SUSTAINABLE SOLUTIONS FOR NUCLEAR USED FUELS INTERIM STORAGE

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Abstract

AREVA has a unique experience in providing sustainable solutions for used fuel management, fitted with the needs of different customers in the world and with regulation in different countries. These solutions entail both recycling and interim storage technologies.

In a first part, we will describe the various types of solutions for Interim Storage of UNF that have been implemented around the world for interim storage at reactor or centralized

Pad solution in canisters dry storage ,

vault type storages for dry storage,

dry storage of transportation casks (dual purpose)

pools for wet storage,

The experience for all these different families of interim storages in which AREVA is involved is extensive and will be discussed with respect to the new challenges :

increase of the duration of the interim storage (long term interim storage)

increase of burn up of the fuels

In a second part of the presentation, special recycling features will be presented. In that case, interim storage of the used fuels is ensured in pools. This provides in the long term good conditions for the behaviour of the fuel and its retrievability.

With recycling, the final waste (Universal Canister of vitrified fission products and compacted hulls and end pieces):

is stable and licensed in many countries for the final disposal (France, UK, Belgium, NL, Switzerland, Germany, Japan, upcoming: Spain, Australia, Italy).

Presents neither safety criticality risks nor proliferation risks (AREVA conditioned HLW and LL-ILW are free of IAEA safeguard constraints thanks to AREVA process high recovery and purification yields).

It can therefore be safely stored in interim storage for more than 100 years before final disposal

Some economical considerations will also be discussed. In particular, in the case of long term interim storage of used fuels, there are growing uncertainties regarding the future needs of repackaging and transportation, which can result in future cost overruns. Meanwhile, in the recycling policy, costs are well known, as they are based on a long experience and are therefore stable and predictable.

1. Introduction

A sustainable back end policy is a policy which:

is reliable in the long term (IAEA defined the long term as between 50 to 100 years)

is not affected by high level of uncertainties (technical questions to solve, change in the regulations, evolution of basic UNF characteristics etc…)

answers globally to a present need but takes into account the future needs

does not leave to future generations unsolved questions for a long time

While recycling complies with these requirements as will be illustrated later (§4 and 5), the present challenge for countries not yet engaged in a recycling policy, is related to Long Term Interim Storage (LTIS) of Used Nuclear Fuels (UNF) before recycling or disposal

In the frame of LTIS, the global need is:

safe interim storage on the reactor site, transport to a centralized Interim Storage (IS) for a LT storage, repackaging and transport to the final storage with, if needed, adjustment of the capacity of containers

retrievability of the UNF in the long term , as required by all the pre-cited operations.

Technical solutions have been developed in all countries, meeting the needs of the utilities and the current requirements from the Safety Authorities and regulatory systems. These solutions are very diverse and may be divided in four families. AREVA has a unique experience within all of these solutions:

Pad solution in canisters dry storage

Vault dry storage solution

Casks (transportation casks for dry storage)

Centralized pool storages

2. Historical elements

A few decades ago, complete and consistent strategies for back end were defined in different countries. At the time, the IS on reactors sites was temporary and short term (less than 20 y) as Centralized IS and final disposal were to come soon.

There are at present two main families of countries:

countries which are being implementing a full back end solution:

- Sweden and Finland for open cycle
- France or the Netherlands for example for closed; (in this case mainly disposal of vitrified waste)

countries which encountered a delay on the implementation of a global back end solution including IS and Final disposal. In these countries the new challenge is related to extended IS on reactor sites with higher burn up and associated constraints

After densification of the reactor pools, without other solution, utilities are using dry storage as the back up solution to make room in their pools.

3. Dry Interim Storage solutions

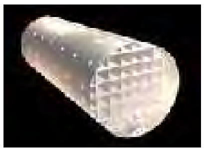
In the United States, the Nuclear Regulatory Commission in its request for comments (Ref 1) this year stated that retrievability of UNF is admitted for 40 years IS with low burn up fuels (up to 45 GWd/t rod burn up) and for 20 years for high burn up fuels (more than 45 GWd/t) (ref 1)

Beyond these values currently admitted throughout the world, the demonstration will rely on extensive R&D that is still to be defined.

