The decommissioning of the Fessenheim NPP: between desappearance of memory and persistence of sameness



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Seminar « Decommissionning Fessenheim: Between Erasure and Transmission»

OHM Fessenheim - LabEx DRIIHM
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Plan

- Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?
- The risk of evidence deletion and memory loss
- Open trajectories
- Supplementary materials

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

- **From closure to decommissioning**
  - **service :** 1977 – 2020
    - **FES1 reactor**
      - duration 42.9 ans
      - net electrical output 880 MWe, thermal output 2785 MWth
      - net electricity production 227.7 TWh
      - net efficiency 31.6 %, average load factor 68.8 %
      - availability 72.2 %
    - **FES2 reactor**
      - duration 42.7 ans
      - net electrical output 880 MWe, thermal output 2785 MWth
      - net electricity production 220.6 TWh
      - net efficiency 31.6 %, average load factor 66.9 %
      - availability 70.7 %
  - **pre-decommissioning**: 12/2020 – 01/2026
  - **decommissioning**: 01/2026 – 30/06/2048 max (Decree No. 2026-336)
    - ➢ 22 years (15 years in the Decommissioning plan EDF 2020)

« *Art. 4.* – Les opérations de démantèlement mentionnées au II de l'article 1er sont achevées au plus tard le 30 juin 2048. »

Chronological milestones

- **06/04/1977, 06/10/1977** : FES1 and FES2 connected to grid
- **06/06/2018** : ASN informed by EDF of the permanent shutdown of the Fessenheim NPP at VD4 (09/2020 FES1, 08/2022 FES2)
- **19/01/2018** : 1st meeting of CoPil territory restructuring
- **01/02/2019** : territory restructuring plan signed
- **19/02/2019** : The ASN exempts EDF from implementing the requirements for the VD4
- **27/09/2019** : State-EDF compensation agreement signed
- **30/09/2019** : request for the revocation of EDF's operating licence for the Fessenheim NPP; declaration of the permanent shutdown of FES1 and FES2; submission of the decommissioning plan for the Fessenheim NPP to the ASN
- **18/02/2020** : decree No. 2020-129 revoking the operating licence for the Fessenheim NPP
- **22/02/2020** : closure of FES1 reactor
- **29/06/2020** : closure of FES2 reactor
- **30/11/2020** : decommissioning file (updates: 23/12/2021, 21/07/2023, 31/01/2025)
- **01/05/2026** : Decree No. 2026-336 requiring EDF to decommission the Fessenheim nuclear power station

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

- **From closure to decommissioning**

→ Questioning the actual duration: Feedback from Europe, Canada, USA

16 years without demolition RB->museum (*Garigliano*, BWR 150 MWe),

25 years + 9 years differed (*Chooz* A, PWR 305 MWe),

10-15 years (Suisse), 24 years (*Stade*, PWR 672 MWe),

46 years differed (PWR USA)[(1)], etc.

→ Questioning the decommissioning strategy

→ Questioning the dismantling itself

Name	Type	Location	Year of shutdown	Year of deferred decommissioning completion
Crystal River – Unit 3	PWR	Crystal River, FL	2013	2073
Dresden – Unit 1	BWR	Morris, IL	1978	2036
Fermi – Unit 1	FBR	Monroe Co., MI	1972	2032
Humboldt Bay – Unit 3	BWR	Eureka, CA	1976	2017
Indian Point – Unit 1	PWR	Buchanan, NY	1974	2026
Kewaunee	PWR	Kewaunee, WI	2013	2073
LaCrosse	BWR	LaCrosse, WI	1967	2026
Millstone – Unit 1	BWR	Waterford, CT	1995	2056
Nuclear Ship Savannah	PWR	Norfolk, VA	1970	2031
Peach Bottom – Unit 1	HTGR	York Co., PA	1974	2034
San Onofre – Unit 1	PWR	San Clemente, CA	1992	2030
San Onofre – Units 2 and 3	PWR	San Clemente, CA	2013	2031
Three Mile Island – Unit 2[1]	PWR	Middletown, PA	1979	2036
Vallecitos[2]	BWR	Sunol, CA	1963	2023
Vermont Yankee	BWR	Vernon, VT	2014	2073
Zion – Units 1 and 2	PWR	Warrenville, IL	1998	2020

Source: Derived from NRC and complementary web research for each unit.

