The Area #1 EXFOR project, and an update on the new SG50

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Nuclear Reaction Data Compilations in USA & Worldwide

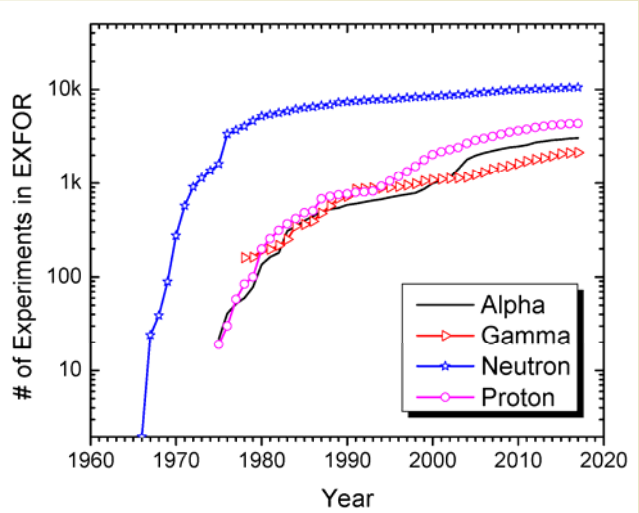
- Experimental neutron reaction data compilations have been pioneered at the Metallurgical Laboratory, University of Chicago and Los Alamos National Laboratory in 1945-1947.
- Brookhaven National Laboratory hired many *Manhattan Project* alumni when it was founded in

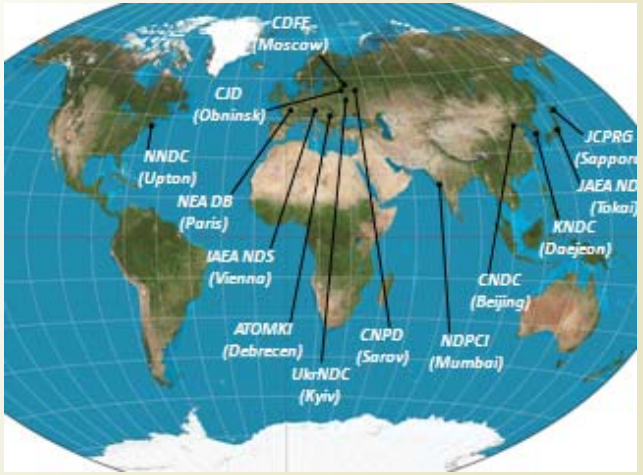
75 Years of Experimental Nuclear Reaction Data Compilatio

- Donald J. Hughes (1915-1960) was behind the BNL-170 (1952); it is a precursor of BNL-325 (Atlas of Neutron Resonances).
- SCISRS (Sigma Center Information and Retrieval System) at BNL (1964) was a precursor of EXFOR.
- Other data centers were created in Paris, France (NEA-Databank), Vienna, Austria (NDS-IAEA), and Obninsk, USSR (IPPE) in 1963-1964.
- Around 1970 four neutron data centers agreed on the data interchange format (EXFOR). The four centers could store data locally in its formats. The Nuclear

EXFOR - Experimental Nuclear Reaction Data

- The largest experimental nuclear reaction database: 24,992 experiments (multiple publications are grouped into a single measurement), 167,872 subentries, 185,543 data sets as of April 29, 2024.
- **EXFOR is a starting point for Evaluated Nuclear Data File (ENDF) libraries evaluations (many evaluated but a single experimental data library), it includes the uncertainties used by evaluators.**
- Presently run by the Nuclear Reaction Data Centres (NRDC) internationally.
- ***EXFOR philosophy is to compile data as they were published (in consultation with authors) unless obvious errors are found.*** **Published nuclear reaction data contain outliers and discrepancies.**





Area #1 FY 2023 (10/1/2022-9/30/2023) Statistics

- Team effort: B.Pritychenko (BNL), O.Schwerer, S.Hlavac, O.Gritsay (Contractors).