An R&D program has been launched decades ago in France for example (PRECCI program by the CEA/EdF/AREVA; ref 2) to assess the different options in the frame of the Public Debate. This program confirmed the prevalence of recycling policy. This study was followed later on by other countries in the world.

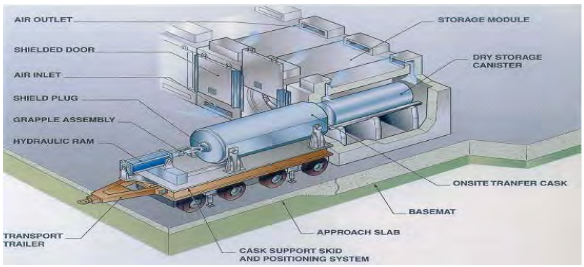
NRC established in ref 3 the 18 top level questions to be solved for extended storage and transportation of UNF. During dry storage, UNF is submitted to thermally activated phenomena. Some of these questions are discussed in ref 5.

3.1. Pad in canister solution



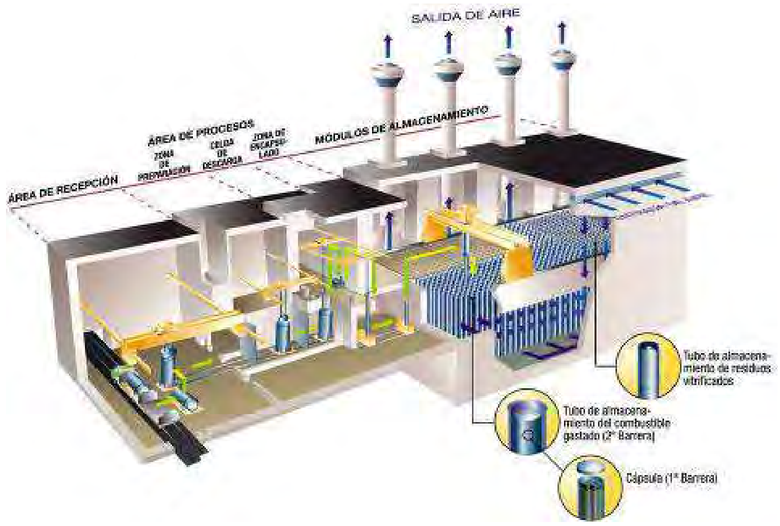
This solution was developed initially for a short term IS on reactor sites (see §2)
The UNF is placed in leak tight inerted welded canisters inside a massive concrete bed for shielding, outside the reactor on the site.
Its advantages are related to natural passive cooling and high capacity of UNF IS.

NUHOMS® systems for example are widely used in USA. . In total, 500 NUHOMS® systems have been ordered. Nuhoms® system can accept from 61 to 69 BWR used fuels, and from 32 to 37 PWR used fuels



3.2. VAULT dry storage solution

Vault solution has been developed in several countries for both purpose of open cycle or closed cycle waste (implemented in France in CASCAD for fuel assemblies from research reactor) and later on in Habog Facility in the Nederlands. Such facility can accommodate UC and UNF.



The concept will be implemented in the Spanish ATC (see picture): here, small canisters (typical capacity 6 UNF) are stored in a protected building with natural convection cooling.Both types of canisters can be stored (vitrified fission products UC generated by recycling or canisters containing UNF).

The possibility of control of the LT behaviour of the fuel can be taken into account with a dedicated hot cell. Control can be also implemented through continuous remote monitoring of each well. In addition, the vault is equipped with a hot cell for unloading of the transport casks and repackaging in canisters. After IS, it enables repackaging of UNF in transport casks.