(1) OECD, NEA, *Costs of Decommissioning Nuclear Power Plants*, 2016

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

- **Questioning the decommissioning strategy**
  - ***immediate dismantling*** (Fessenheim, particular reactors in Germany, Japan, Spain)
  - ***diferred dismantling*** (particular reactors in various countries)
  - ***unified strategy*** (South Corea, Spain, France, The Netherlands, Czech Rep.)
  - ***case-by-case strategy*** (others) most often[(1)]

→ What are the objectives of decommissioning a NPP, and more specifically the Fessenheim plant?

	immediate dismantling	differed dismantling
Advantages	- availability of qualified staff - good knowledge of the facility - less risk of damage to technical archives - faster reuse of the site - no transfer of the decommissioning burden to future generations - reduced degradation-corrosion	- high reduction in radioactivity - reduction in radiation risks - reduced volume of radioactive waste produced - possible preservation of RBs for archival, storage and museum purposes - cost reductions, availability of funds for decarbonisation - shared responsibility for the storage of ILLW-LL waste - coordination of decommissionings
Disadvantages	- higher irradiations - more complex radioprotection - larger volume of radioactive waste - higher cost of radioprotection - psychological difficulties for staff - loss of the memory of buildings and past activity - apparent disappearance and transfer of radioactive elements and materials to other sites - erasure of liability for nuclear waste - limited technical solutions - additional radioactive waste to be stored	- risk of losing archives, or knowledge of the installation - possible shortage of qualified staff - unavailability of the nuclear site over a long period - transfer of the decommissioning burden to future generations - maintenance to prevent deterioration and corrosion

[(1)] OECD, NEA, *Costs of Decommissioning Nuclear Power Plants*, 2016

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

- **Fessenheim : questioning the greenfield strategy**
  - **Prescription** : « *assainissement des structures et des sols* » and « *démolition des bâtiments jusqu'à une profondeur d'au moins un mètre par rapport au niveau du terrain actuel* »[1]

Décret n° 2026-336 du 1er mai 2026 prescrivant à la société Électricité de France de procéder aux opérations de démantèlement de l'installation nucléaire de base n° 75, dénommée « centrale nucléaire de Fessenheim », sur le territoire de la commune de Fessenheim (département du Haut-Rhin) et modifiant le décret du 3 février 1972 autorisant la création de cette installation

« *Art. 3.* – Les opérations de démantèlement mentionnées au II de l'article 1er sont réparties en quatre étapes, dont certaines peuvent se dérouler concomitamment :

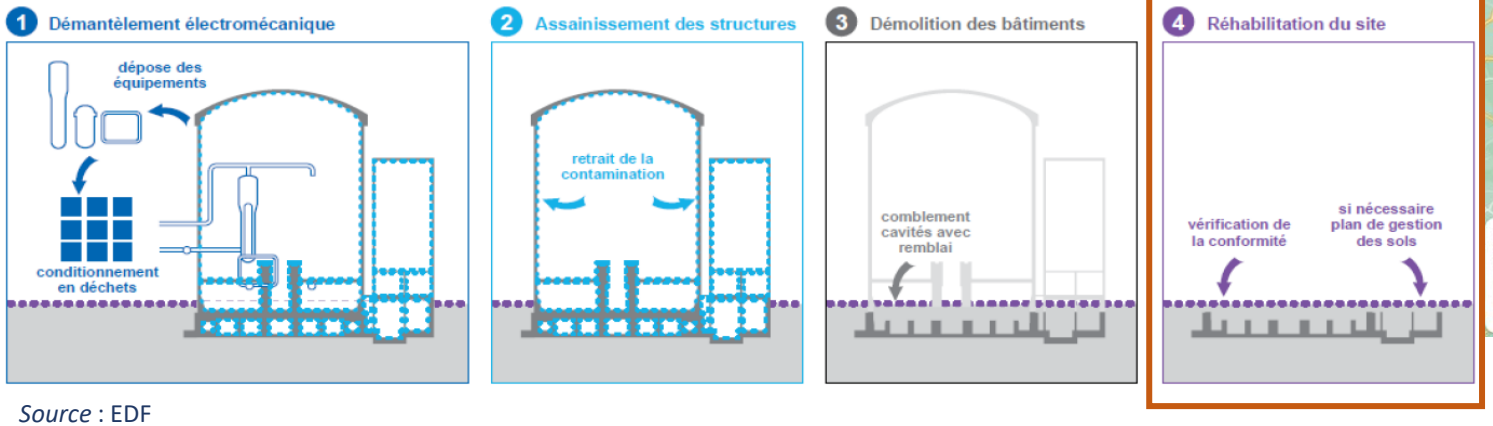
« 1° Etape 1 : Le démantèlement électromécanique, comprenant notamment :

« 2° Etape 2 : L'assainissement des structures et des sols ;

« 3° Etape 3 : La démolition des bâtiments jusqu'à une profondeur d'au moins un mètre par rapport au niveau du terrain actuel à l'exception des installations conventionnelles et bâtiments administratifs mentionnés au II de l'article 2 ;

« 4° Etape 4 : La réhabilitation du site.

