Introduction to Nuclear Data for Medical Applications

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Opening lecture delivered during the Workshop on Nuclear Data for Medical Applications, Abdus Salam ICTP, Trieste, Italy, 12 to 23 November 2007

Topics

- Historical development and general considerations
- Overview of nuclear data needed for medical investigations

  - decay data

  - nuclear reaction data
- Motivations for nuclear data measurements
- Interdisciplinary nuclear data activities

  - development of data libraries

  - coordination of international efforts

Radionuclides for Medical Applications
(Historical Development)

1920s Biological experiments with natural radioactivity
(***Tracer principle***) G. v. Hevesy

Use of Ra/Be-Source

1935 O. Chievitz, G. v. Hevesy
Phosphorus metabolism in rats (^{32}P)

1938 S. Hertz, A. Roberts, R.D. Evans
Physiology of thyroid (^{128}I)

Cyclotron Era

1937 J.G. Hamilton, R.S. Stone
Studies with ^{24}Na

1942 J.G. Hamilton, M.H. Soley
Therapeutic applications of radiophosphorus and radioiodine

1945 C.A. Tobias, J.H. Lawrence, F. Roughton
Inhalation of ^{11}CO

Reactor Era

since 1946 Availability of many long-lived radioisotopes, e.g. ^{3}H, ^{14}C, ^{32}P, ^{60}Co, $^{125,131}I$ for

- in-vitro studies
- biochemistry, pharmacology, therapy

Renaissance of Cyclotron

since 1960 Production of large number of short-lived radionuclides for in-vivo studies

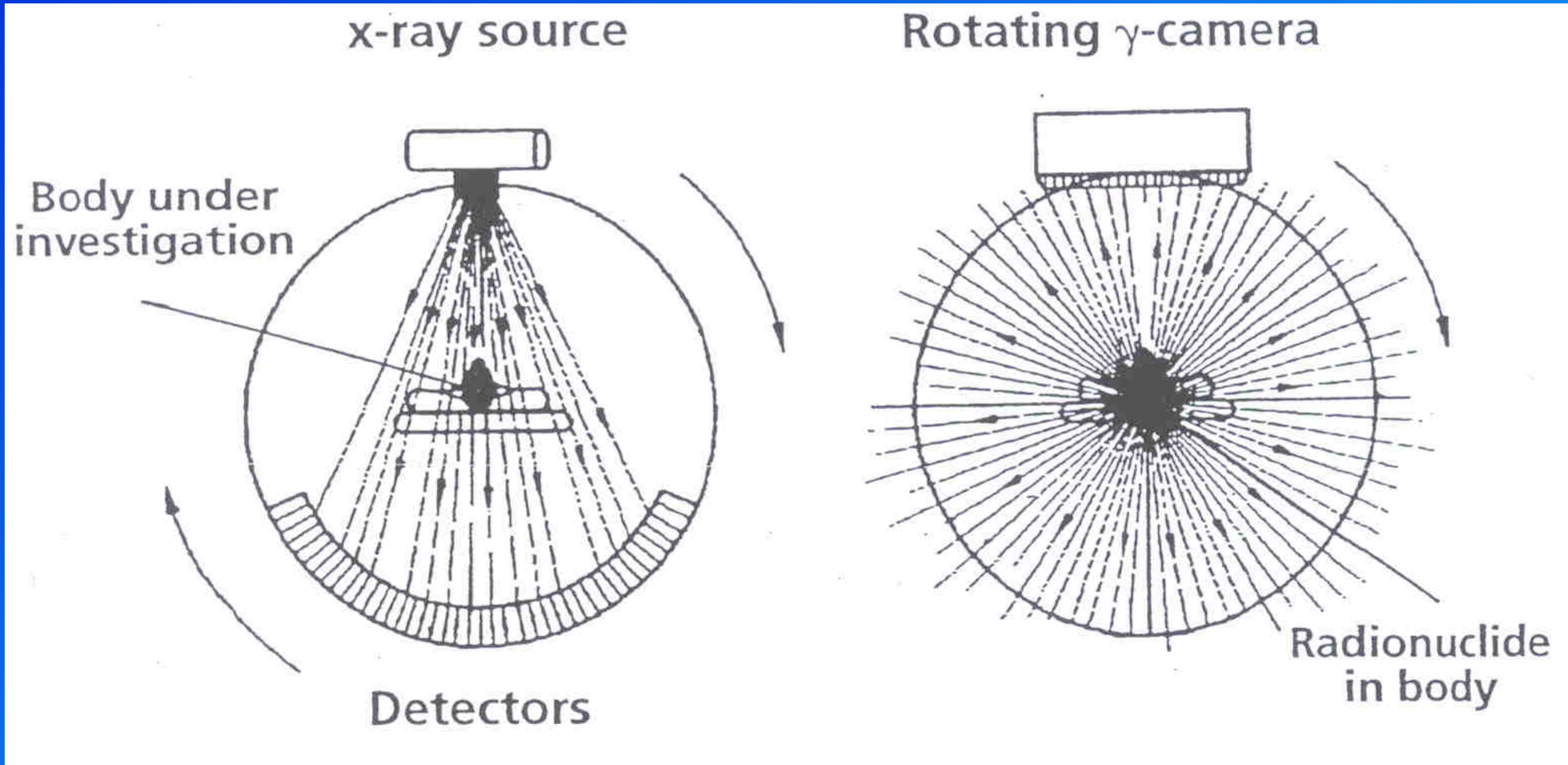
Several types of cyclotrons have been developed, the smallest one with E_d = 3 MeV to produce ^{15}O and the largest ones with proton energies of several hundred MeV to produce many long-lived radionuclides