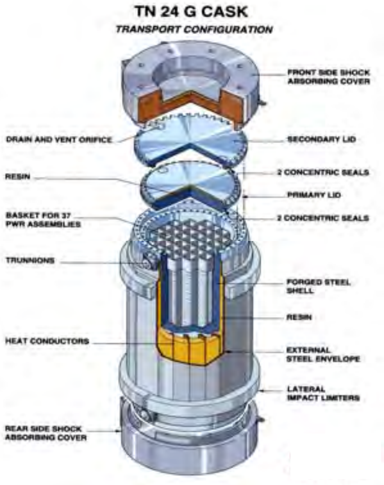
The modular concept of vaults give flexibility: in construction several additional vaults can be delayed to cope with future needs for an increased capacity.

The advantages are related to passive cooling in a protected building and higher flexibility which is leaving open the solutions for the future.

3.3. Cask Interim Storage solution

AREVA has developed metallic dual purpose (storage and transport) casks with more then 200 casks ordered: it is the TN®24 family. Casks are in operation in USA, Japan, Belgium, Switzerland, and Germany, Italy. The capacity reaches 40 PWR FA or 97 BWR FA, and maximum 65 to 70 GWd/t burn ups, cooling times 5 to 7 years for the contents accepted in these storage designs**.**

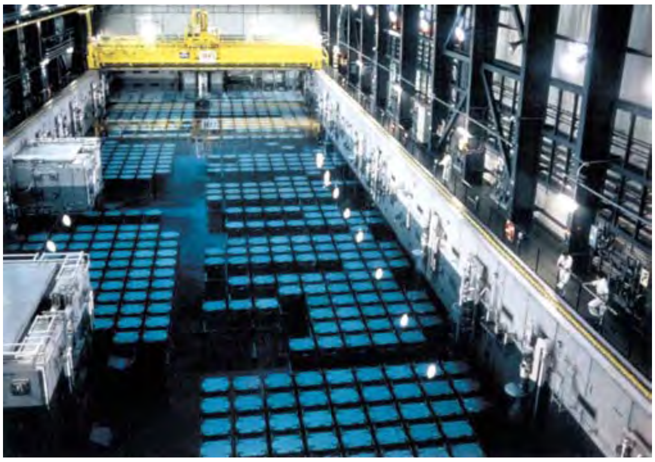
TN NOVA ™ system is the latest system designed. It is a canister system with storage over pack which can be tilted vertically.



The advantages are modularity, high capacity, passive cooling and dual purpose storage and transport capability.

Containment and dose are monitored during the interim storage.

4. Pool centralized Interim Storage solution



4.1. Basic features

This solution provides favourable features for the Long Term behaviour of LWR UNF during interim storage:

each UNF remains accessible; monitoring enables to detect failures

there are no thermally activated phenomena which could affect the retrievability of the UNF. Temperature of the pool is limited to 50°c there is a very satisfactory return of experience since 50 years and for huge volumes of diverse UNF in the world

This solution provides in addition, a high level of flexibility:

characteristics of UNF could evolve (burn up for example or residual power of the UNF) with new designs in the future or new fuel management in the reactors

easy to optimize the choice of precise UNF to optimize the next step (recycling or transportation in casks for final repacking and disposal)

can accommodate a wide range of casks including future changes which can occur in the future casks designs

ensuring future retrievability of UNF it leaves open the two paths for the future : closed cycle or open cycle

The main criticism especially after Fukushima event, on the pool solution is its "active cooling "feature, whilst the behaviour of dry storage did not rise any concern during the accident .This question is dealt with in next paragraph 4.3 where a passive cooling solution for Interim Pool Storage that is in operation is listed.

4.2. Lessons learnt from Fukushima event on IS of UNF in pools

It is important to distinguish between the reactors pools and the common pool for Fukushima site.

The common pool is a centralized IS, separated from the reactors without any connection with the reactors systems .In this common pool there were no concern during and after the accident (no common mode failures and low residual power after cooling in the reactor pools).

Each reactor is equipped with a dedicated pool and many questions were raised on the risk of water uncovery of the UNF, especially on the pool of reactor n°4 which had the highest residual power.

it can be stated now that there is no evidence of gross leakage in the reactor pools . Several days of grace period were available before actions were taken to prevent risks of water uncovery.