« L'exploitant procède, en outre, aux opérations de surveillance, maintenance et entretien nécessaires au maintien de l'installation dans un état sûr. »



Source : EDF



[1] EDF, *Plan de démantèlement, INB 75 FESSENHEIM*, 2023

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

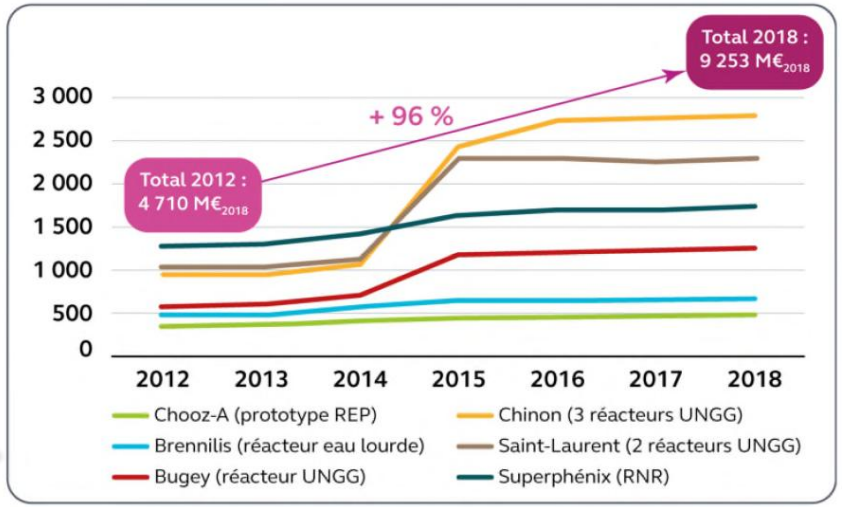
- **Fessenheim : questioning the greenfield strategy**
  - **Greenfield status, the EDF's choice?**
    articles R. 593-16, 28 et 69 of Decree No. 2019-190 of 14 March 2019:
    (the regulatory section of the Environment Code, and the decrees relating to basic nuclear installations and transparency in the nuclear sector) : « *mise à jour du plan de démantèlement décrivant les étapes prévues pour la réalisation du démantèlement ainsi que l'état du site visé à l'issue de celui-ci* », without requiring any return to greenfield whatsoever. « *Ce plan justifie que les opérations de démantèlement sont réalisées conformément aux principes définis à l'article L. 593-25. Il présente la stratégie d'assainissement envisagée pour les structures des bâtiments et des sols ainsi que ses prévisions d'utilisation ultérieure du site* ».
    → The site's status following decommissioning is, by regulation, 'open'.
  - **Greenfield status, meaning?**
    « *EDF engagera une démarche d'optimisation visant à un assainissement poussé, pour aller aussi loin que possible dans l'assainissement compte tenu des meilleures techniques disponibles à un coût économiquement acceptable* ».
    « *Les cavités restantes sous le niveau du sol sont comblées avec un remblai approprié. Les gravats non nucléaires issus de la démolition sont utilisés dans la mesure du possible comme remblai après avoir été concassés* ».
    « (…) *si la modélisation des phénomènes physiques montre que la contamination se répartit sur toute l'épaisseur du béton, l'impact sur les sols sous-jacents devra être évalué afin de définir la gestion nécessaire* ».
    « *Le dossier de demande de déclassement de l'INB pourrait alors comprendre les demandes de servitudes finales à maintenir pour conserver la **mémoire** et restreindre l'utilisation du site aux usages compatibles avec les éventuelles concentrations ou activités résiduelles* » [(1)].
    → Uncertainties regarding the final radiological status of the soil, under the supervision of the ASNR
    → What trade-offs between radiological data, metrological uncertainties, final easiments, decision to decommission?

[(1)] EDF, *Plan de démantèlement, INB 75 FESSENHEIM*

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

- **Fessenheim : questioning the greenfield strategy**
  - **What strategy lies behind the objectives?**
    - **a showcase** for EDF's future services in the competitive market for the decommissioning of closed nuclear reactors worldwide
    - **control and nuclear reoccupation of the territory**:
      - **technocentre** project EDF of VLL-ILL radioactive waste treatment[(1)]
      - hypothetical **SMR** (*small modular reactor*) project
  - **What are the financial implications?**
    - **decommissioning costs that remain uncertain**
      - estimation EDF ~ 700 M€ / reactor
      - average cost Germany ~ 1 G€ / reactor
      - French Court of Accounts 2012, 2016, 2020
      - comparaison OCDE
    - **future investments that remain uncertain**
      - estimated investment **technocentre** ~ 450 M€
      - **SMR** : hypothetical feasability, costs
    - **a financial burden for the energy transition**

      What capacity remains for investment in renewable energy, storage, grid integration, charging points and electric vehicles?