Factors Contributing to Recent Progress in the Medical Application of Radionuclides

- New efficient automated production methods
- High intensity dedicated accelerators
- Fast labelling, separation and purification methods (GC, HPLC)
- High resolution emission tomographs (SPECT, PET)

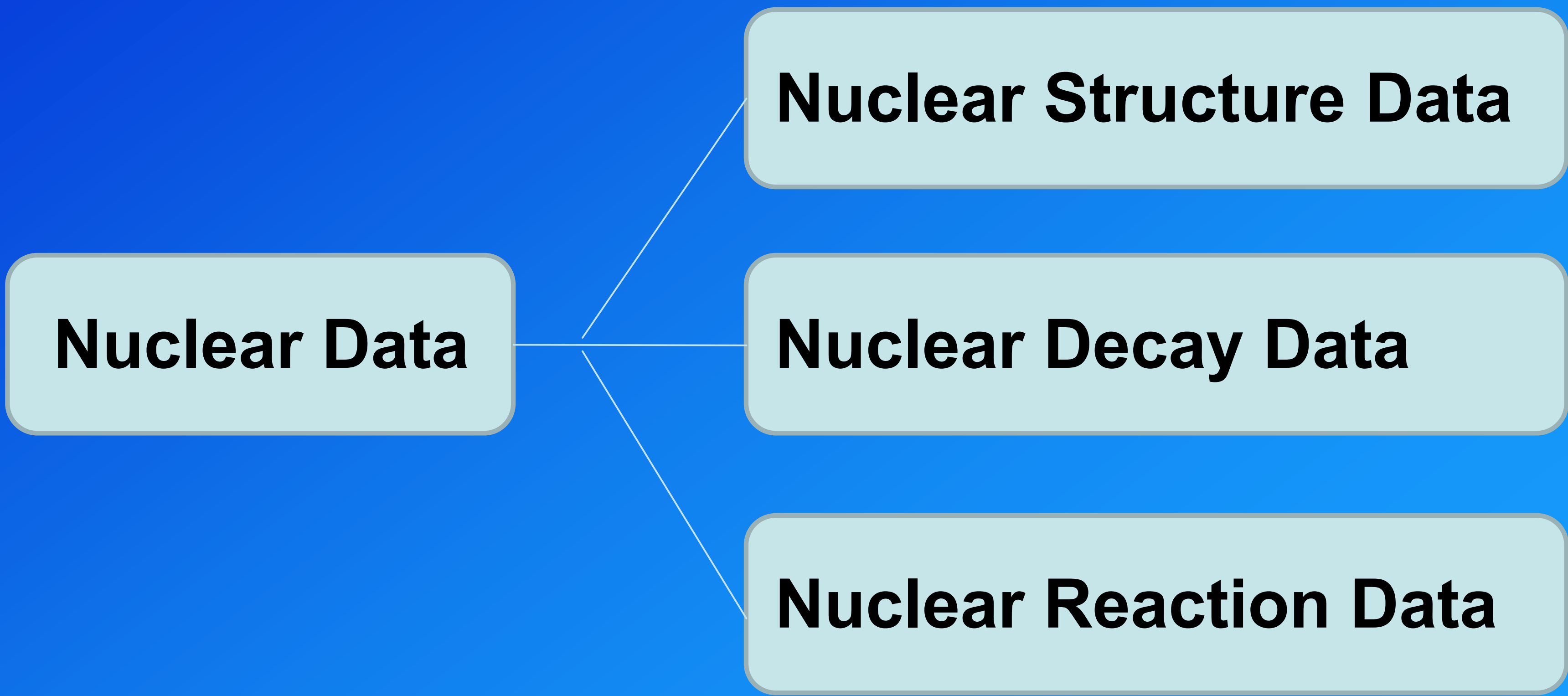
Transmission Tomography

Emission Tomography



Nuclear Data

The term "nuclear data" is very broad; it includes all data which describe the characteristics of nuclei as well as their interactions.



