, specific activity; absorbed, equivalent and effective dose

Principles: justification, optimization, limitation

Ethics: utilitarian & deontological

Exposure situations: planned, existing, emergency

Exposure types: occupational, public, medical

Tools: limits, constraints, reference levels
### The System of Radiological Protection

<table>
<thead>
<tr>
<th>Biology:</th>
<th>deterministic &amp; stochastic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units:</td>
<td>activity, specific activity; absorbed, equivalent and effective dose</td>
</tr>
<tr>
<td>Principles:</td>
<td>justification, optimization, limitation</td>
</tr>
<tr>
<td>Ethics:</td>
<td>utilitarian &amp; deontological</td>
</tr>
<tr>
<td>Exposure situations:</td>
<td>planned, existing, emergency</td>
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<td>occupational, public, medical</td>
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<td>Tools:</td>
<td>limits, constraints, reference levels</td>
</tr>
</tbody>
</table>

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### Quantities and units: Activity

The **activity** of a radioisotope may be described as the number of atomic transformations per unit time within that radioisotope.

\[
1 \text{ Bq} = 1 \text{ disintegration per second}
\]
Absorbed dose
Energy deposited in tissue.

SI unit is gray (Gy)
measured in J/kg

Equivalent dose
Absorbed dose modified by the radiation weighting factor.

SI unit is the sievert (Sv)
Effective Dose

Effective dose is the total of the equivalent doses to each organ multiplied by the appropriate tissue weighting factor. (May be considered to be the whole-body radiation dose)

SI unit is the sievert (Sv)

Quantities and units: Summary

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>A becquerel</td>
</tr>
<tr>
<td>Absorbed dose</td>
<td>D gray</td>
</tr>
<tr>
<td>Equivalent dose</td>
<td>H sievert</td>
</tr>
<tr>
<td>Effective dose</td>
<td>E sievert</td>
</tr>
<tr>
<td>Dose rate</td>
<td>Sv/h, Sv/a</td>
</tr>
<tr>
<td>Specific activity</td>
<td>Bq/m², Bq/m³, Bq/g, Bq/l</td>
</tr>
</tbody>
</table>
## Conversion Non-SI Units to SI Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Old unit</th>
<th>SI unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>curie (Ci)</td>
<td>becquerel (Bq)</td>
<td>$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$</td>
</tr>
<tr>
<td>Absorbed Dose</td>
<td>rad</td>
<td>gray (Gy)</td>
<td>$1 \text{ rad} = 0.01 \text{ Gy}$</td>
</tr>
<tr>
<td>Equivalent Dose</td>
<td>rem</td>
<td>sievert (Sv)</td>
<td>$1 \text{ rem} = 0.01 \text{ Sv}$</td>
</tr>
</tbody>
</table>

## Multiples & prefixes (Activity)

<table>
<thead>
<tr>
<th>Multiple</th>
<th>Prefix</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–</td>
<td>Bq</td>
</tr>
<tr>
<td>1,000,000</td>
<td>Mega (M)</td>
<td>MBq</td>
</tr>
<tr>
<td>1,000,000,000</td>
<td>Giga (G)</td>
<td>GBq</td>
</tr>
<tr>
<td>1,000,000,000,000</td>
<td>Tera (T)</td>
<td>TBq</td>
</tr>
</tbody>
</table>
Fractions & prefixes (Dose)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Prefix</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>Sv</td>
</tr>
<tr>
<td>1/1000</td>
<td>milli (m)</td>
<td>mSv</td>
</tr>
<tr>
<td>1/1,000,000</td>
<td>micro (µ)</td>
<td>µSv</td>
</tr>
</tbody>
</table>

Principles of Radiation Protection

Three key principles of radiation protection are retained!

Justification
Optimization
Dose limitation
Principles of Radiation Protection

• **Justification**

  Any decision that alters the radiation exposure situation should do more good than harm.

• **Optimization of Protection**

  The likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.

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Principles of Radiation Protection

**Dose limitation**

Dose limits should be set to ensure that no individual faces an unacceptable risk in normal circumstances.

**Application of dose limits**

The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission.
Types of Exposure Situations

Planned exposure situations
situations involving the planned introduction and operation of sources (including decommissioning, disposal of radioactive waste, rehabilitation)

Emergency exposure situations
unexpected situations such as those that may occur during or a planned situation, or from a malicious act, requiring urgent attention

Existing exposure situations
situations that already exist when a decision on control has to be taken, such as those by natural background radiation and residues from past practices operated outside the system

Categories of Exposure

Occupational exposures
exposure of workers incurred as a result of their work (with the exception of excluded exposures and exposures from exempt activities; medical exposure; and background)

Public exposures
all exposures of the public other than occupational exposures and medical exposures of patients

Medical exposures of patients
incurred by patients as part of their own medical or dental diagnosis or treatment; volunteers helping in the support and comfort of patients; and biomedical research volunteers
Summary

<table>
<thead>
<tr>
<th>Exposure Category</th>
<th>Planned</th>
<th>Emergency</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupational</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Public</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Medical</td>
<td>✓</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Dose limits vs. dose constraints/reference levels

Protection of individuals from occupational and public exposures

**Dose Limits**
- All regulated sources
- Planned exposure situations

**Constraints & Reference Levels**
- A single source
- All exposure situations
Dose Limits, Constraints, and Reference Levels

<table>
<thead>
<tr>
<th>Exposure Category</th>
<th>Planned</th>
<th>Emergency</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupational</td>
<td>Dose Limits</td>
<td>Reference Levels</td>
<td>n/a</td>
</tr>
<tr>
<td>Public</td>
<td>Dose Limits</td>
<td>Reference Levels</td>
<td>Reference Levels</td>
</tr>
<tr>
<td>Medical</td>
<td>Diagnostic Reference Levels (Dose Constraints)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Dose Limits