Source : CdC, *L'arrêt et le démantèlement des installations nucléaires*, 2020

ISDC level 1 cost items reported per unit in USD$_{2013}$ million

Name	ID	MWe	ISDC Level 1 – items											Total
			01	02	03	04	05	06	07	08	09	10	11	
José Cabrera	ES-P1	160	16.9	5.3	N/R	55.5	12.8	87.2	19.6	69.5	–	55.1	18.8	340.6
Generic – ESP	ES-P2	1 066	18.2	1.5	N/R	70.3	22.6	89.7	108.6	95.3	–	–	11.3	417.5
Generic – CH	CH-P1	1 000	57.8	481.2	N/R	96.4	116.9	338.1	46.8	55.8	–	–	7.6	1 200.6
Generic – FR	FR-P1	3 600/4	–	30.4	N/R	149.4	69.0	21.4	31.7	30.0	–	–	33.1	365.0
S M Garona	ES-B1	466	18.2	4.2	N/R	64.4	18.6	123.7	28.0	52.7	–	–	13.7	323.6
Generic – ESB	ES-B2	1 092	17.9	1.5	N/R	74.4	34.0	87.3	109.9	88.7	–	-	11.2	424.8
Loviisa	FI-V1	976/2	–	38.6	N/R	105.2	20.0	7.1	0.0	5.5	–	–	60.5	236.9
Bohunice	SK-V1	880/2	31.1	39.6	N/R	96.0	215.5	96.6	123.5	120.9	–	18.1	11.7	753.0

ESB = Spain BWR; ESP = Spain PWR; N/R = Not received. (ISDC : International Structure for Decommissioning Costing)

Source : OECD, NEA, *Costs of Decommissioning Nuclear Power Plants*, 2016

[(1)] T. de Larochelambert, *Analyse critique du projet de technocentre EDF (installation de valorisation de métaux très faiblement radioactifs) à Fessenheim (Haut-Rhin) : faisabilité technique, risques radiologiques, incertitudes scientifiques, écologiques et économiques*, RISEO 2025-2.

Return to greenfield: choice of erasure, redistribution, or nuclear redevelopment?

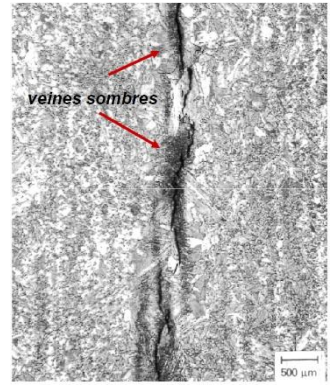
- **Fessenheim : questioning the greenfield strategy**
  - **What erasures are involved by such a greenfield status ?**
    - **the removal** (« *éliminer* », « *retirer* ») **of radioactivity** (visible and detectable traces) produced by the nuclear power station during its decades of operation
      → *relocation, physical transfer to other facilities (radioactive waste storage sites)*
      → *release, dispersion of radionuclides into the atmosphere and the environment*
      → *dilution, banalisation of reprocessed VLL radioactive metals released onto the conventional market*
    - **the deletion of evidence of embrittlement of old, cracked and irradiated commercial nuclear reactors**
      → *loss of scientific information* (*cf*. next section)
    - **the erasure of the region's industrial nuclear heritage**
      → in contrast to the preservation of the heritage of the Alsace Potash Mines
      → *loss of historical and anthropological knowledge ?*



Source : Musée de la Mine de Potasse, Wittelsheim, France

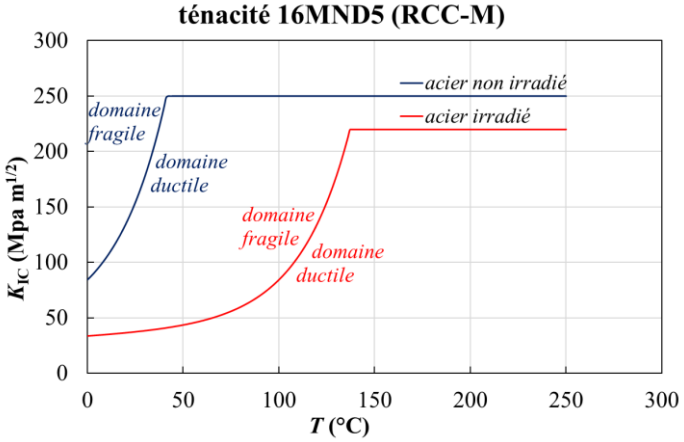
The risk of evidence deletion and memory loss

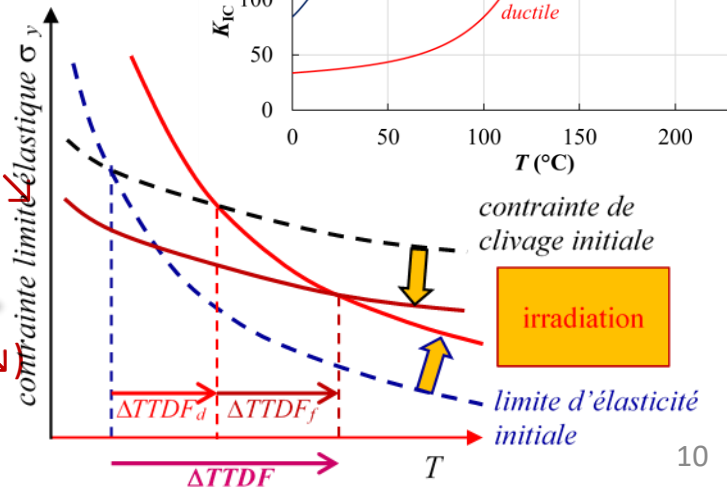
- **The embrittlement of old and irradiated nuclear vessels**
  - **Nuclear vessels, as non-replaceable components, and exclusive of breakage**
    - **16MND5,** *non-stainless, low-alloy steel* (*e* = 20 cm, *D* = 4 m, *H* = 12 m) tempered bainitic structure (ferrite + cementite precipitates + MnS) with major (pos. and neg.) and minor (*dark veins*) segregations C, Cu, P
    - **stainless steel inner cladding** 304L-316L (*e* = 8 mm)
    - defects under cladding (DSR) + intergranular dislocation caused by reheating (DIDR) + hydrogen-linked defects (DDH) → *cracks* (mm à cm)