EXFOR	FY2022	FY2023
New Compilations	158	152
Updated Compilations	210	181
Preliminary Transmissions	29	19
Final Transmissions	31	22
Database Updates	41	40

The IAEA EXFOR compilation control system

- EXFOR compilation control system is one of the tools used for this co-ordination (Developed by Viktor Zerkin, IAEA, retired on October 31, 2023).
- Top panel: New entries only.
- Bottom panel: New and Updated entries, number of data points and transmissions.
- Overall performance of the Area #1 is very good.
- Potential issue is EXFOR maintenance or correction of existing entries.
- Area #1 has the largest number of entries -7,809. Only 4,790 (~61.3%) of entries were corrected.

https://www-nds.iaea.org/public/exfor/x4compil/exfor_input.htm

Full EXFOR Compilation Statistics (based on HISTORY)
Information updated: 03-Oct-2023, 16:06:36

#. Year	NNDC	NEA-DB	NDS	CJD	ATOMKI	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	KAZMON	CAJaD	KCPDG	RIKEN	Sum	
53. 2023	12	24	5	2		3	7	3	11		9	2	3				81	-294
52. 2022	154	39	35	9	9	5	19	19	18	7	41	9	11				375	-147
51. 2021	181	103	41	23	5	12	29	18	35	15	38	10	12				522	-141
50. 2020	217	134	77	40	10	12	31	29	41	11	35	3	23				663	+90

EXFOR Compilation Statistics based on N2 and EXFOR archive.
Information updated: 03-Oct-2023, 16:06:36

	NNDC	NEA-DB	NDS	CJD	ATOMKI	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	KAZ
2023	12	27	5	2		3	7	3	24		12	2	
	16	228	14	44	7	22	1	4	10		2		
	1,106	15,472	-361	651	-45	9	6,719	448	1,856		720	180	
	18	11	7	6	2	5	3	3	3	4	6	4	
2022	154	39	41	9	9	6	21	19	48	7	38	9	
	218	409	134	148	37	86	31	164	5	16	28	6	
	361,364	123,140	31,703	1,729	1,032	867	7,432	4,907	10,992	262	3,296	840	3
	28	14	7	7	2	5	4	9	5	4	8	5	
2021	183	105	35	23	5	11	27	18	19	16	41	10	
	272	160	130	167	39	45	18	140		12	34	2	
	108,438	322,343	12,734	3,235	-3,761	1,168	1,526	7,337	17,001	2,789	11,469	320	1
	27	18	14	10	4	6	6	12	2	7	9	5	
2020	221	129	80	39	10	12	32	29	36	13	33	3	
	307	379	53	143	9	19	9	223	12	13	8	6	
	27,119	314,506	53,204	5,348	1,276	312	5,642	3,809	7,505	1,484	2,638	733	27
	24	15	10	7	2	6	5	13	8	6	8	3	
1971		4		1									
		2		26									
		23		1									
			2										
1970				2									
				1									
Total	7809	6070	2586	1753	411	1033	455	2190	1390	335	624	119	
	4790	5614	3061	2569	433	1170	306	1325	587	278	216	45	
	9,477,497	6,479,266	831,189	287,819	61,439	164,876	49,448	806,832	649,591	41,171	89,624	17,232	32
	539	280	403	211	95	115	122	201	166	150	147	76	
	NNDC	NEA-DB	NDS	CJD	ATOMKI	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	KAZ

Legend: New Entries / Updated Entries / Added data points / Number of TRANS

Note. Year is defined from N2, i.e. it is the date when ENTRY/SUBENT has been finalized.

EXFOR Database and Web programming: Viktor Zerkin, IAEA-NDS, 1999-2023
Data Source: Network of Nuclear Reaction Data Centers (NRDC), 1970-2023

Missing (Unobtainable) Data: Existing EXFOR Entries

- C32 The subentry coded with STATUS= UNOBT may be deleted if the dataset is not suitable for digitization or optical character recognition (OCR) data recovery, and the source article was published before 2000.
- SG50 should provide an extra motivation for EXFOR improvements.