Medical Investigations

Radioactivity is unique: it finds application both in diagnosis and therapy

Diagnosis

via imaging techniques, mainly emission tomography

- choice of a radionuclide (decay data)
- production of the radionuclide in a pure form (reaction data)
- preparation of a suitable radiopharmaceutical (fast radiochemistry)

Radiation dose should be as low as possible

Medical Investigations
(Continued)

Therapy

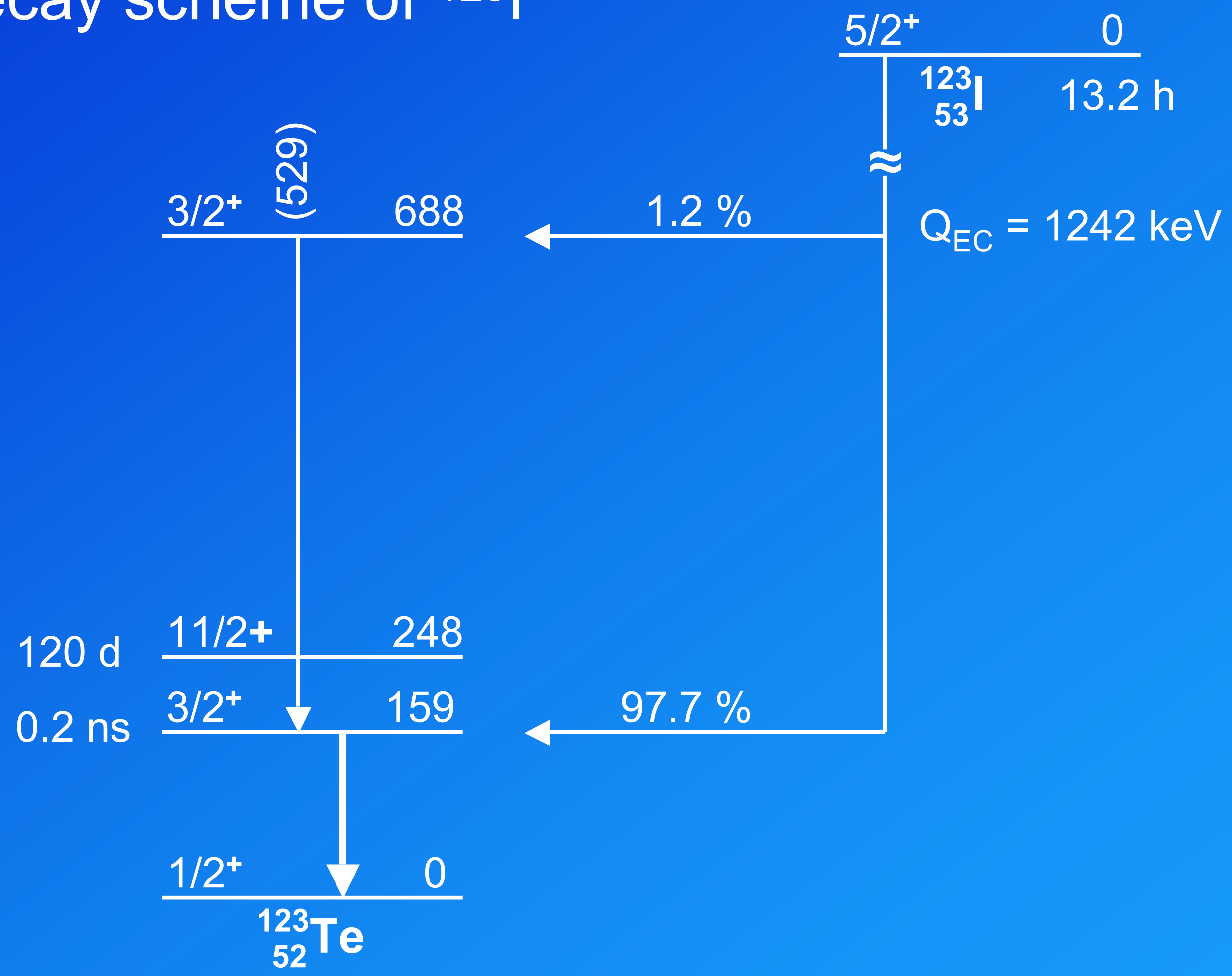
(a)via external radiation
- reaction data and radiation transport calculations