Reactor pools function is related to the reactor normal operation and a high level of densification of the reactor pools for UNF storage purpose should be avoided in order to maintain high safety margins .In Fukushima, interim storage was safely ensured in a common pool.

4.3. Discussion on the active cooling in centralized pools

Normal active cooling of a pool needs pumps and heat exchangers which enable a very efficient and reliable cooling: 28 kW/m2 in pool instead of 2 to 3 kW/m2 in passive dry condition. That means in addition a cost reduction in pool solution if important quantities of UNF are involved.

Of course passive normal cooling design is always possible and AREVA reference exist as well (Goesgen in Switzerland for example)

In the case of centralized IS of UNF in pools the thermal inertia of the water of the pool combined with a low level of residual power , is the important safety feature, the evolution of temperatures in case of total failure of electrical supply is slow and provide long grace time (several days) before water uncovery of stored UNF. The mitigating actions are simple with external water supply.

Good engineering and design features (ex leak detection etc…) of the pool enable the highest level of safety required and controlled by the safety authorities

In fact, in severe accidental conditions the passive behaviour of the centralized pool provides a high level of safety leaving long time to react with simple mitigation measures.

It is worth to point out that for GEN3+ EPR™ reactors planned to be constructed on Hinckley Point site in UK, EDF has decided the option of a centralized pool on the site, for storage during up to 100 years of the total quantity of UNF produced by 2 EPR™ reactors during 60 years of operation.(high burn-up fuel)

This option, in a country which did not decided yet for recycling , is part of a flexible and sustainable policy taking into account all the possible future needs for recycling or direct disposal and possible changes in the design of fuels or transport characteristics, in the future...

5. Advantages of recycling policy

Recycling presents clear advantages regarding potential LTIS for countries which will not have in the short and medium term a final disposal. It is a sustainable solution per se that increases public acceptance and does not leave the solving of key issues to next generations.

Final waste for disposal resulting from reprocessing consists mainly in the vitrified fission products , as well as the compacted hulls and end pieces

It is an important difference with UNF which is a living material with possible evolutions during IS, which have to be monitored : with recycling the final waste is not subject to evolution and a LTIS before final disposal presents no concern, even beyond the long term

The waste is contained in the Universal Canister.

Interim Storage of the Universal Canisters is ensured in Vault type solution. (EVLH in La Hague or HABOG (COVRA) in Netherlands; see picture) or in casks (Switzerland, Belgium, Germany)

The Universal Canister offers safety features of utmost importance:

- stability in the long term and easy qualification for LTIS and final disposal,
- no significant plutonium content which results in no criticality risks and no risks of proliferation (the UC is not under safeguards),
- the final volume, the radio toxicity and radioactive lifetime of waste are strongly reduced.
- all the costs are known because it is an industrial reality and under a continuous progress policy.
- costs are predictable and stable (no volatility due to for example natural Uranium costs) and are not subject to significant uncertainties in the long term.

6. Conclusions

There is a wide variety of AREVA interim storage solutions licensed and in operation in the world. They all present different advantages and all comply with the utilities requirements and the safety authorities regulations.

Recycling is sustainable: mastering of each step after fuel irradiation in the reactor, transports, centralized interim storage of UNF, LTIS of UC, and final disposal of UC .It is an industrial reality with no significant uncertainties and under continuous progress policy.

In the case of differed decision on the final choice between recycling or direct disposal, solutions can be built, that secure the highest level of safety, sustainability and flexibility and ensure the best conditions for UNF retrievability after LTIS. These solutions combine in a smart and responsible way both dry and wet storage solutions, taking into account their performance and limits along time.