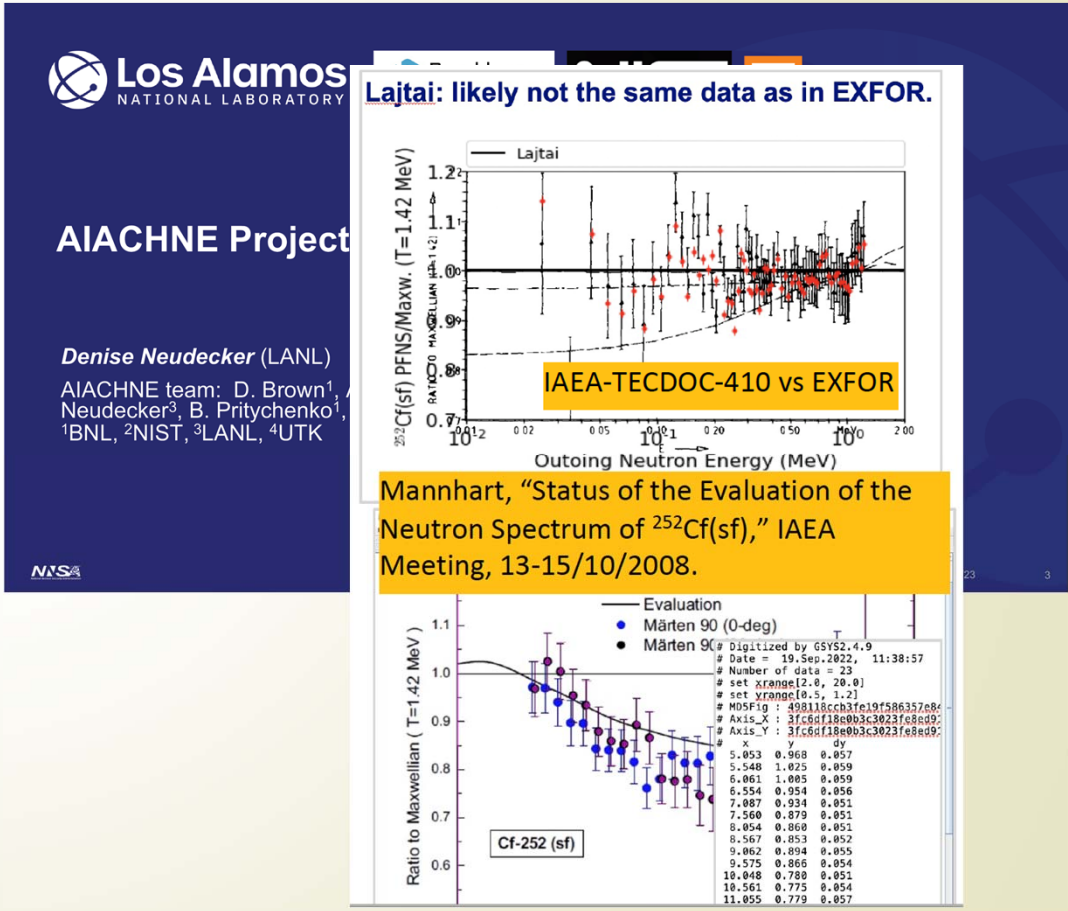
Area	NRDC 2021	NRDC 2022	NRDC 2023	NRDC 2024
#1	130	66	47	13
#2	114	117	106	104
#3	42	46	44	39
#4	21	20	5	4

Update on NRDC Actions

- A1: Center Heads send to Otsuka… Done.
- A18: Create meta schema for bibliographic data…. Ben Shu is working up a short presentation about progress on action A18.
- A19-29, A 29,31: Continuing actions
- A 32: Completeness check against Atlas of Neutron Resonances is in progress.
- A 33-39, 41-42, 45-50, 52, 59, 77, 79-82, 85: Continuing actions