(b) via internal uptake
- nuclear decay data and pharmacokinetics

Radiation dose should be compatible with therapy requirement

Radioactive Decay Data

Example: Decay scheme of ^{123}I



- Complete knowledge of decay scheme is needed, including information on conversion and Auger electrons

Radioactive Decay Data

Radiation dose calculation

According to Medical Internal Radiation Dose Committee (MIRD), the radiation dose ($\bar{D}$) is determined via the expression:

$$\bar{D} = 2.13 \cdot \bar{c} \cdot \sum_i n_i \cdot \bar{E}_i \cdot \ddot{O}_i$$

where

$\bar{c}$	is the cumulative concentration of activity $\left(Bq \cdot \frac{T_{eff}}{\ln 2} / kg \right)$
n_i	the number of emitted particles or photons per decay,
E_i	the average energy of the emitted radiation,
Φ_i	the part of the radiation absorbed in the organ,
T_{eff}	the effective half-life of the radioisotope in the organ.

- ***Short-lived single photon and β^+ emitters preferred for diagnostic investigations***
- ***Corpuscular radiation required in endotherapeutic studies***

Nuclear Reaction Data

Neutron data for production in a nuclear reactor

- Production of neutron excess radionuclides
- Experimental data and comparison with theory
  (n,γ); (n,f); n,p)

Charged particle data for production at a cyclotron

- Production of neutron deficient radionuclides
- Crucial role of nuclear data in check of impurity
- Experimental data and comparison with theory
  (p,xn); (d,xn); (^{3}He,xn); (α,xn); (^{7}Li,xn)