References:

[1] Request for comments on retrievability, cladding integrity, and safe handling of used fuels at an independent Spent Fuel Storage Installation and during transportation
US NRC January 2013 http://epw.senate.gov/nwpa82.pdf

[2] POINSSOT, C. (2002b). Overview of the French R&D project on spent fuel long term evolution PRECCI. Waste Management Avignon. 2003

[3] Identification and prioritisation of the technical information needs affecting potential regulations of extended storage and transportation of spent nuclear fuels
US NRC May 2012

[4] The choice of Interim Spent Fuel Management Storage Technology for the Hinckley Point C UK EPRs – NNB-OSL-STR-034 issue 1- October 2011.

[5] Fuel behaviour in transport after dry storage: a key issue for the management of UNF
H Issard, OECD/NEA INTERNATIONAL WORKSHOP ON SAFETY OF LONG TERM INTERIM STORAGE FACILITIES, Munich, Germany, 21-23 May 2013

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Sustainable Solutions for Nuclear Used Fuels Interim Storage

Marc ARSLAN
VP, Recycling Business Unit, AREVA
Munich, Germany, 21-23 May 2013

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What is a sustainable back end policy ?

- A sustainable back end policy is a policy which:
  - is reliable in the long term (IAEA defined the long term as between 50 to 100 years)
  - is not affected by high level of uncertainties (technical questions to solve, change in the regulations, evolution of basic UNF characteristics etc…)
  - answers globally to a present need but takes into account the future needs
  - does not leave to future generations unsolved questions for a long time

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Technical Solutions for Long Term Interim Storage (LTIS)

- Technical solutions have been developed in all countries, meeting the needs of the utilities and the current requirements from the Safety Authorities and regulatory systems.
- These solutions are very diverse and may be divided in four families. AREVA has a unique experience within all of these solutions:
  - Pad solution in canisters dry storage
  - Vault dry storage solution
  - Casks (transportation casks for dry storage)
  - Centralized pool storages

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Historical elements

- A few decades ago, complete and consistent strategies for back end were defined in different countries. At the time, the IS on reactors sites was temporary and short term (less than 20 y) as Centralized IS and final disposal were to come soon.
- There are at present two main families of countries:
  - countries which are being implementing a full back end solution:
    - Sweden and Finland for open cycle
    - France or the Netherlands for example for closed cycle (mainly disposal of vitrified waste)
  - countries which encountered a delay on the implementation of a global back end solution including IS and Final disposal. In these countries the new challenge is related to extended IS on reactor sites with higher burn up and associated constraints

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Dry Interim Storage solutions

- In the United States, the Nuclear Regulatory Commission stated this year that retrievability of UNF is admitted for 40 years IS with low burn up fuels (up to 45 GWd/t rod burn up) and for 20 years for high burn up fuels (more than 45 GWd/t)
- Beyond these values currently admitted throughout the world, the demonstration will rely on extensive R&D that is still to be defined.

Open question: long term behaviour of UNF towards retrievability

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New challenge:extended IS and increasing burn up

- After IS on the reactor site, the UNF will have to be transported to a centralized IS and after an extended IS UNF have to be transfered to Recycling or direct disposal
- These operation may require repackaging and transport
- Retrievability of UNF in the long term is a key question

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Pad in canister solution

- This solution was developed initially for a short term IS on reactor sites
- The UNF is placed in leak tight inerted welded canisters inside a massive concrete bed for shielding, on the reactor site.

Its advantages are related to natural passive cooling and high capacity of UNF IS.

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VAULT dry storage solution

Spanish VAULT solution (ATC)

- The modular concept of vaults give flexibility: in construction several additional vaults can be delayed to cope with future needs for an increased capacity
- Such facility can accommodate Universal Canisters (UC) from reprocessing and UNF

The advantages are related to passive cooling in a protected building and higher flexibility leaving open the final waste solutions for the future.

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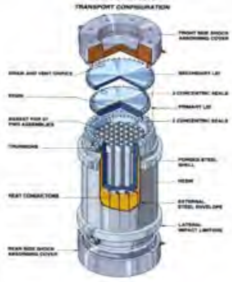
Cask Interim Storage Solution

TN 24 G CASK
TRANSPORT CONFIGURATION



- AREVA has developed metallic dual purpose (storage and transport) casks with more then 200 casks ordered : the TN®24 family
  - in operation in USA, Japan, Belgium, Switzerland, and Germany, Italy
  - capacity reaches 40 PWR FA or 97 BWR FA, and maximum 65 to 70 GWd/t burn ups
  - cooling times 5 to 7 years for the contents accepted in these storage designs
- TN NOVA TM system is the latest system designed. It is a canister system with storage over pack which can be tilted vertically.