J. Ruste, *Les matériaux du nucléaire endommagement et évolution*, Ecole Doctorale Univ. Limoges, 2013

impureté % masse	C	Mn	Ni	Mo	Si	Cr	Cu	P
matrice	0,16	1,35-1,46	0,8-0,84	0,5-0,58	0,25-0,28	0,15-0,23	0,08	0,005-0,013
joints soudés	-	-	0,78	-	-	-	0,13	0,019
veines sombres	-	1,97-2,32	0,98-1,06	1,28-2,33	0,35-0,38	0,31-0,47	0,11-0,14	0,024-0,034





- **thermo-mechanical ageing** : 43 year with *T*° and *P*° variations
  → ductile-to-brittle transition temperature *TTDF* ↗, fracture toughness K_{IC} ↘
- **vieillissement sous irradiation neutronique** :
  → hardening and embrittlement of steel with neutron fluence φ_t
  (*hardness and yield strength* σ_Y↗, *TTDF* ↗, resilience K_v ↘, toughness K_{IC} ↘)
  - recent research : embrittlement accelerating $\varphi_t > 6.10^{19}$ neutrons/cm²

→ *further investigation needed on nuclear vessel embrittlement*

The risk of evidence deletion and memory loss

- **The embrittlement of old and irradiated nuclear vessels**
  - **Using the dismantling of the Fessenheim nuclear vessels**
    - **Proposal for the scientific decommissioning of a reactor for a European research programme**[(1)]
      - a research project involving in-depth investigations into the thermal ageing of reactor vessel steels and cladding under irradiation, and into the propagation and development of cracks beneath the cladding in the various zones (shells, welds, bolts, cover) irradiated by the neutron flux
      - establishment of a European consortium of public research laboratories
    - **request of the IRSN for a supplementary programme of investigations and sampling**[(2)]
      - request to EDF dated 21 December 2022 to '*supplement the available knowledge on the ageing of equipment*' and to '*verify the absence of any unforeseen degradation or ageing phenomena that could affect components critical to safety*'
      - « *however, taking toughness test specimens from a Fessenheim NPP's reactor would provide a basis for assessing the 40-year margin relating to material embrittlement, particularly if these specimens were taken – unlike the PSI specimens – from outside the reactor vessel foot*»

(1) T. de Larochelambert (2021), *Sûreté, démantèlement, prolongation de fonctionnement des réacteurs nucléaires et transition énergétique*, Sûreté de sécurité des installations nucléaires civiles, pp 85-147, CERDACC – Université de Haute-Alsace, Editions Mare & Martin, janvier 2021, ISBN 978-2-84934-536-8.
(2) IRSN, N° 2022-00241, 21 décembre 2022.

Open trajectories

- **Preserving the nuclear memory**
  - **Retain both reactor buildings**
  - **to establish, as a matter of principle, the preservation and continuity of the visible and physical legacy of the Fessenheim power plant nuclear history** (and all others) by keeping both reactor buildings intact and by enhancing their long-term sealed integrity so that the main radioactive components can be stored in them (vessels, vessel covers, primary piping, primary pump units, pressurisers, steam generators) without being cut up, except for samples taken from the Fessenheim reactors for analysis of steel ageing and embrittlement
  - **to preserve, *in situ*, the long-term memory of the radioactivity produced during the decades of reactor operation and the risks associated with it**, without relocating them to other sites or other French departments, whilst saving the bulk of the decommissioning costs
  - **to wait through the long period of the slow decline in radioactivity** before carrying out any safe recycling operations
  - **Cutting apart the FES1 (or FES2) reactor vessel for European study on commercial nuclear vessels' embrittlement**
  - **to keep a physical record of the ageing of commercial-grade nuclear reactors** to address the lack of global scientific data[(1)]
  - **to build up a catalog of samples** from these irradiated vessels
  - **to support a European research programme on the actual ageing of commercial nuclear reactors**, in order to better understand and manage the risks associated with extending the service life of reactors beyond 40 years

[(1)] R. Vuiart (2021), *Analyse du vieillissement sous irradiation neutronique des cuves des réacteurs nucléaires à eau sous pression*, thèse de l'Université de Paris-Saclay, 2021.

