International Atomic Energy Agency

Mini-workshop:

NDS/IAEA Activities and available Services related to the Nuclear Data

NDS' front page (Nuclear Data Services): https://www-nds.iaea.org/

S.P. Simakov

Nuclear Data Section (NDS), IAEA, Vienna, Austria

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I. Introduction: Nuclear Data Section of IAEA

- **Organizational Settings:**
  - NDS belongs to the Division of Physical and Chemical Sciences which is a part of the Department of Science and Applications (1 of 5) *http://www.iaea.org/OurWork/*
  - NDS has 12 professionals and consists of 3 Units: **Atomic and Molecular Data**
    Nuclear Data Development } **My talk**
    Nuclear Data Services } **about this**

- **Missions and work' style of NDS:**

- Develop, collect and maintain the Nuclear and Atomic data for peaceful nuclear applications (science, nuclear energy, analytical applications, medicine, environment, …)
- Provide (Disseminate) data to the IAEA Member States (162) for their capacity development
- Transfer basic Nuclear Knowledge from developed to developing Counties

NDS' work and outcomes are characterised by:

- many databases (EXFOR, Standards, IRDFF, …) are considered as **internationally acceptable reference sources of numerical data** and documentation
- unrestricted access to information (after finishing of development)
- political neutrality

What is a distinguish between NDS/IAEA and other Nuclear Data Centres, e.g.:

- OECD Nuclear Energy Agency - serves to OECD Stakeholders (31 counties)
- National Nuclear Data Centres - serves to own Countries (e.g. NNDC/BNL – for USA)

I. Introduction: Nuclear Data Section of IAEA (cont.)

- **How does NDS technically work** (balance between “Experts” & “non-Experts”):

Development and Dissemination of Nuclear and Atomic data (mainly Experts)

- Coordinated Research Project (CRP): on definite issues, 4-5 years, ≈ 10-20 countries
- Data Development Projects: long standing issue, external Experts + NDS staff

Transferring of the basic Nuclear Knowledge (involvement of “non-Experts”)

- NDS coordinates 2 Networks: - Nuclear Reaction Data Centres (**NRDC**),
  - Nuclear Structure & Decay Data (**NSDD**).
- Training: IAEA workshops, ICTP-Trieste schools (co-)organised by NDS …
- Mirroring of NDS web-page and databases in China (*http://www-nds.ciae.ac.cn/*) and India (*http://www-nds.indcentre.org.in/*)
- Responds to the Individual Requests

- **Ways of Disseminations**:
  - (main way) through the NDS web site *http://www-nds.iaea.org/*
  - dispatch Documentations as hard copies and Databases on CD-ROM/DVD

to Overview of IAEA and NDS: *http://www.iaea.org/OurWork/*
https://www-nds.iaea.org/

II. Nuclear Structure and Decay Data

NDS hosts on front page following Interactive Interfaces which allow to search and display nuclear structure and decay data:

- **LiveChart of Nuclides** - **developed & maintained by NDS** (App available on Google Play)
- **NuDat 2.6** - developed & maintained by NNDC/BNL

Both (LiveChart more than NuDat) **provide following Quantities** (mostly with Uncertainties)

- **Ground states**: Isotope Abundance; J^{π}; half-life $T_{1/2}$ or width Γ; Q-values for β^-, α, EC, β^{--}-n; Nucleon Separation Energies S_n, S_p; Isotope Atomic Mass M; Mass Excess Δ; Binding Energy; Isospin; thermal capture cross section $\sigma(n_{th},\gamma)$; Resonance Integral RI; Fission Yields; Electr. & Magnetic Moments μ; Nuclei Radius R; Dipole or Quadrupole Moments Decay info (Modes, Emission radiation Energy and Probabilities, Mixing δ …) …
- **Excited States:** U, J^{π}, $T_{1/2}$, de-excitation γ ($E\gamma$, $E_i \rightarrow E_f$, Multipolarities, Branching, Bands …)

Nuclear Ground states properties are also available as **a compact Pocket Booklet "Nuclear Wallet Cards"** by J.K. Tuli, 2011, BNL

It includes: Isotope Abundance; Mass Excess, J^{π}; $T_{1/2}$; Decay modes

II. Nuclear Structure and Decay Data (cont.)

Information Sources used by Interfaces (N.B.: this explains observe differences):

- **Masses, Q, Sn** - from Atomic Mass Data Center (**AMDC**), latest version – 2012