- Apply to planned exposure situations
- Apply to occupational and public exposures

<table>
<thead>
<tr>
<th>Dose Limits</th>
<th>Occupational Dose Limits</th>
<th>Public Dose Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Dose (Whole Body)</td>
<td>20 mSv/a averaged over 5 years (and 50 mSv/a)</td>
<td>1 mSv/a</td>
</tr>
<tr>
<td>Equivalent Dose (Lens of the Eye)</td>
<td>20 mSv/a averaged over 5 years (and 50 mSv/a)</td>
<td>15 mSv/a</td>
</tr>
<tr>
<td>Equivalent Dose (Skin)</td>
<td>500 mSv/a</td>
<td>50 mSv/a</td>
</tr>
<tr>
<td>Equivalent Dose (Hands and Feet)</td>
<td>500 mSv/a</td>
<td>-</td>
</tr>
</tbody>
</table>

Dose limits in ICRP = Dose limits in BSS
Dose constraints

- Prospective and source-related restriction on the individual dose from a source
  - an upper bound for optimization
  - a basic level of protection for the most highly exposed individuals

- Occupational: limits the range of options considered in the process of optimisation

- Public: an upper bound on public doses from a planned operation

Ref.: ICRP

Reference levels

- Applied in emergency and existing exposure situations

- Similar to constraints

- Level of dose (or risk):
  - above which it is judged to be inappropriate to plan to allow exposures to occur
  - below which protection should be optimized
Optimization

- Key role and is central to the system of protection and applies to all three exposure situations
- It is a source-related process
- Optimization is a prospective and iterative process that requires both qualitative and quantitative judgments to be made.

Planned exposure situations

1. Added dose
2. Averted dose
3. Residual dose

Emergency and existing exposure situations

1. Limit
2. Optimization
3. Reference level
4. Optimization
5. 2. Averted dose
6. 3. Residual dose
Applicability of the fundamental principles according to the exposure situations

IAEA Safety Standards
for protecting people and the environment

Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards
INTERIM EDITION

General Safety Requirements Part 3
No. GSR Part 3 (Interim)

Jointly sponsored by

The IAEA Board of Governors approved the revised Basic Safety Standards in September 2011

The UN agencies, with the International Atomic Energy Agency as the lead agency, used the 2007 ICRP Recommendations as a major input to their project of revising the International BSS
International Basic Safety Standards (BSS) 2011

Scope

These standards apply to all situations involving exposures that are amenable to control. Exposures deemed to be unamenable to control are excluded from the scope of these Standards.

(For example, it is generally accepted that it is not feasible to control 40K in the body and cosmic radiation at the surface of the earth.)

(IAEA Safety Standards
Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards
INTERNATIONAL

General Safety Requirements Part 1

IAEA

IAEA

International Basic Safety Standards (BSS) 2011

Objective

To establish basic requirements for protection of people and the environment from harmful effects of ionizing radiation and for the safety of sources

Aimed at

Governments
Regulatory bodies
Principal parties
Health authorities
Professional bodies
Providers of specialized services (TSO)
Graded approach

The application of the requirements for the system of protection and safety shall be commensurate with the radiation risks associated with the exposure situation.

Justification

…justification of any type of practice and for review of the justification, as necessary, and …ensure that only justified practices are authorized.

Practices deemed not to be justified:

• deliberate addition of radioactive substances (or by activation) in food, feed, beverages, cosmetics…….
• frivolous use of radioactive substances in commodities, toys, jewelry
• human imaging for art or publicity purposes
• human imaging for theft purposes

Exceptional circumstances for other applications considered
The application of the justification principle to medical exposures requires a special approach.

- **Overarching justification**: use of radiation in medicine does more good than harm.

- **Next level**: a need for generic justification of a given radiological procedure. This applies to the justification of new technologies and techniques as they evolve.

- **Final level**: the application of the radiological procedure to a given individual has to be considered.
  - The specific objectives of the exposure, the clinical circumstances and the characteristics of the individual involved have to be taken into account through referral criteria developed by professional bodies and the health authority.
  - Germany: referral criteria don’t replace justifying indication.

The medical exposure has been justified through consultation between the radiological medical practitioner and the referring medical practitioner, as appropriate, or is part of an approved health screening programme.
International Basic Safety Standards (BSS) 2011

Prevention and mitigation of accidents

The most harmful consequences arising from facilities and activities have come from the loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or other source of radiation. Consequently, to ensure that the likelihood of an accident having harmful consequences is extremely low, measures have to be taken:

- To prevent the occurrence of failures or abnormal conditions (including breaches of security) that could lead to such a loss of control;
- To prevent the escalation of any such failures or abnormal conditions that do occur;
- To prevent the loss of, or the loss of control over, a radioactive source or other source of radiation.

A multilevel (defence in depth) system of sequential, independent provisions for protection and safety that is commensurate with the likelihood and the magnitude of the potential exposures is applied

- Structures, systems and components, including software, that are related to protection and safety for facilities and activities are designed, constructed, commissioned, operated and maintained so as to prevent accidents as far as reasonably practicable
International Basic Safety Standards (BSS) 2011

Protection of present and future generations

- Relevant parties shall apply the system of protection and safety to protect members of the public against exposure.
- Relevant parties shall ensure that radioactive waste and discharges of radioactive material to the environment are managed in accordance with the authorization.

- Establish and implement monitoring programs

  Monitoring of
  - external exposure from sources;
  - discharges;
  - radioactivity in the environment;
  - other parameters important for the assessment of public exposure.

Thank you for your attention