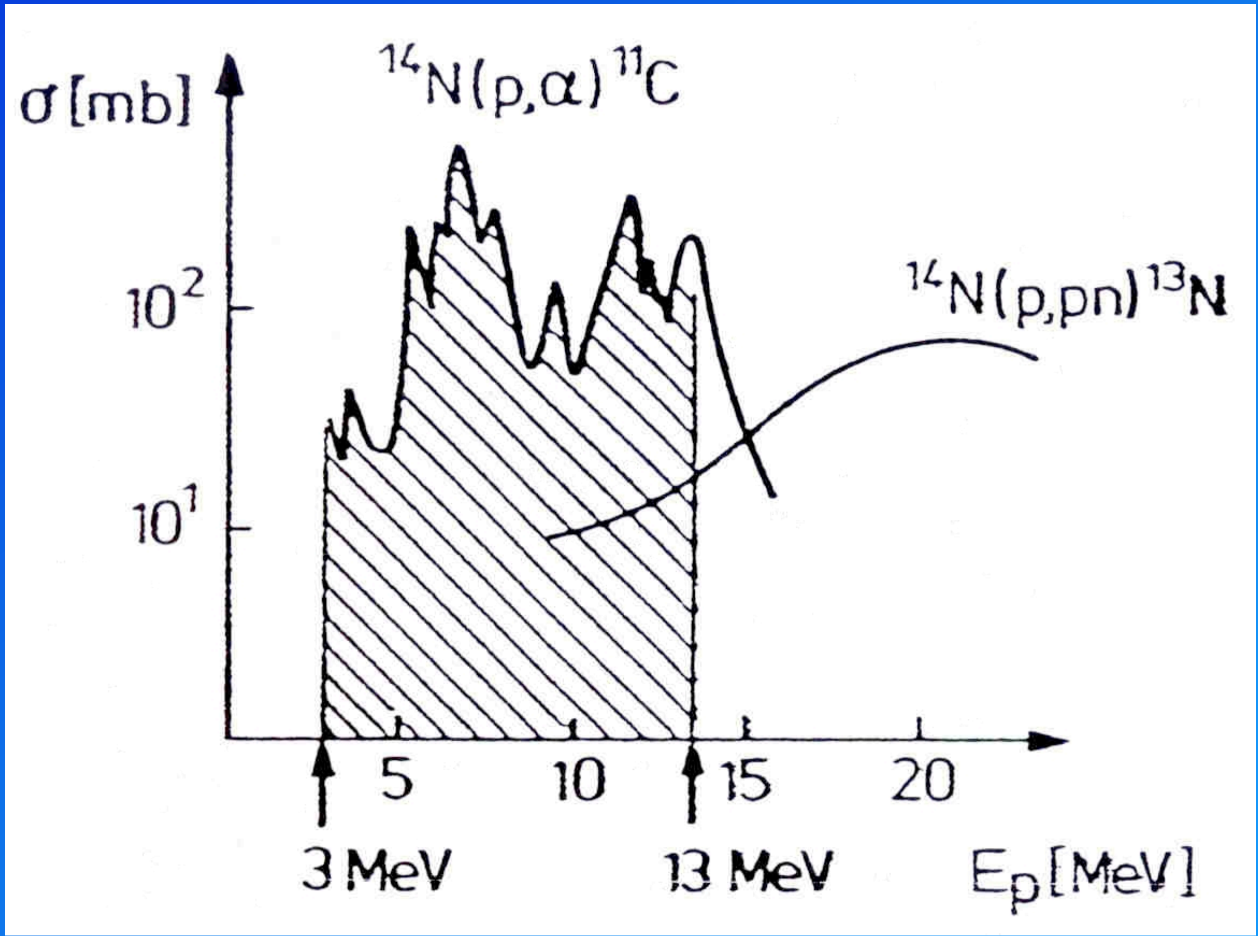
Radionuclide Production via (n,γ)-Process

Example:

$^{152}Sm(n,\gamma)^{153}Sm$

- Neutron capture in thermal and resonance regions described well by statistical model; at $E_n \geq 10$ MeV, direct interactions need to be considered
- Double neutron capture possible in high flux reactors, e.g. $^{186}W(n,\gamma)^{187}W(n,\gamma)^{188}W$
- Low specific activity overcome via generator systems (e.g. $^{99}Mo \rightarrow {}^{99m}Tc$; $^{188}W \rightarrow {}^{188}Re$)

Production of ^{11}C via the $^{14}N(p,\alpha)$-Process



Optimum energy range:	E_p = 13 → 3 MeV
^{11}C-yield :	3.8 GBq/µAh
^{13}N-impurity:	ca. 5%

Radiation Therapy

- Biological changes under the impact of radiation
- Of significance is linear energy transfer (LET) to tissue