- **Structure (Levels, Transition, Decay)**
  - mainly from **ENSDF** (≈*3000 nuclides) produced* by NSDD network coordinated by NDS/IAEA *https://www-nds.iaea.org/nsdd/*
  - light nuclei from **TUNL** (*A = 3 - 20*) *http://www.tunl.duke.edu/nucldata/index.shtml*

  (alternatively) from **DDEP** (*214 nuclides*) coordinated by **CEA/LNHB** *http://www.nucleide.org/DDEP.htm*

- **Thermal $\sigma(n_{th},\gamma)$, Resonance Integral, Resonance Fission Integral**
  - S. Mughabghab, **Atlas of Neutron Resonances**, 2006

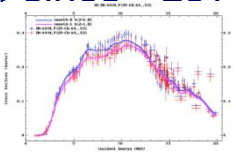
- **Independent and Cumulative Fission Yields**
  - **JEFF** evaluations *http://www.oecd-nea.org/dbforms/data/eva/evatapes/jeff_32/*

to Demonstrations: , LiveChart, AMDC, NuDat https://www-nds.iaea.org/

III.1. EXFOR: unique repository of Experimental Reaction Data

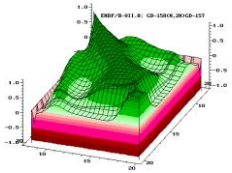
Short History of EXFOR

- started as **CSISRS** (Cross-Section Information Storage & Retrieval System) in USA ≈ 1960th
- transformed in EXchange FORmat (**EXFOR**) by 4 Centers (NEA, NDS, USA, USSR) - 1970
- **NDS/IAEA** manages **NRDC network**, stores master EXFOR, provide access … since - 1976



Physical Quantities and their "Abundances" in EXFOR:

- Cross Sections (*CS*) for *(N,TOT), (G,ABS), (N,EL), (N,G), (P,INL), (D,A), (A,3N)* … - 51%
- Differential Angular (Partial) distributions, dσ/dΩ *(DA, DAP) for (P,EL), (N,INL)* … - 39%
- Resonance Parameters (*RP*): Energy *(EN),* Spin/Parity *(±J),* width *(WID)* for *(N,0), (N,EL)..* - 9%
- Cross Sections Partial (*CSP*) for *(N,INL), (P,D),* … - 8%
- Fission Yields (*FY*) for *(N,F), (0,F)* - 5%
- Polarization (*POL*) Parameters - 5%
- Double differential Angular-Energy distributions or $d^2\sigma/d\Omega/dE$ *(DAE)* - 5%
- Thick/Thin Targets, Partial, Differential , Saturated … Yields (TTY) - 2%
- outgoing Particles Multiplicity (*MLT*) for induced *(N,F),* and spontaneous *(0,F)* fission - 2%
- Cross sections Averaged over incident energy or SPectrum *(SPA)* - 1%



Challenges and New type of Data in EXFOR

- **Uncertainties:** Total/Partial - available for many Entries, Covariance Matrices only ≈ 70 of 20,000!
- New EXFOR Quantities: β^- (*B*-) decay Probabilities (*Pn)* & Spectra (*DE*) for individual Precursors

III.1. EXFOR – repository of Experimental Reaction Data (cont.)

Incident (or outgoing) particles (total 336):

- Neutrons (*N* or *0-NN-1*) - 49% (decreasing)
- Protons (*P*), Deuterons (*D*), Alphas (*A*), ^{3}He (*HE3*), ^{3}H (*T*) - 40% (increasing)
- Gammas (*G* or *0-G-0,* and even *DG* – decay *G*) - 6%
- Spontaneous Fissions (*0*) - 2%
- Electrons (*E*) - 0.1%
- "Exotic": Pion (*PIP, PIN*), Kaon (*Kn*), η (*ETA*), ṗ (*AP*), ṅ (*AN*), Λ (*LM*) ~ 0.1%
- Heavy Ions form Li-6 to U-238 - rest (≈ 3%)

Targets (total 105**) and Energies**:

- Elements/Isotopes from H (7%) via U (12%) to unnamed 118-*-294 (1 experiment)
- Compounds (*-*CMP*), Oxides (*-*OXI*), Water (*H-WT*R), Air (*N-AIR*), Benzene *(H-BNZ*) …
- Energies from Ultra-cold Neutrons (UN) to Protons 4 TeV = 10^{+15} eV

EXFOR contains now:

20,465 **experiments** or ***12 376,750*** **data points**

(*suggesting 1 Mio. USD per experiment brings an EXFOR worth 20 Mrd. USD*)

EXFOR is filled by NRDC = 14 National Centers Network (NRDC) managed by NDS:

- scans 60 journal titles and generates ~ 500 New Entries per Year
- compilation time = 6 Months, update of EXFOR ≈ every month

to Demonstrations: EXFOR, search, retrieve, plot … : https://www-nds.iaea.org/exfor/exfor.htm

III.2. ENDF – collection of Evaluated Nuclear reaction Data Files

- **ENDF** contains ENDF-6 formatted Files for ***n, γ, p, d, t, ^{3}He, ^{4}He*** induced reactions**,**
  thermal scattering**,** ***spontaneous fission*****,** **photo-nuclear,**
  photo- and electro-atomic, radioactive decay**:**
  - **27** of general use or application oriented
  - **16** archival (previous versions, some in ENDF-5 format)
  - **3** derived (ENDF/B-VI.8 and JENDL-3.3 at 300^{0}K, IRDF-2002 GENDF)

- **Major (inter)national libraries** and actual versions**:**
  - **ENDF/B-VII.1** US Evaluated Nuclear Data Library (distributed by BNNL)
  - **JEFF-3.2** European Evaluated Fission and Fusion File (coordinated by NEA Bank)
  - **JENDL-4.0**u Japanese Evaluated Nuclear Data Library
  - **CENDL-3.1** Chinese Evaluated Nuclear Data Library
  - **ROSFOND-2010** Russian Evaluated Nuclear Data Library

- **POINT-2012**
  - **ENDF/B-VII.**1 point–wise library at set of Temperatures 0 – 2100^{o}K and 0.1eV - 10keV (≈ M^{o}K)

- **Processing codes** used by NDS to work with ENDF-6 formatted files:
  - **PREPRO-2012, PLOTTAB-2013** - processing and plotting codes (free available)
  - **NJOY-99, -2012** – used for processing and generation ACE files for MCNP (for internal use)

to Demonstrations: ENDF retrieving/plotting: *https://www-nds.iaea.org/exfor/endf.htm*
POINT-2012 *https://www-nds.iaea.org/point2012/*

III.3. RIPL - Reference Input Parameter Library for calculations

- **History (versions):** RIPL-1 (1998), RIPL-2 (2006), RIPL-3 (2009)
  new CRP to extent CRP is planned

- **Content**

Model Parameters:

- **Masses:** Experimental or Evaluated Mass Excesses,
  Ground state properties (deformation parameters, radii, diffuseness …),
  Natural Abundances, Nuclear Matter Densities
- **Levels:** Discrete and Decay Data
- **Resonances**: Average Spacings of Neutron Resonances
- **Optical Model Parame**ters (OMP): phenomenological OMP, Deformation Parameters
- **Densities**: Level Density Parameters (phenomenological and microscopic)
- **Gamma:** Experimental and Theoretical Giant Dipole Resonance (GDR) Parameters
- **Fission:** Empirical and Theoretical Fission Barriers

Model Codes (collection of sources, input parameters, test cases …):

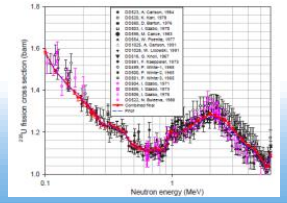
- **SCAT2000** (O. Bersilon) – optical model code
- **ECIS** (J. Raynal) - optical coupled–channel model code
- **OPTMAN** (E. Soukhovitskii) – optical model with coupling deformed rotary states
- **PFNS** (P. Talou) – Los Alamos Model Prompt Fission Neutron Spectra model

to Demonstrations: RIPL-3 *https://www-nds.iaea.org/RIPL-3/*

IV.1. Neutron Cross Section Standards (long term DDP)

Reaction	Previous Version: 1987 Neutron Energy Range	Actual Version Version: 2002-2005/06	
		Neutron Energy Range	Uncertainty
H(n,n)	1 keV to 20 MeV	1 keV to 20 MeV	0.2 – 0.3 %
^{3}He(n,p)	0.0253 eV to 50 keV	0.0253 eV to 50 keV	0.30 – 5.0 %
^{6}Li(n,t)	0.0253 eV to 1 MeV	0.0253 eV to 2.8 MeV	0.15 – 3.0 %
^{10}B(n,$\alpha_{0+}\alpha_1$)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	0.24 – 3.0 %
^{10}B(n,$\alpha_1\gamma$)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	0.08 – 1.5 %
C(n,n)	up to 1.8 MeV	up to 1.8 MeV	0.2 – 0.8 %
^{197}Au(n,γ)	0.0253 eV, 0.2 to 2.5 MeV	0.0253 eV, 0.2 to 2.5 MeV	0.14 – 2.2 %
^{235}U(n,f)	0.0253 eV and 0.15 - 20 MeV	0.0253 eV, 0.15 to 200 MeV	0.15 – 4.5 %
^{238}U(n,f)	threshold to 20 MeV	2 to 200 MeV	1.2 – 4.5 %
^{238}U(n,γ)		0.0253 eV to 2.2 MeV	0.50 – 3.0 %
^{239}Pu(n,f)		0.0253 eV to 200 MeV	0.24 – 4.5 %
^{252}Cf(s.f.)	Spontaneous Fission Neutron Spectrum 10^{-10} to 20MeV		0.2-8.5 MeV <2%