The advantages are modularity, high capacity, passive cooling and dual purpose storage and transport capability

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Pool centralized Interim Storage

- This solution provides favourable features for the Long Term behaviour of LWR UNF during interim storage:
  - each UNF remains accessible; monitoring enables to detect failures
  - no thermally activated phenomena which could affect the retrievability of the UNF. Temperature of the pool is limited to 50°C
  - very satisfactory return of experience since 50 years and for huge volumes of diverse UNF in the world

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Pool Solution Flexibility

- This solution provides in addition, a high level of flexibility:
  - characteristics of UNF could evolve (burn up for example or residual power of the UNF) with new designs in the future or new fuel management in the reactors
  - easy to optimize the choice of precise UNF to optimize the next step (recycling or transportation in casks for final repackaging for disposal)
  - can accommodate a wide range of casks including future changes which can occur in the future casks designs
  - ensuring future retrievability of UNF it leaves open the two paths for the future : closed cycle or open cycle

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Lessons learnt from Fukushima event on IS of UNF in IS pools

- It is important to distinguish between the reactors pools and the common pool for Fukushima site
- The common pool is a centralized IS, separated from the reactors without any connection with the reactors systems. In this common pool there were no concern during and after the accident (no common mode failures and low residual power after cooling in the reactor pools)

» Reactor pools function is related to the reactor normal operation : avoiding excessive densification for UNF ensures high safety margins.

In Fukushima, interim storage was safely ensured in a common pool.

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Active cooling in centralized pools

- Normal active cooling of a pool needs pumps and heat exchangers which enable a very efficient and reliable cooling: 28 kW/m² in pool instead of 2 to 3 kW/m² in passive dry condition.
  - of course passive normal cooling design is always possible and AREVA reference exist as well (Goesgen in Switzerland for example)
- The thermal inertia of the water of the pool combined with a low level of residual power is the important safety feature,

» In fact, in severe accidental conditions the passive behaviour of the centralized pool provides a high level of safety leaving long time to react with simple mitigation measures

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Advantages of recycling policy

- Final waste for disposal resulting from reprocessing consists in the vitrified fission products, as well as the compacted hulls and end pieces
- With recycling, the final waste is not subject to evolution (stable waste) and a LTIS before final disposal presents no concern, even beyond the long term. The waste is well suited for final disposal
- The waste is contained in the Universal Canister (UC).

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The Universal Canister

- The Universal Canister offers safety features of utmost importance:
  - stability in the long term and easy qualification for LTIS and final disposal,
  - no significant plutonium content which results in no criticality risks and no risks of proliferation (the UC is not under safeguards),
  - the final volume, the radio toxicity and radioactive lifetime of waste are strongly reduced.
  - all the costs are known because it is an industrial reality .
  - costs are predictable and stable (no volatility due to for example natural Uranium costs) not subject to significant uncertainties in the long term.

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Interim Storage of the Universal Canisters

- Interim Storage of the Universal Canisters is ensured in Vault type solution :
  - EVLH in La Hague
  - HABOG (COVRA) in Netherlands (see picture)
  - ATC in Spain
  - Or in casks : Switzerland, Belgium, Germany

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Conclusions

- Wide variety of AREVA interim storage solutions licensed and in operation in the world
- Recycling is sustainable: mastering of each step after fuel irradiation in the reactor, transports, centralized pool interim storage of UNF, LTIS of UC, and final disposal of UC .It is an industrial reality with no significant uncertainties and under continuous progress policy.
- Solutions can be built, that secure the highest level of safety, sustainability and flexibility and ensure the best conditions for UNF retrievability after LTIS.

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