Types of Therapy

- ***Photon therapy***: use of linear accelerators (*low-LET radiation*)
- ***Fast neutron therapy***: accelerator with E_p > 50 MeV (*high-LET radiation*)
- ***Proton beam therapy***: accelerators with E_p = 70 -250 MeV (*treatment of deep-lying, rather resistant tumours*)
- ***Heavy-ion beam therapy*** (*rather specialized; limited application*)
- ***Boron neutron capture therapy*** (BNCT): use of low energy neutrons (*pharmacological problem: comparable to endotherapy)*

Radiation Therapy
(Continued)

Atomic and nuclear data required to

- calculate radiation transport
- calculate the absorbed dose at a point in the tissue
- optimise the design of the treatment delivery system

Data Needs (up to 250 MeV)

- Total and non-elastic cross sections
- Production yields and average energies of emitted n, p, d, α, γ
- Double differential cross sections at various incident energies
- Excitation functions for the formation of radioactive products

Internal Radionuclide Therapy

- **Brachytherapy**

  (insertion of sealed sources near the tumour)

  Examples: ^{192}Ir as wire

  ^{103}Pd and ^{125}I as seeds

- **Administration in cavities**

  (for pain palliation)

  Examples: ^{32}P colloid for arthritis

  ^{90}Y, ^{186}Re and ^{188}Re complexes for joint inflammation

- **Metabolic therapy**

  (incorporation of radionuclide via a biochemical path)

  Examples: ^{131}I for thyroid cancer

  ^{89}Sr, ^{186}Re and ^{153}Sm are bone seekers

- **Radioimmunotherapy**

  (administration of a radionuclide chemically conjugated to antibodies)

  Examples: low-energy high-LET value radionuclides

Internal radionuclide therapy is a fast developing field.

Nuclear Data Measurements

Motivations

Reaction data

- Search for alternative route of production of an established radionuclide
  - constraint of available charged particle and energy
  - demand for higher purity
- Development of novel radionuclides for medical applications
- Improvement in radiation dose calculation

Decay data

- Removal of discrepancies and uncertainties, e.g. in
  - β^+ branching in ^{120}I, ^{124}I, ^{76}Br, etc.
  - intensities of γ-rays
  - end point energies of β^- and β^+ emitters
  - intensities of low energy conversion and Auger electrons

Interdisciplinary Nuclear Data Activities

- **Experimental measurements**

  - on-line and off-line methods
  - interdisciplinary techniques
  - detailed description of experiment, uncertainties and their correlations