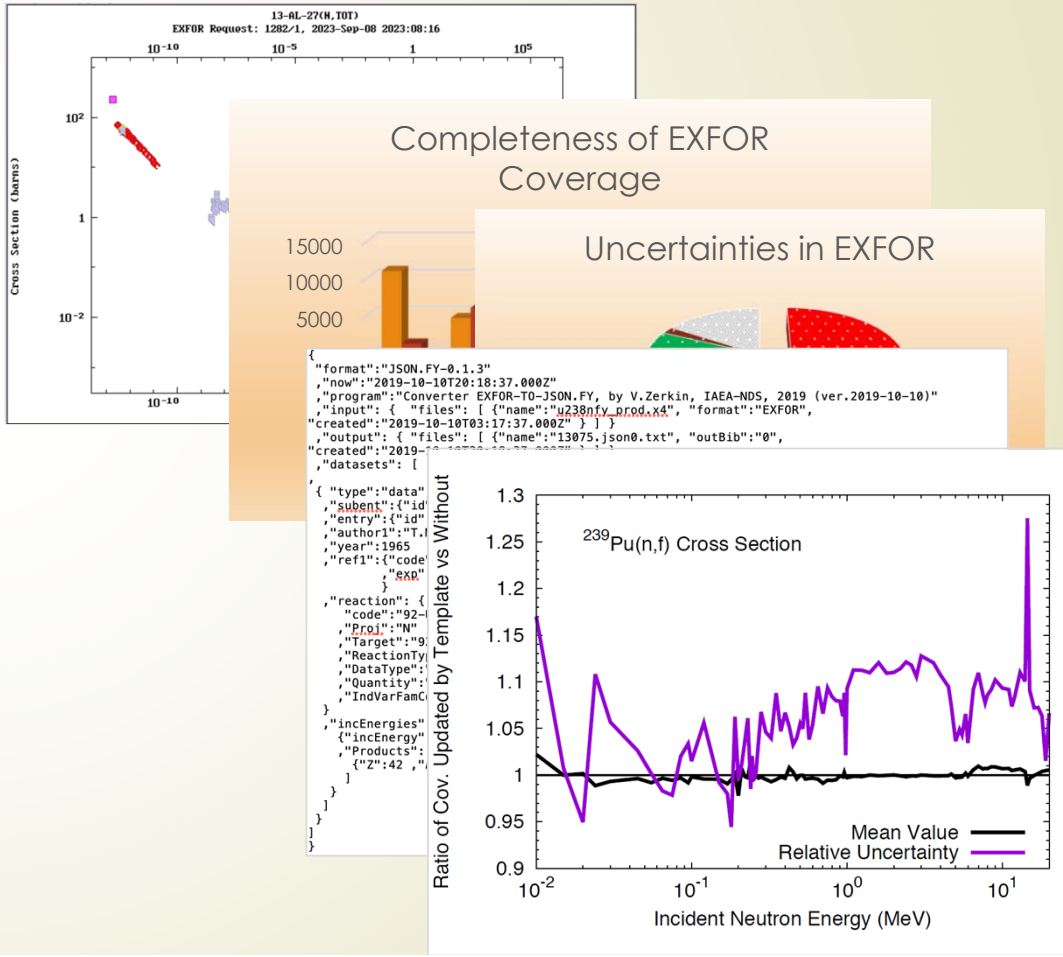
AIACHNE Project

- Why EXFOR corrections are important???
- AIACHNE (AI/ML Informed cAlifornium CHi Nuclear data Experiment): "Designing Nuclear-data Measurements that Resolve Discrepancies in Existing Data".
- EXFOR library analysis is often the key starting point for nuclear data evaluations.
- We used NRDC network plot digitization software GSYS to obtain input used by Mannhart.
- Mannhart input vs. EXFOR: 2 uncovered experiments for Area#2 are being included. Metadata found for existing EXFOR compilations will be included.