- **Actual work goes on to include new reactions in Standards (**see *Report INDC(NDS)-0583*):
  - ^{235}U(n_{th},f) Prompt Fission Neutron Spectrum (PFNS)
  - (n,xγ) reactions ^{7}Li(n,n'γ), ^{48}Ti(n,n'γ)
  - ^{209}Bi(n,f), Pb(n,f)



to Demonstrations of Standards:
https://www-nds.iaea.org/standards/

IV.2. International Reactor Dosimetry and Fusion File (IRDFF)

- **IRDFF serves** as internationally accepted reference cross sections for dosimetry (determination of neutron fluence and spectra) at power & research Fission, Fusion and Accelerator Nuclear Facilities

- **IRDFF history** (is being developed under NDS coordination since 1982):

1982: IRDF-82	35 reactions,	IAEA-NDS-41	E < 20 MeV
1993: IRDF-90 v. 2	37 reactions,	IAEA-NDS-141	
2006: IRDF-2002	69 reactions,	Tech. Rep. 452	
2012: IRDFF, v. 1.00	69 reactions,	INDC(NDS)-0616	E < 60 (200) MeV

- Actual version **IRDFF-1.04** (released March 2014)
  contains **76** dosimetry reactions + **3** cover materials (B, Cd, Gd)
  covers **Energy range** from 1E-4 eV up to 60-200 MeV

- NDS runs CRP on "**Testing and Improving of IRDFF"** with goals to extend IRDFF (new reactions, higher energies), experimentally validate, remove discrepancies, reduce uncertainty ...

to Demonstrations: IRDFF https://www-nds.iaea.org/IRDFF/
IRDFF CRP https://www-nds.iaea.org/IRDFFtest/

IV.3. Fusion Evaluated Nuclear Data Library (FENDL-3)

- **FENDL Library serves** for neutronics characterization of operated and projected Fusion Facilities (JET, ITER, IFMIF, DEMO …)
- **History**: FENDL-2.0 (1997), FENDL-2.1 (2004), FENDL-3.0 (2013)
- **FENDL-3 essential extensions cp. FENDL-2.1:**
  - energies > 20 MeV (at least up to 60 MeV to cover IFMIF)
  - more materials (now 180 targets)
  - includes incident charged particles (p-, d-), photons and cross sections uncertainties
- **FENDL-3.0 library contains:**
  - evaluated nuclear reaction ENDF-6 formatted data for General Purpose *FENDL-3* (< 150 MeV) and Activation *FENDL-3/A* (<60 MeV)
  - inclusion of covariances was not be possible for all neutron-induced reactions -> a 'shadow library' based on TENDL-2010 for 180 targets with covariances released
  - processed files in PENDF, GENDF, ACE, MATXS formats for use in applications
- *FENDL-3.0 has been released as a **result of the IAEA CRP** (2008-2011)*

to Demonstrations: FENDL-3 https://www-nds.iaea.org/fendl30/

IV.4. Prompt Gamma-ray Neutron Activation Analysis (PGAA)

- **PGAA serves** for non-destructive **Elemental Analysis** of materials using characteristic **prompt** γ-rays from neutron capture (*usually do not form products with delayed γ-rays*)

- **PGAA database contains** following recommended data at thermal neutron energy:
  - **prompt** (*sometimes also delayed*) **discrete gamma energies** $E_{\gamma i}$
  - **partial & total isotopic capture cross sections** $\sigma_\gamma^{ZA}(n_{th},\gamma_i)$, $\sigma_\gamma^{ZA}(n_{th},\gamma)$
  - **Westcott *g*-factors** to account for *non-1/v* absorber
  - parameters to account for the ***epithermal*** **n-spectrum component:**

    $\sigma = \sigma_0\,(g_w + r \cdot s)$, σ_0 – value at neutron speed 2200 m/s

    where *r* – index for epithermal fraction, *s* – reduced resonance integral
  - **prompt k_0 factor** $k_0 = \frac{P_a(E_{\gamma,a})}{P_c(E_{\gamma,c})}\frac{\sigma_{0,a}}{\sigma_{0,c}}\frac{\theta_a/M_a}{\theta_c/M_c}$

    where ***a*** stands for *Analyte (isotope of interest)* co-irradiated with *comparator* ***c***,