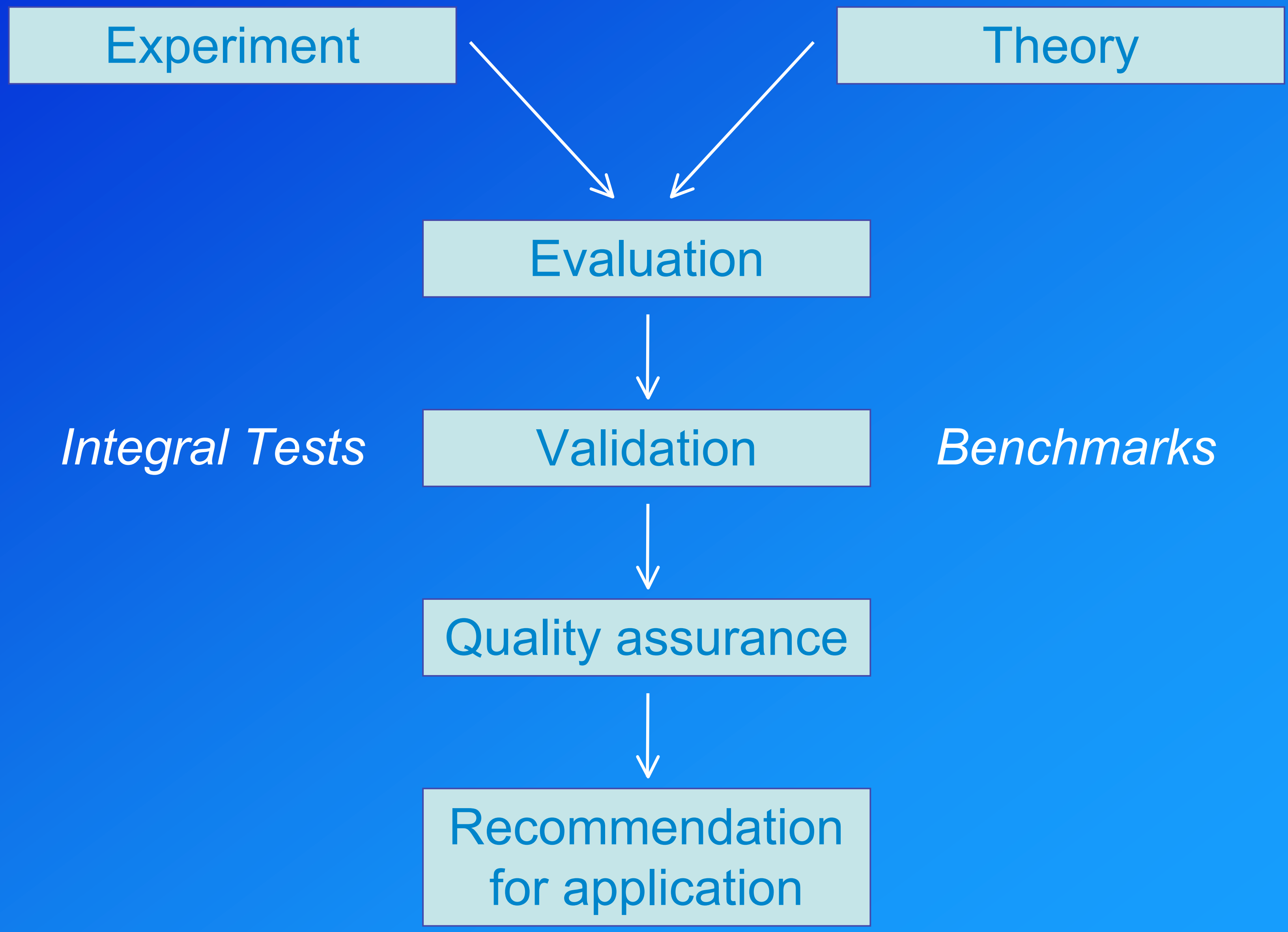
- **Compilations and evaluations**

  - collection of data in a uniform format
  - evaluations
    (critical consideration of experimental parameters, standardization of data, development of systematics, use of nuclear models, construction of data files)

- **Nuclear theory**

  - improvement of known models and parameters
  - development of new models of high predictive values

Nuclear Data Development for Applications



Nuclear Data Centres

- NNDC, Brookhaven, USA
- OECD-NEA Data Bank, Paris, France
- IAEA Nuclear Data Section, Vienna, Austria
- Nuclear Data Centre, Obninsk, Russia

International Co-ordinating Bodies

IAEA
(INDC)

- Energy related applications
- Non-energy related applications

Functions

- EXFOR
- Coordinating Research Projects
- Special Data Files
- Training

NEA
(NSC)

- Energy related applications
- Spin-off effects of nuclear energy
- Nuclear sciences

Functions

- JEFF
- Data Bank
- Conferences

Observations Regarding Nuclear Data for Medical Applications

• ***Radioactive decay data***

generally well characterised and well documented
(Table of Isotopes; Decay Data Sheets; Nuklidkarte; MRID Compilation)

• **Nuclear reaction data**

mostly available in the context of energy research
Much less effort has been devoted to medically oriented data.

Radionuclide production: High accuracy data needs (uncertainty ≤ 10 %)
Recent efforts: IAEA-CRP on diagnostic radionuclides (TECDOC-1211)
IAEA-CRP on therapeutic radionuclides (TECDOC, in preparation)

Radiation therapy : Extensive data needs, though not with high accuracy (uncertainty ≤ 25 %)

Several coordination efforts underway.