Thank you for attention



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Supplementary materials

- on the embrittlement of old, irradiated nuclear reactors…
- on the risks of nuclear reactor vessel failure due to Pressurized Thermal Shocks…

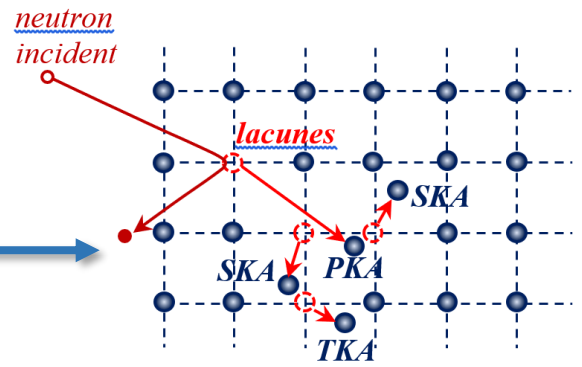
The risk of evidence deletion and memory loss

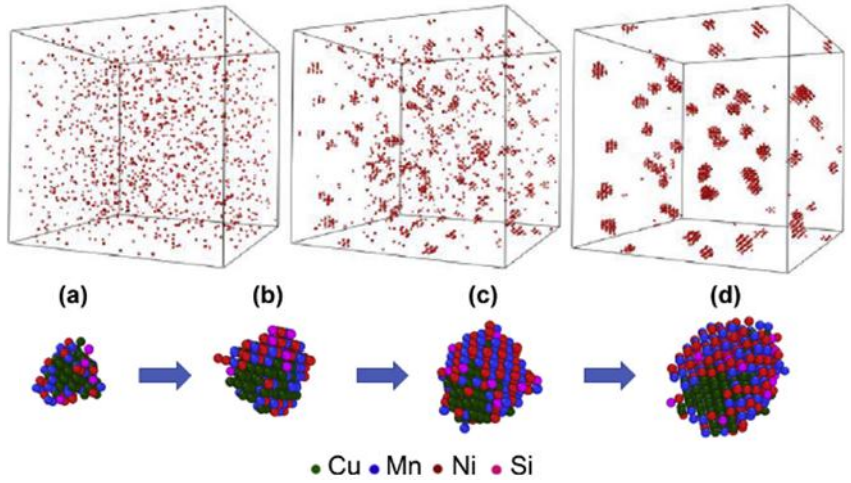
- **The embrittlement of old and irradiated nuclear vessels (complements)**
  - **New international results**
    - **a better understanding and simulation of ageing mechanisms** (1)

      irradiation → displacements of atoms (dpa) by neutron-nucleus collisions
      - ➢ crystalline defects (interstitial atoms, vacancies)
      - ➢ **fast** structural modificatons:
        - dislocations
        - defects and interstitial loops
        - fast precipitation of solutes (Cu)
        - aggregation of vacancy-impurety instersticial solutes (Mn, Ni, Si, P)
      - ➢ dominating **slow** phenomenon '*Late Blooming Phases*' (MnNiSi precipitates):
        - slow precipitates of soluble impurities Mn, Ni, Si, P ↗ with φ_t ↗
          - ► strongly increase with Ni and $\varphi_t > 6.10^{19}$ n/cm^2, ∀ %Cu
          - ► strongly increase *hardness* and *yield strenght* σ_y
          - ► strongly increase the *ductile-to-brittle temperature shift* (ΔRT_{NDT})
        - segregations at grain boundaries

    - **consequences**

      accelerated embrittlement at high fluence $\varphi_t > 6.10^{19}$ n/cm^2 :
      - ► $\Delta RT_{NDT} \propto \varphi_t^{0,5}$ if $\varphi_t < 6.10^{19}$ n/cm^2, and $\Delta RT_{NDT} \propto \varphi_t$ if $\varphi_t > 6.10^{19}$ n/cm^2
      - ► ΔRT_{NDT} *linearly increase* with φ_t if $\varphi_t > 6.10^{19}$ n/cm^2 (Cu > 0,07%)
      - ► hardening effet of phosphorus à φ_t élevée
      - ► moderating effet of neutron flux φ (n s^{-1} cm^{-2})





(1) Odette et al., *On the history and status of reactor pressure vessel steel ductile to brittle transition temperature shift prediction models*, J. Nucl. Mat. 526 (2019) 151863

The risk of evidence deletion and memory loss

- **The embrittlement of old and irradiated nuclear vessels (complements)**
  - **The need to improve nuclear materials' embrittlement models**[1]
    - **modificating the formula for embrittlement at higher irradiation levels (FIS)**