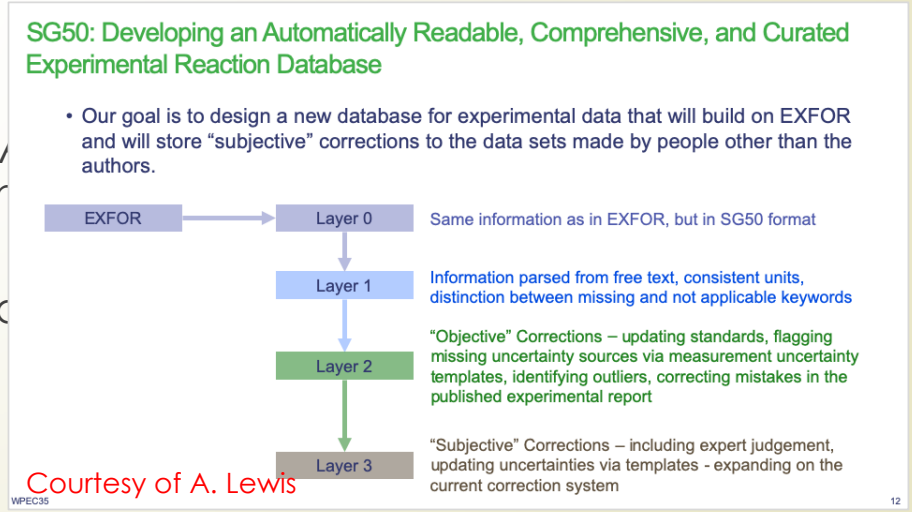
EXFOR Database Modernization

- EXFOR is 75-year-old: It has to capitalize on modern computer technologies: Automatization of the EXFOR life and production cycle
- New data formats: JSON (JavaScript Object Notation) lightweight data interchange format for EXFOR is now in progress at the NNDC and IAEA-NDS.
- Implementation of uncertainty templates developed by Denise Neudecker et al. (LANL) for resolving issues with missing uncertainties and covariances.
- Potential collaboration: BNL, Los Alamos, IAEA, LBNL, NEA-DB, LLNL, …
- Proposal was presented to NDAC on September 14, 2023.



WPEC SG50

- The current evaluation process needs well-documented, fully traceable data corrections to make evaluations reproducible. We need to exclude or reduce repetitive work in data evaluations, evaluators should not re-analyze the same data sets again and again.
- SG50 (2021-2024): Developing an Automatically Readable, Comprehensive, and Curated Experimental Reaction Database
- SG50 requirements (LA-UR-20-28933) 2022.
- Amanda Lewis, Denise Neudecker, A May 17, 2023: Goals, documentatior (JSON, …), ...
- Precursor prototype of curated data



Courtesy of A. Lewis

Continuation of SG50 Proposal

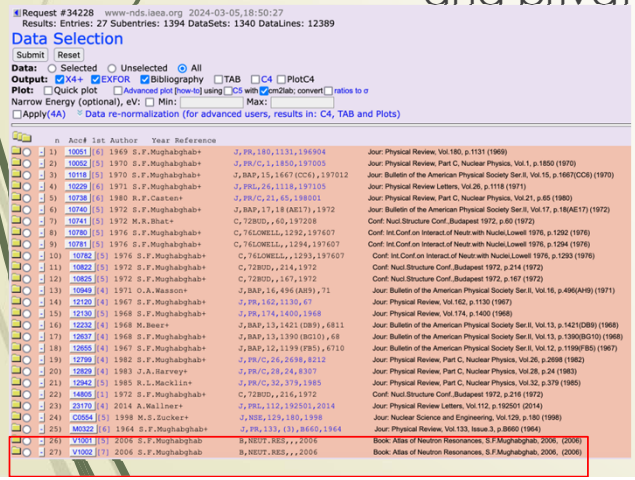
- Continuation of the Subgroup 50 on developing an automatically readable, comprehensive, and curated experimental reaction database.

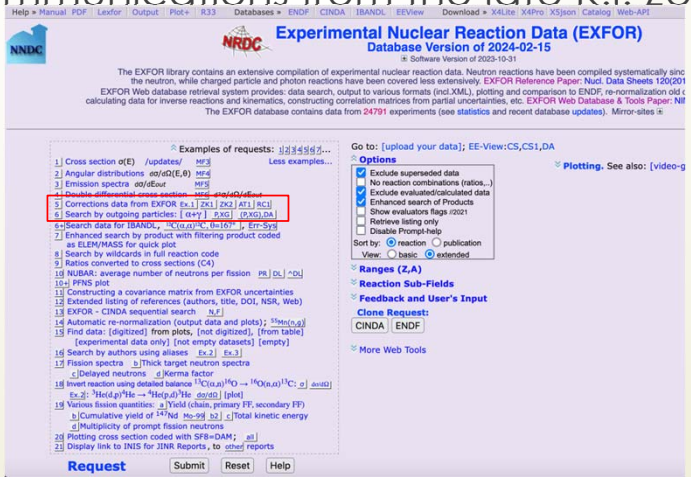
Expected results and deliverables	1) Finalize the version of JSON (JavaScript Object Notation) format for EXFOR using presently available prototypes, explore free text to JASON conversion, work on quality assurance (QA) of conversion to JSON. JSON is an open standard file format and data interchange format that uses human-readable text to store and transmit data objects consisting of attribute-value pairs and arrays. 2) Correct multiple EXFOR entries using commonly-acceptable criteria (e.g., updates with recent standard evaluations, highlighting missing uncertainties with templates of expected measurement uncertainties), and collect existing corrected EXFOR files from nuclear data evaluators (V.Zerkin, D.Neudecker, M.Paris, P.Talou, A.Carlson, R.Capote, K.Kravvaris, I.Thompson, A.Mattera). The curated EXFOR should not be considered as recommended. Users should make selections among the available curated data sets.