    $P(E_\gamma)$ – absolute γ-ray emission Probability with energy *E*,

    σ – capture cross section, Θ - abundance, *M* – molar mass

- **Standard comparator** by convention: ***σ = 0.3326(7)b*** **for E_γ = *2223 keV* from H(n,γ)**

- PGAA database covers **materials from H to U**

- *PGAA has been released by the IAEA CRP (1999 – 2003)*

to Demonstrations: PGAA https://www-nds.iaea.org/pgaa/

IV.5. Neutron Activation Analysis: k_0-NAA standardization

- **NAA serves** for non-destructive nuclear **Elemental Analysis** of materials by **Delayed** γ-ray emissions from neutron capture products (sensitivity ≈ μ/g for 60 elements)
- **Comparator method**: finding the concentration of Analyte (*a*) co-irradiated with Au (by convention the ***E_γ = 411.8 keV from* (n,γ) on 197Au** is adopted a standard):

$$\rho_a = \frac{(N_p/W\, t_m\, SDC)_a}{(N_p/W t_m SDC)_{Au}} \frac{\varepsilon_{p,Au}}{\varepsilon_{p,a}} \frac{1}{k_{0,Au}(a)} \frac{f+Q_{0,Au}(\alpha)}{f+Q_{0,a}(\alpha)}$$

Facility parameters: Det. Counts (*N*) and Efficiency (*ε*), Mass (*W*), Corrections (*S D* C), [n-spectrum] thermal temperature *T*, thermal-to-epithermal ratio *f*, deviation from perfect 1/E epithermal spectrum *α,* fast spectrum parameters

Composite parameters which comprised nuclear data constants from ***k_0*-NAA database:**

$k_{0,Au}(a)$ - k_0 factor for Analyte

$Q_0 = I_0/\sigma_0$ - Q_0 factor (resonance integral ratio to 2200 m/s cross section)

- Parameters could be found in **experimental** k_0-NAA database by Frans de Corte or based on it "Classic" k_0-NAA database
- **NDS/IAEA run CRP (2005-2010) to improve the status of reference *k_0*-NAA** (the final report and data base is not available yet, see NAA portal)
- **Complimentary IAEA project** by Industrial Application and Chemistry Section: development of k_0-IAEA Software

to Demonstrations: NAA https://www-nds.iaea.org/naa/portal.htmlx

IV.6. Ion Beam Analysis Nuclear Data Library – IBANDL

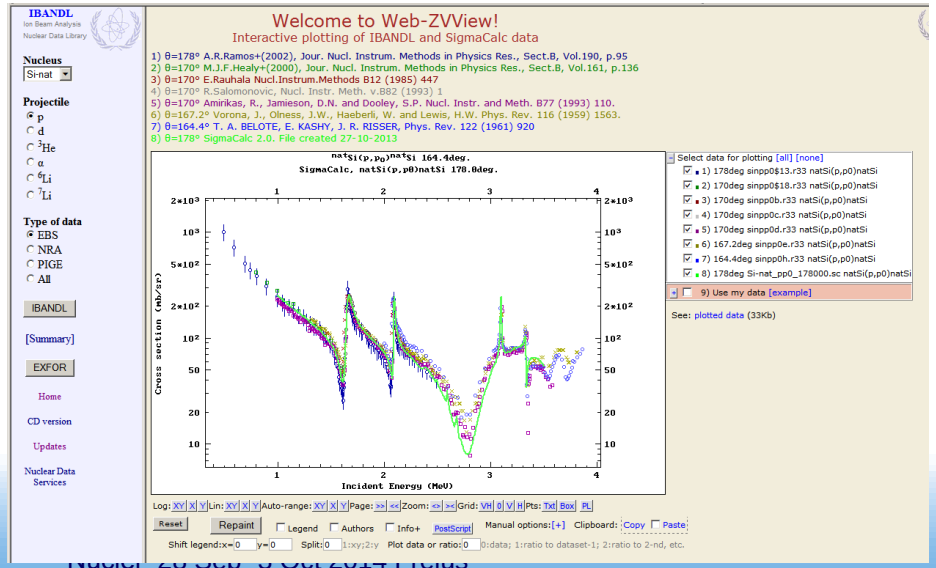
- **IBANDL –** contains **experimental** (≈ 2,800 datasets) **and evaluated cross sections** and serves as a base for nuclear Analytical **Ion Beam Analysis** techniques:

  - **EBS** - Elastic proton Backscattering Spectroscopy: **protons** from elastic scattering (p,p_{el})
  - **NRA** - Nuclear Reaction Analysis: reaction **ejectiles** from $(p,\alpha_{0,1})$, $(d,p_{0,1})$, $(^3He,\alpha_{0,1})$, $(\alpha,p_{0,1})$ …
  - **PIGE** - Particle Induced Gamma-ray Emission: **gammas** from $(p,p'\gamma_i)$, $(p,x\gamma_i)$, $(d,p\gamma_i)$

  (the IAEA CRP was launched in 2010 to extend the scope of IBANDL by PIGE data)

- **IBA techniques use** interaction of fast (~ MeV) charged particles with materials to determine the elemental composition and profile up to 500 μm surface depth by measuring the back scattered protons, light ions or characteristic prompt γ-rays …

- **Software for such Application**: SIMNRA (M. Mayer): v. 6 http://home.rzg.mpg.de/~mam/
  v. 7 NIM B332(2014)176



to Demonstrations:
IBANDL https://www-nds.iaea.org/exfor/ibandl.htm

IV.7. Medical Portal – Nuclear Data for Medical Applications

This Portal contains experimental, evaluated and recommended cross sections for:

- (p,x), (d,x) reactions that produce **Diagnostic Radioisotopes** which are proper γ or e^+ emitters for diagnostic

- (p,x), (d,x), (α,x) reactions that produce **Therapeutic Radionuclides** which are clinically Established or Emerging emitters for treatment

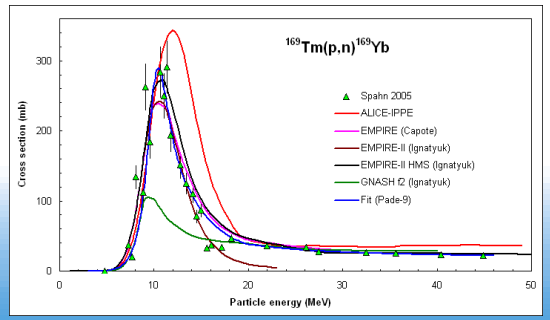
- **Beam Monitor** activation reactions (p,x), (d,x), (^{3}He,x), (α,x) – to monitor a beam dose

- **Phase-Space Database** for External Radiotherapy by ^{60}Co source, Photon or Electron Linacs

- Heavy Charged Particle Interaction data with materials relevant to radiotherapy: data needed to model beam collimation and collision with patient tissue and detectors

(CRP on "Heavy charged-particle interaction data for radiotherapy", 2007-2011, not finished)

- **MIRD** - **Medical Internal Radiation Dose** = energy absorbed in the infinite material due to uniformly distributed source (calculated by Radlist code using ENSDF data)



to Demonstrations:
Medical Portal *https://www-nds.iaea.org/medportal/*

IV.8. High Energies: Cross Section Libraries and Benchmarks

- **ADS-2.0 -** library for **Accelerator Driven Systems** exists on NDS since **2006**
  - 155 isotopes from H-1 to Cm-247
  - compound materials H_2O, D_2O and Graphite (thermal scattering law)
  - neutron energy range from 1E-5 eV up to 150 MeV
  - data storage formats: ENDF, ACE for MCNP, 421 groups GENDF at set of T = 300 – 2000 ^{0}K

- **ADS-HE** - extension to the **High Energies = 1 GeV** in **2012**
  - 10 isotopes: Hg-202, Pb-208, Bi-209, Th-232, U-235,238, Np-237, Pu-239, Am-242, Cm-245
  - source of information new HE evaluations (*S. Yavshits et al. INDC(NDS)-0615, 2012)*
  - data available in different formats (ENDF, ACE), as plots and NJOY inputs …

to Demonstrations: ADS-2 https://www-nds.iaea.org/ads/
ADS-HE https://www-nds.iaea.org/ads/adshe.html

- **"IAEA Benchmark of Spallation models"** contains**:**
  - results of sequence of dedicated **IAEA Meetings**: 2008 to 2010
  - covered domains: **Targets** A > 12, **Incident Particles** (p & n) and **Energies** 20 MeV to 3 GeV
  - list of verified **Models**: those are used in MCNPX, PHITS, GEANT
  - collection of **Experimental data** (ref., link to EXFOR, plots): $d^2\sigma/dE/d\Omega$ for production of
    n, p, d, t, ^{3}He, ^{4}He, π^+, π^-, Mass/Charge/Isotope distributions, neutron multiplicities …
  - **Calculation Results and Intercomparison with Measurements** (plots, tables, FOM …)

to Demonstrations: Spallation https://www-nds.iaea.org/spallations/

V. Stopping Power for Electrons, Light and Heavy Ions

- **Stopping Power for Light Ions -** electronic and nuclear stopping power database maintained by *Helmut Paul (Uni Linz, Austria),* mirrored by NDS:
  - Hydrogen-, He- an heavier Ions in many pure and compound materials
  - numerical data, graphs, computer programs, statistical analysis and comments
  - at NDS-web regular updated (last version – Sep 2014)

to Demonstrations: Stopping https://www-nds.iaea.org/stopping/

- **NDS provides Hyper Links to the other reference databases or software:**

SRIM - Stopping and Range of Ions in Matter by J. Ziegler (USA): *http://www.srim.org/*

Stopping-Power and Range Tables by NIST (USA)
- **ESTAR** for electrons in 72 materials and energy range 10 keV to 1000 MeV
- **PSTAR** for protons in 74 materials and energy range 1 kev to 10 GeV
- **ASTAR** for alphas in 74 materials and energy range 1 kev to 1 GeV

Access to databases: *http://www.nist.gov/pml/data/star/index.cfm*

VI. Scientific Bibliography Resources

- **CINDA** (maintained by NDS) – Computer Index of **Nuclear Reaction Data**
  ≈ 60,000 publications, updated 2 times per year by **automatic import from EXFOR and NSR**
- **NSR** (maintained by BNNL) - Nuclear Science Reference database
  index to > **200,000** articles on **Nuclear Physics** (manual compilation)
- **EXFOR collection of papers, lab reports, thesis…** ≈ 36,000 pdf files *(for internal use)*

  [CINDA, NSR and EXFOR databases are hyper-linked
  – this allows quick inter-database search for documentation and data]

- **NDS Publication Portal** has ≈ 3,000 documents:
  - NDS and National reports, IAEA TecDocs … since 1962 (*free pdf*)
  - Conference proceedings organised by IAEA (*free pdf*)
  - NDS Staff Publications – collection of Titles, Abstracts (*doi: links*)
- **NDS collaborates with IAEA Library and INIS (Department of Energy):**
  - IAEA Library provides access to Journals and helps to search rare, historical documents
  - International Nuclear Information System **INIS** indexes **non-conventional literature** publications on peaceful uses of nuclear Science and Technology (3.6 mio. records: *http://www.iaea.org/inis/)*

to Demonstrations of CINDA: https://www-nds.iaea.org/exfor/cinda.htm
NSR: http://www.nndc.bnl.gov/nsr/
NDS publications: https://www-nds.iaea.org/publications/

VII. Codes collection at NDS

NDS/IAEA was not meant to be a formal repository of computer codes (as NEA Data Bank in Paris or RSICC in Oak Ridge) however we have several open source software from Authors, Labs or Networks

(i) Physical Quantities Simulation/Calculation Codes

- **DROSG-2000 -** accelerator based **neutron source reactions:** Li(p,n), T(d,n), D(d,n), … (*M.Drosg*): *https://www-nds.iaea.org/drosg2000.html*
- **Larelkin - two-body Relativistic Kinematics** (*M.Drosg) : https://www-nds.iaea.org/public/libraries/larelkin/*
- **EMPIRE-3.2.2 - nuclear reaction model code** (*M. Herman et al.) http://www.nndc.bnl.gov/empire/* portable (plug & play) version for Windows (*V. Zerkin*) *https://www-nds.iaea.org/cdroms/*
- **RIPL collection of nuclear reaction modelling codes** *https://www-nds.iaea.org/RIPL-3/*
- **GMA** – least-squares method for simultaneous evaluation of reaction cross sections (W.P. Poenitz et al.) *https://www-nds.iaea.org/standards/codes.html*
- **STAYSL PNNL** – **determination of neutron spectrum** at fission and accelerator-based neutron sources from activation measurements *(L. Greenwood*)
- **SPECTER, SPECOMP** – **radiation damage parameter calculation** and determination displacement cross sections for compound materials *(L. Greenwood): https://www-nds.iaea.org/irdf2002/codes/index.htmlx*

VII. Codes collection at NDS (cont.)

(ii) Data Processing, Checking , Plotting Codes

- **MF, MF-2** - missing level corrections using neutron-resonance spacings (Gary E. Mitchell, John F. Shriner) *https://www-nds.iaea.org/missing-levels/*
- **RR_UNC** and **COVEIG** – calculate spectrum averaged cross sections from ENDF-6 formatted data with covariance and eigenvalues (*A. Trkov*) *https://www-nds.iaea.org/IRDFF/*
- **PREPRO-2012** and **PLOTTAB** - ENDF/B-6 pre-processing code and plotting utility (*D. Cullen*) *https://www-nds.iaea.org/public/endf/prepro/*
- **ENDF-6 utilities** and **checking codes** - *https://www-nds.iaea.org/public/endf/utility/*
- **ENSDF utilities** and **checking codes** - *https://www-nds.iaea.org/public/ensdf_pgm/index.htm*
- **ENDVER - ENDF-6 File Verification Support Package** (A.Trkov) *https://www-nds.iaea.org/public/endf/endverI*
- **ZVView -** Interactive Plotting of Nuclear Data (V. Zerkin) *https://www-nds.iaea.org/public/zvview/*
- **myEXFOR, myENDF, myENSDF, myPlot -** tools under test (for access conact V. Zerkin)

These Packages provide access, retrieve and plotting of the EXFOR and ENDF data

- ***Several other Codes*** *(not mentioned here) are scattered on NDS pages*

VIII. On- and off-line Dissemination

- **Following a Greening policy, NDS prefers distribute information on-line**

  Nuclear Databases for downloading or ordering on CD/DVD (e.g., page fragment):

Nuclear Data on CD/DVD-ROMs

Select products from the list below

#	Product	Issued	Title [Link] Comment [Download]
1	**ADS v-2.0**	Dec-2008	Application Library for Accelerator Driven Systems [page]
2	**EMPIRE-3.2.2 Portable for Windows**	Jan-2014	System of codes for nuclear reaction calculations and nuclear data evaluation [screen-shots] Download (zip, 753Mb)
3	**ENDF libraries**	Aug-2013	30 Evaluated Data Libraries including ENDF/B-VII.1, JEFF-3.2, JENDL-4.0u2, CENDL-3.1, ROSFOND-2010
4	**EPDL97**	Mar-2002	Photon and Electron interactions Download (zip, 58Mb)
5	**EXFOR-CINDA for Windows**	Apr-2013	Database (MS-Access) and retrieval system (Java-2). Portable. [screen-shots] Download (zip, 247Mb)
6	**EXFOR-CINDA for Applications + Endver/GUI**	Feb-2014	Database retrieval systems for Linux, Windows and Mac. Includes Endver/GUI package integrated with Prepro-2012 and full EXFOR database. Portable: does not need neither installation nor configuration. [screen-shots] Download (tar.gz, 386Mb)
7	**FOND2.2**	Mar-2002	Evaluated Neutron Data Library Download (zip, 21Mb)
8	**IBANDL**	Mar-2014	Ion Beam Analysis Data Library [web] Download (zip, 45Mb, data + Web interface for Windows)

- **On the User specific request** (nds.contact-point@iaea.org), **NDS will send off-line**:
  - CD/DVD with databases
  - Hardcopies of INDC Reports, Charts of Nuclides, Nuclear Wallet Cards etc.
  - NDS Newsletters – hold Meetings, latest publications (two times per year)

to Demonstrations: Data on CD/DVD: https://www-nds.iaea.org/cdroms/

IX. Databases/Codes on USB "Miniworkshops"

to use EXFOR and ENDF off-line

1. Directory: **ENDF_Libraries ~ 3,000** Mb (most of the files are zipped):

   Collection of the ENDF-6 formatted Evaluated Nuclear Reaction Libraries for General Use and for specific Applications

   Click on readme.htm to see content, navigate and retrieve

2. Directory: **x4app-2014-02-04 ~ 950** Mb:

   EXFOR & CINDA databases with PREPRO, Endver, ZVView, Docs, …

   Run run_x4cd.bat (Windows), run_x4cd.sh (Linux), run_x4cd-mac.sh (MacOSX

3. Directory: **Empire322zv2win ~ 3,000** Mb

   (This is a beta version of the package. NOT intended for RE-DISTRIBUTION. Attention. Not all menu options are active):

   Empire code platform independent package with Empire, RIPL, EXFOR in C4, documentation ..

   Run run_empire.bat to start sample case Pd-105 …
   (more info in readme.txt and IAEA Empire workshop Dec 2013:
   https://www-nds.iaea.org/index-meeting-crp/EmpireWorkshop2013/index.htm)

Words at the End

... and that is not all ….

NDS/IAEA has accumulated much of information and knowledge

from the **Scientists all around the world**

during 50 years functioning,

which was celebrated on 2 June of 2014:

http://www.iaea.org/newscenter/news/2014/nds50.html

Thanks for the past, current and future contributions