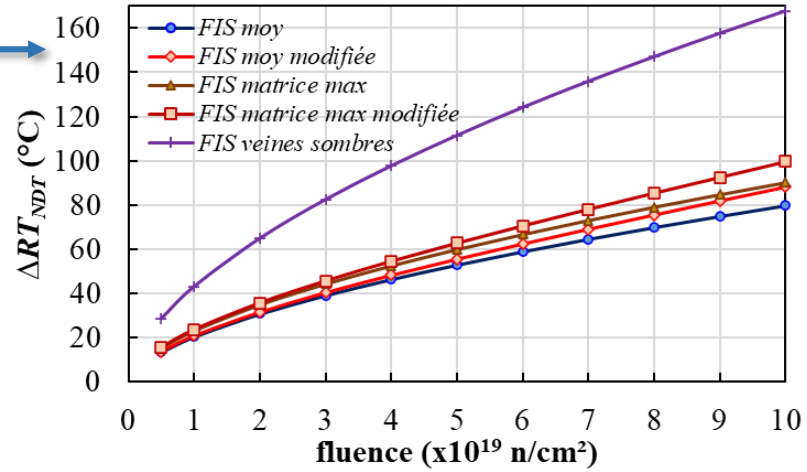
      → $\Delta RT_{NDT} = f(C_P, C_{Cu}, C_{Ni}) \times \varphi_t^m$ with m varying from 0,5 (low φ_t) to 1 (high φ_t)

      → improved evaluation of ΔRT_{NDT} from effective experienced fluence and flux

      → improved evaluation of toughness K_{IC} (T, φ_t, ΔRT_{NDT}) in shell steel

    - **improved consideration of the cumulative effect of uncertainties**

      - in the variable chemical composition of alloying elements Cu, P, Ni, Mn, Si
      - in the measurement of toughness
      - in the measurement of RT_{NDT} of steel test specimens (8 to 33 °C)
      - in the measurement of neutron fluxes (> 16 %) with neutron kinetic energy 0,1 – 10 MeV/n
      - in the neutron fluence calculation (9 to 20 %)
      - in the measurement of of the neutron capture cross-sections of numerous atomic nuclei (5 to 32 %)
      - in the real, precise history of fuel loading of the reactor
      - etc.

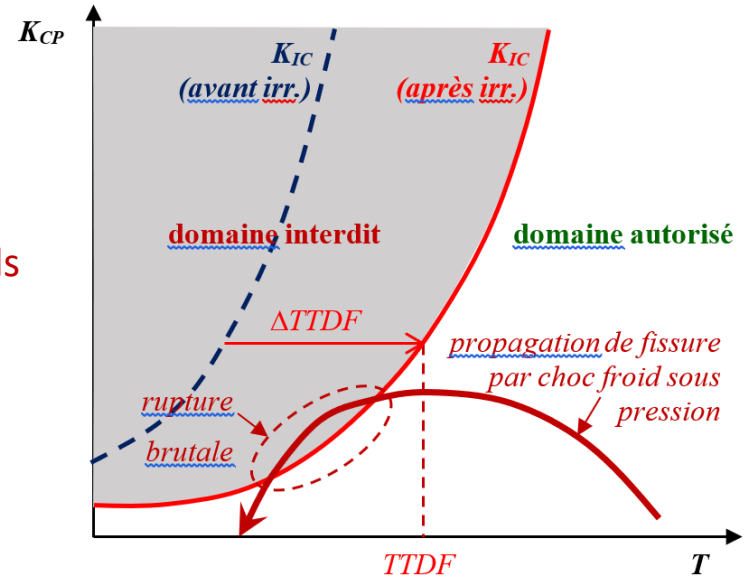


[1] T. de Larochelambert (2025), *Étude des risques de rupture de cuves nucléaires irradiées âgées par chocs froids sous pression accidentels*, RISEO 2024-2 – CERDACC, Université de Haute-Alsace, pp.149-174.

The risk of evidence deletion and memory loss

- **The embrittlement of old and irradiated nuclear vessels (complements)**
  - **Anticipating the risk of nuclear vessel failure caused by pressurized thermal shocks**[1]
    - **incorporation of uncertainties into improved ageing models**
    - **improved evaluation of safety margin in the events of pressurised thermal shocks**
      - the **stress intensity factor** K_{CP} (en MPa $m^{1/2}$) gouverns craks' opening ; K_{IC} **fracure toughness** is the critical value of K_{CP} and represents the material's resistance to crack propagation
      - during a PTS(*), complex evolution of the stress intensity factor K_{CP} at the ends and along the internal ligament of existing cracks and defects
      - if $K_{CP} > K_{IC}$, **cracks open up and propagate** across vessel's depth and width
      - Depending on the severity of the PTS, their propagation may cease if the K_{CP} falls below a local stop threshold for toughness K_{Ia}; otherwise, if this is not the case, continue through the entire thickness *e* of the vessel → draining of the water from the vessel into the concrete vessel pit → brutal failure of the vessel depending on the creep behaviour of the steel (brittle or ductile fracture)