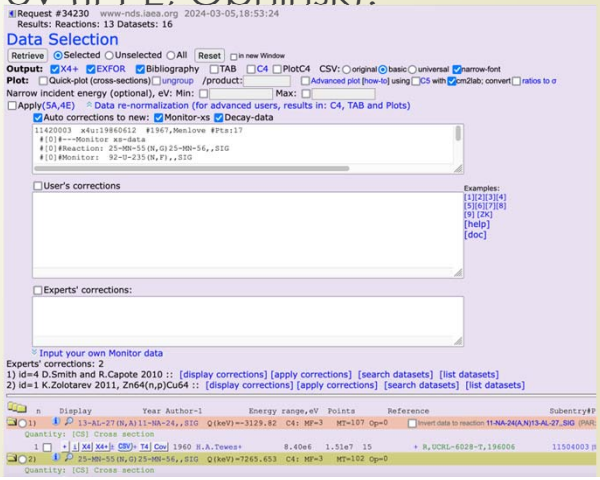
Milestones vs. time	1) 2024-2025: Finalize the version of JSON format and develop EXFOR to JSON format conversion code. Start working on EXFOR corrections. 2) 2025-2026: Continue work on EXFOR corrections and collect existing corrected files from ENDF evaluators. Explore free text to JSON conversion and quality assurance of EXFOR to JSON conversion. 3) 2026-2027: Finish work on EXFOR corrections and collection of existing corrected files, convert all corrected files to JSON format.

Sources of Curated Data Sets

- Curated data are already exist in EXFOR: v-series compilations, i.e. Atlas of Neutron Resonances integral values: EXFOR entries V1001, V1002.
- I prepared compilation of neutron cross section standards data sets in 2015.
- Precursor curated database by V. Zerkin: Viktor has implemented Web (virtual space) corrections to some existing EXFOR data sets using the updated reaction monitor values, the latest decay gamma-ray intensities, and private communications from the late K.I. Zolotarev (IPPE, Obninsk).







More Sources of Curated Data Sets

- Neutron: M. Paris, P. Talou (LANL), R. Capote (IAEA), A. Carlson (NIST), …
- Actinides: D. Neudecker (LANL)
- Charged Particles: K. Kravvaris (Solar Fusion), I. Thompson (LLNL)
- Fission Yields: A. Mattera (BNL)
- Spontaneous Fission: D. Neudecker/B. Pritychenko (LANL/BNL)

Outlook

- NNDC EXFOR compilation efforts are complex and well-organized: B. Pritychenko (BNL), O. Schwerer, S. Hlavac, O. Gritzay (Under contract with BNL), V. Zerkin (IAEA).
- EXFOR modernization proposal was reported to NDAC.
- We should continue SG50.
- Finalize JSON format, explore free text to JSON conversion, work on JSON conversion quality assurance (QA).
- Collect curated EXFOR data sets.
- People is the most important resource in nuclear data.

International Network of Nuclear Reaction Data Centres (NRDC)

- The International Network of Nuclear Reaction Data Centres (NRDC) constitutes a worldwide cooperation of nuclear data centres under the auspices of the International Atomic Energy Agency. The Network was established to coordinate the world-wide collection, compilation and dissemination of nuclear reaction data.

Technical Meeting on International Network of Nuclear Reaction Data Centres
IAEA Headquarters, Vienna, Austria, 9 – 12 May 2023

The International Atomic Energy Agency: (https://www.iaea.org/about/mission)

- is an independent intergovernmental, science and technology-based organization, in the United Nations family, that serves as the global focal point for nuclear cooperation;
- assists its Member States, in the context of social and economic goals, in planning for and using nuclear science and technology for various peaceful purposes, including the generation of electricity, and facilitates the transfer of such technology and knowledge in a sustainable manner to developing Member States;
- develops nuclear safety standards and, based on these standards, promotes the achievement and maintenance of high levels of safety in applications of nuclear energy, as well as the protection of human health and the environment against ionizing radiation;
- verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes.