Open Comprehensive Nuclear Events Database

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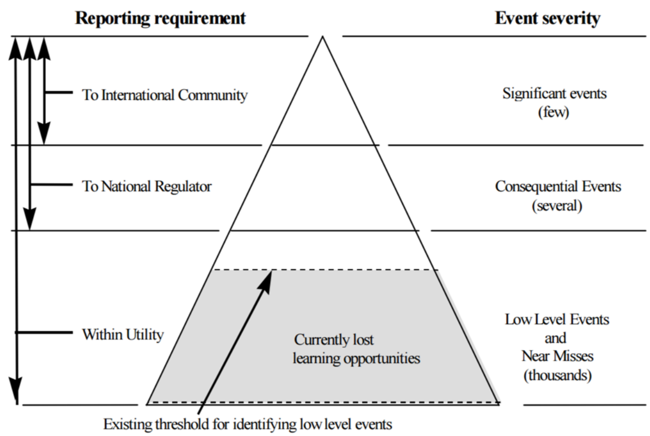
Learning from experience*

“Nuclear safety requires a continuing quest for excellence including learning from safety research and operating experience” - IAEA

- Pooling events and statistical/empirical testing is desirable, incl. to answer big-picture risk questions
  - Completeness?
- More lessons can be learned from the operating history, incl. for PSA methodology
- Lack of open comprehensive info for scientists and the public about adverse events in commercial NPP
- The total consequences of events must be studied to understand the true value of safety investments.

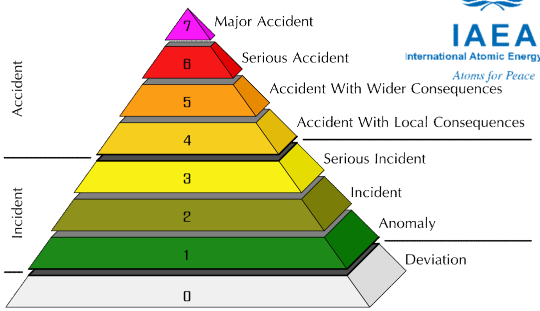


Only “few” significant events need to be reported to the international community; “several” consequential events to national regulators; and “thousands” of low-level events need not be shared outside of the utility.

*448 (mid 2018) reactors in operation, more than 15’000 accumulated reactor-years, event reporting systems are established

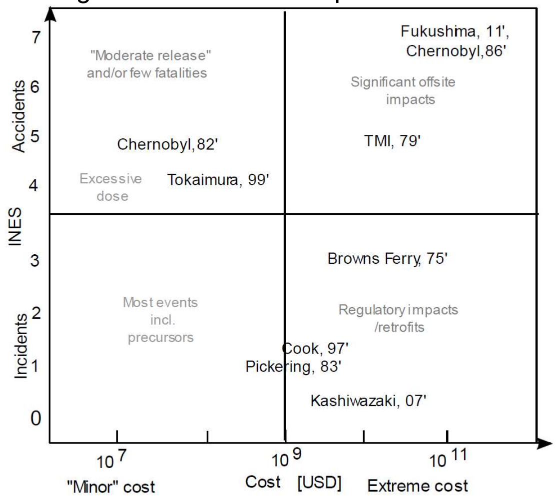
Cost & safety measurement

International Nuclear Event Scale



IAEA
International Atomic Energy Agency
Atoms for Peace

Diverse relationship between safety significance and consequences of events



Regulatory analysis

- INES inconsistent wrt safety relevance, mixes core relevant with not.
  - One fatality or minor release (INES 3-4), near-miss of major accident (INES 3).
- Frequency: Incidents/precursors to study probability of core damage and large releases.
  - 100s of events rather than 5/15’000 ~ (1,10)x10^{-4}
- Severity: CCDP, cost of consequences, mushrooming upon core damage.
  - Approximate / order of magnitude sufficient
- Regulation does not require study of consequences (PSA level 3), despite being key for risk-informed decisions, e.g., CBA on buying down risk.

Limited data for scientific & public use

Existing event databases

- IAEA **IRS**: Not open, about 400 events have an INES score, mostly 0-1, none above 2.
- **WANO** opEx: Not open. High quality and degree of technical detail.
- EU **JRC** opEx: Draws on reports from Western national regulators since 2006. Provides practical safety lessons-learned. Open by request.
- NRC **LER**: Open, enormous, US only, since 1980. No searchable severity measure.
- NRC **ASP**: Comprehensive precursor analysis, US only, no database.
- **National** regulatory agencies: diverse, limited scope
- **KINS**: Useful search-able database of hundreds of anomalies and incidents. Korea only.
- …

- A number of academic studies have relied on very limited samples of INES events[1,2] as well as cost/consequences[3-5].

[1] M. Ha-Duong, V. Journe. "Calculating nuclear accident probabilities from empirical frequencies", Environment Systems and Decisions 34.2 (2014).
[2] L. Escobar Rangel, & F. Leveque. "How Fukushima Daiichi core meltdown changed the probability of nuclear accidents?", Safety Science 64 90-98 (2014).
[3] M. Hofert, & M. Wüthrich. "Statistical review of nuclear power accidents." *Asia-Pacific Journal of Risk and Insurance* 7.1 (2011).
[4] D. Sornette, T. Maillart, & W. Kröger. "Exploring the limits of safety analysis in complex technological systems." *International Journal of Disaster Risk Reduction* 6 (2013): 59-66.
[5] S. Wheatley, B. Sovacool, & D. Sornette. "Of disasters and dragon kings: a statistical analysis of nuclear power incidents and accidents." *Risk analysis* 37.1 (2017): 99-115.

Comprehensive open nuclear events database

- Approach: compile, expert review, simplify, annotate
- Threshold completeness
- Comprehensive*: full history, global, and all technologies

Content

- Brief description: initiator, development, counsequence
- Severity*: INES, approx total cost, CCDP
- Attributes: Origin, failure mode (H/T), etc.
- Operational modes

Sources

- NRC: ASP, LER; IAEA INES; NEA topical reports; EU JRC; Reports from national regulators
- Diverse documented online search

Examples

- **15-10-1982, Armenian-1** (PWR), former-USSR: Series of failures, short circuits, cable overheatings and fires after switching of reserve service water (boron) pump to vital 6 kW bus ordered during maintenance of service water pump; later, control rods dropped, emergency protection system activated; 3 hours later total plant blackout, 5 hours later a high pressure injection pump became operational, and 6.5 hours later fires liquidated and feedwater pump activated to fill steam generators and provide primary circuit cooling.
  INES=3 $\leftrightarrow$ **CCDF** $> 10^{-2}$**; secondary origin; human and technical failure modes.**

- **27-12-1999, Blayais-2** (PWR), France: Unexpected combination of the tide and high winds partially flooded the site with units 1,2,4 operating and unit 3 shut down for refueling; all units lost their 225 kV power supply and units 2 and 4 also lost their 400kV power supply, leading to automatic shutdown after failure of self supply and triggered start of diesel backup generators; damage to safety related systems; inadequate emergency response: restoration of 400kV power supply after less than 3 hours; no damage to the reactors but triggered generic upgrades...
  INES=2. $10^{-4} <$**CCDF**$< 10^{-3}$**; external origin; technical mode; forerunner to Fukushima.**

Data overview & basic insights

Breakdown of events by category:

Civilian use facilities: 870 events
- Power plants: 787
- Reprocessing: 43
- Demo/Experimental/Research: 24
- Fuel Fabrication/Preparation/Recovery: 10
- Uranium Mine/Processing: 5
- Waste Disposal: 1

Power Plants: 787 events
- PWR: 453
- PHWR: 83
- BWR: 190
- (HW)GCR: 33
- LWGR: 19
- FBR: 3
- HTGR: 4

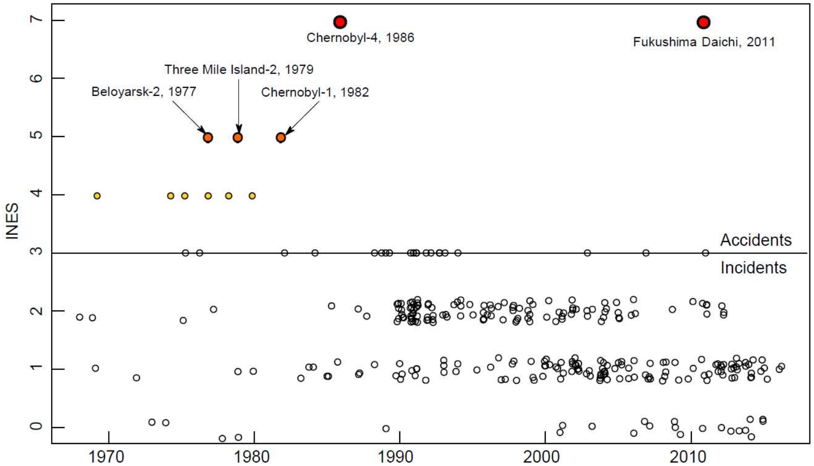


Figure 2: INES scores for events at commercial nuclear power stations. Including only events deemed to have core-safety relevance (e.g., excluding Tokai-mura, 1999), from the database. The incident points are spread around their INES value for visibility. The INES 4 events include: 1969 St Laurent-1; 1974 and 1975, Leningrad-1; 1977 Bohnice-1; 1978, Beloyarsk, which has INES 3-4; and 1980, St Laurent-2.

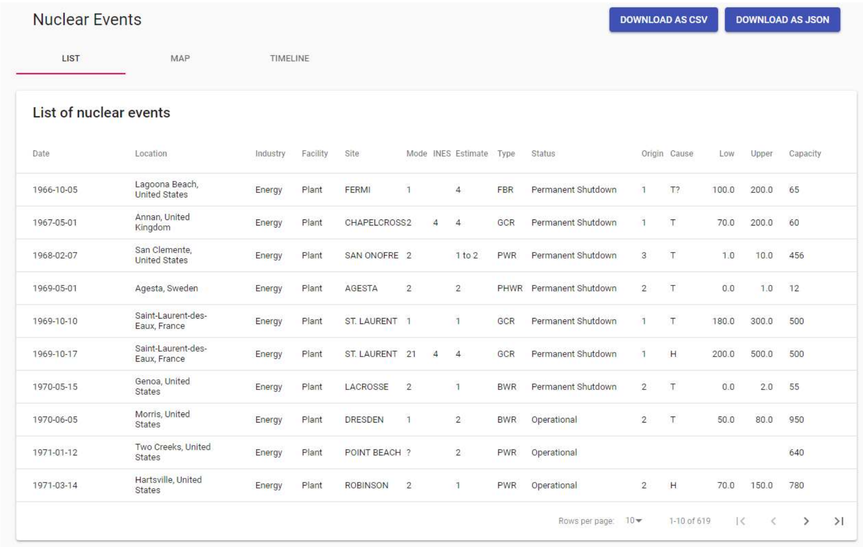
Of the >500 events at NPP with potential core safety relevance:

- 15% were when powering up or down, 11% were with the unit “cold”, and 74% at full power.
- The share of events by region (with share of global reactor-years’ experience in parenthesis): North America: 55% (29%), North and Western Europe: 23% (37%), Asia: 13% (19%), and Eastern Europe: 9% (15%).
- More than 165 events were found to have a significant or event dominant human element (incl. design, maintenance by own staff or contractor, operation, etc.).
- The origin of the trigger/cause by location breakdown as: nuclear 65%, secondary 23%, and external 13% -- demonstrating the importance of triggers outside of the primary nuclear part.
- 20 percent of events are multi-unit.

Region	Reactor years	INES 0+1	INES 2	INES≥3
US	4’300	245	87	15
US*	3’440	245	75	7
NWE	5’500	86	78	7
JKI	2’800	57	13	12
EE	2’300	12	27	15

Table: Count of specified INES scores by region

Snapshot of online database


Nuclear Events

DOWNLOAD AS CSV DOWNLOAD AS JSON

LIST MAP TIMELINE

List of nuclear events

Date	Location	Industry	Facility	Site	Mode	INES	Estimate	Type	Status	Origin	Cause	Low	Upper	Capacity
1966-10-05	Lagoona Beach, United States	Energy	Plant	FERMI	1		4	FBR	Permanent Shutdown	1	T?	100.0	200.0	65
1967-05-01	Annan, United Kingdom	Energy	Plant	CHAPELCROSS	2	4	4	GCR	Permanent Shutdown	1	T	70.0	200.0	60
1968-02-07	San Clemente, United States	Energy	Plant	SAN ONOFRE	2		1 to 2	PWR	Permanent Shutdown	3	T	1.0	10.0	456
1969-05-01	Agesta, Sweden	Energy	Plant	AGESTA	2		2	PHWR	Permanent Shutdown	2	T	0.0	1.0	12
1969-10-10	Saint-Laurent-des-Eaux, France	Energy	Plant	ST. LAURENT	1		1	GCR	Permanent Shutdown	1	T	180.0	300.0	500
1969-10-17	Saint-Laurent-des-Eaux, France	Energy	Plant	ST. LAURENT	21	4	4	GCR	Permanent Shutdown	1	H	200.0	500.0	500
1970-05-15	Genoa, United States	Energy	Plant	LACROSSE	2		1	BWR	Permanent Shutdown	2	T	0.0	2.0	55
1970-06-05	Morris, United States	Energy	Plant	DRESDEN	1		2	BWR	Operational	2	T	50.0	80.0	950
1971-01-12	Two Creeks, United States	Energy	Plant	POINT BEACH	?		2	PWR	Operational					640
1971-03-14	Hartsville, United States	Energy	Plant	ROBINSON	2		1	PWR	Operational	2	H	70.0	150.0	780

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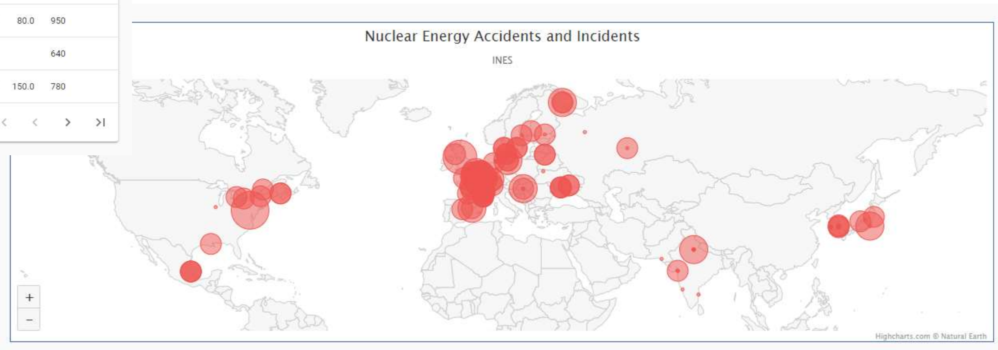

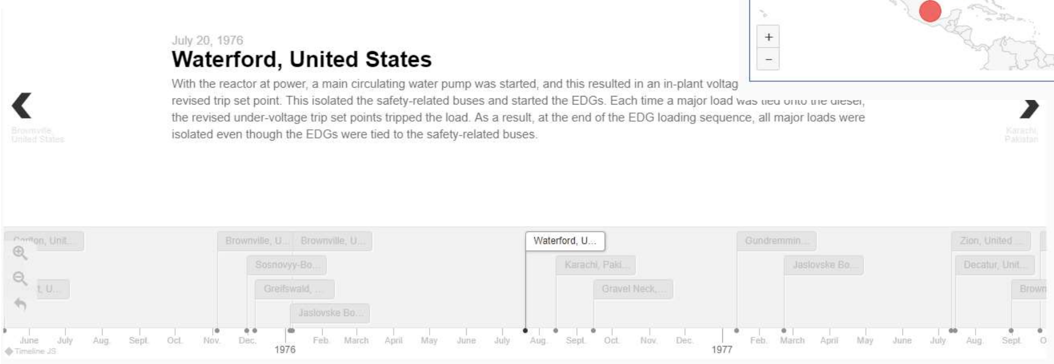

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Cost of incidents & accidents

Table 1. Approximate estimated full cost of major nuclear accidents. Given in Billions of 2017 USD, including the French hypothetical major accident. The interval in the approximate total is the sum of the upper and lower bounds of the individual costs. Comparatively large costs given in bold. Life and health impacts include deterministic and projected radiological fatalities, and evacuation related trauma. Replacement is the incremental cost of replacement power. The "beyond" category identifies potential costs that are outside of the scope of the estimation. Arguably the TMI retrofit costs could be excluded on the basis that they were beneficial. Deeply uncertain costs and potential benefits relating to impacts on energy policy are not quantified.

Cost (USD Bil.)	ISRN, 2011	TMI, 1979	Chernobyl, 1986	Fukushima Dai-ichi, 2011
On-site	10	5-10	**25-35**	**20-30**
Life & Health + Public-Economic	< 60 + 110	0.1	26-33 + **150-250**	14-15 + 50-100
Replacement + Retrofits	110	5-15 + **100-200**	10-30 + 2-8	**100-150** + 60-120
Beyond...	200 "reputation"	**Sector inflection point.**	**Political instability?**	**German nuclear exit, etc.**
Approx. Total	< 500	110-225	213-356	244-415

Table 3: Breakdown of costs, excluding "Big 3". In USD Billions, only for events at NPP.

Events	**Costs**	**Significant cost components**
Browns Ferry fire in 1975	32.3 – 53.9	30 – 50 industry impact
Kashiwazaki earthquake in 2007	12.6 – 16.1	10 – 13.5 downtime, 2.6 repair
Browns Ferry & Sequoyah programmatic weaknesses in 1984	8.8 – 10. 2	4.5 – 5.5 downtime, 4.3 – 4.7 repair
Between 1-5 Bil. costs: 34 events	66.2 – 124.3	
Less than 1 Bil. costs: 747 events	32.6 – 75.5	
Subtotal of NPP events (excl. big 3)	**153 - 280**	

Table 4: Breakdown of cost by type, in USD Billions, only for events at NPP, excluding Sellafield, industry impacts of generic defects, events with very limited safety relevance, etc. * of which $30-50 billion is from the Browns Ferry fire incident (1975). ** mostly impact on the health of employees/contractors.

Cost Types	**Chernobyl, Fukushima, TMI**	**All other events**	**Row total**
Downtime / Replacement	115 – 195	94 – 156	209 – 351
Industry impact / retrofits	162 – 328	39 – 70*	201 – 398
Public Economic	200 – 350	~0	200 – 350
Life & Health	40 – 48	<1**	40 – 49
On-site	50 – 75	20 – 53	70 – 128
Column total	567 – 996	153 – 280	**720 - 1276**

- NRC Regulatory Analysis, 2013 OECD/NEA workshop, ISRN estimate, provide guidelines.

- TMI: Costly reforms, increasing the price of electricity (also increasing safety).
- Fukushima: Large economic costs, with costs due to latent cancer relatively low.
- Alarming precursors have led to costly retrofitting (also increasing safety), and programmatic weaknesses have led to costly downtime.

- Major accidents dominate → approx. estimates sufficient.
  - ~0.1 cents per kWh accident externality.

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Key messages

- Goal: provide a basis to fully learn from experience
- Answer big-picture questions about risk

Project

- Small-scale, 3 years PhD-project, supervised by experts in relevant disciplines – in close cooperation with industry
- Progressing and still open to (foreign) collaborations.
- Wide-scale precursor analysis making use of our large-scale open database, model development where appropriate

Use, review, and contribution to the db greatly appreciated!