(*) Pressurised Thermal Shock

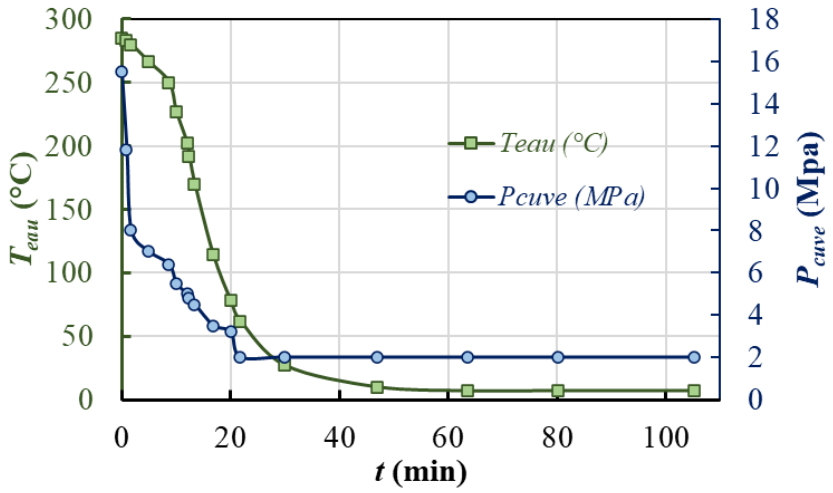


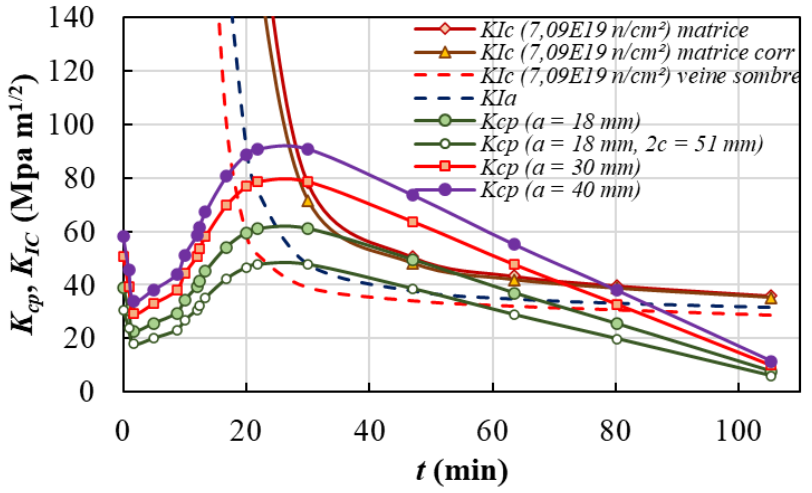
(1) T. de Larochelambert (2025), *Étude des risques de rupture de cuves nucléaires irradiées âgées par chocs froids sous pression accidentels*, RISEO 2024-2 – CERDACC, Université de Haute-Alsace, pp.149-174.

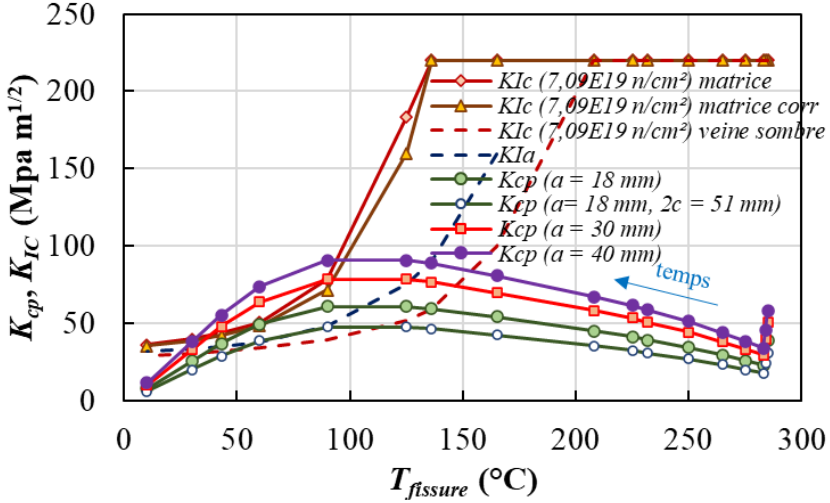
The risk of evidence deletion and memory loss

- **The embrittlement of old and irradiated nuclear vessels (complements)**
  - **Anticipating the risk of nuclear vessel failure caused by pressurized thermal shocks**[1]
    - **simulation of Pressurised Thermal Shocks**
      - **assumptions**: existing crack on a vessel's inner surface, Accident by Primary Coolant Loss (medium-sized breach), integration of uncertainties, 'realistic' projection of neutron flux after 50 years of operation

      → risk of margin factor < 1 (vessel rupture possible depending on the conditions)







[1] T. de Larochelambert (2025), *Étude des risques de rupture de cuves nucléaires irradiées âgées par chocs froids sous pression accidentels*, RISEO 2024-2 – CERDACC, Université de Haute-Alsace, pp.149-174.