R&D challenges in improving civil structures design rules for sustainable nuclear energy technology

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Summary

- ✓ What is **WS 64** and PG3 (from phase 2 to phase 3)
- ✓ What are the **output** of WS 64 for PG3
- ✓ Focus on **aircraft crash**
- ✓ First **conclusions**

CEN Workshop & CEN workshop agreement

- ✓ **What is a CEN Workshop**
  - A "project" which aims to develop best-practice recommendations in specific area
  - Open for participation for anyone with an interest to contribute, specialists from utilities, designers, constructors, researchers and regulators gathered
  - A panel of European experts constituted in order to give recommendations on what should appear in nuclear codes to make them usable at a European level
  - Within a structure (CEN workshop) allowing a form of recognition among European stakeholders
  - Initiated by AFCEN that is currently the only active code development organization in Europe

- ✓ **What is a CEN Workshop Agreement (CWA)**
  - The CWA is a document published by CEN and contains the recommendations from the Workshop
  - A CWA does not have the status of a Standard

WS 64

- ✓ **WS64 phase 2: 2014 -> 2018**
  - 12 code modification proposals
  - 1 research proposal (focusing on earthquake engineering)

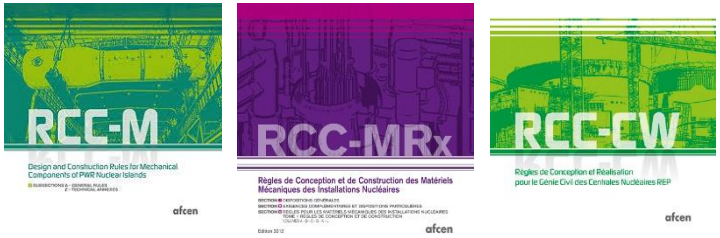
- ✓ **WS64 phase 3: 2019-> 2023**
  - A large number of code modification proposals edited, but not yet decided
  - Several research proposals linked to aircraft crash (« « «)

WS064-3, PG3, active Members

Organization	Country	Type of organization
AFCEN (EDF)	France	Standardization and education entity (Utility)
ATKINS LTD	United Kingdom	Engineering Entity
BASLER & HOFMANN AG	Switzerland	Engineering Entity (Safety authority support)
ENSI	Switzerland	Safety Authority
IRSN	France	Technical Safety Organization
KAISERSLAUTERN TECHNICAL UNIV.	Germany	University
MAX AICHER ENGINEERING GmbH	Germany	Engineering Entity
ORANO SA	France	Engineering Entity
STUK	Finland	Safety Authority
VATTENFALL	Sweden	Utility

CEN WS 64 phase 2 general description

- ✓ **Duration : autumn 2014 - 2018**
  - ➢ The final report CEN Workshop Agreement (CWA) was published in 2018
- ✓ **Workshop general organization**
  - ➢ 3 technical domains, each covered by an AFCEN code:
    - Mechanical equipment for GEN II-III reactors:
    - Mechanical equipment for GEN IV reactors:
    - Civil works :



  - ➢ **A working group (“Prospective Group”) of experts for each domain with the mission of elaborating:**
    - Code Evolution recommendations, to be submitted to AFCEN
    - R&D programme proposals, to be submitted to EC DG-RTD

CEN workshop phase 3 general description

1. Duration : 2019 - today
    1. 4 technical domains, each covered by an AFCEN code:
        1. Mechanical equipment for GEN II-III reactors
        2. Mechanical equipment for GEN IV reactors
        3. Civil works
        4. Electrical equipment

First output of WS 64 phase 3

✓ **Liners (both containments and pools)**

« Liners » is a difficult topic for many reasons:

- Loads are mainly « imposed deformations »
- Anchors are key element and their stiffness are very « technology dependant »
- The acceptance criteria depend on welds quality
- The acceptance criteria depend the accuracy of the model due to strain localisation effects
- Ageing effects are not easy to manage, especially for spent fuel pools

What is inside RCC-CW is the fruit of experience but with many « non explicit » criteria and ageing management is still to be introduced

Due to the fact that this topic is « critical » and supposed to catch the attention of many countries, it has been transferred to a OECD/NEA/WGIAGE CAPS activity

First output of WS 64 phase 3

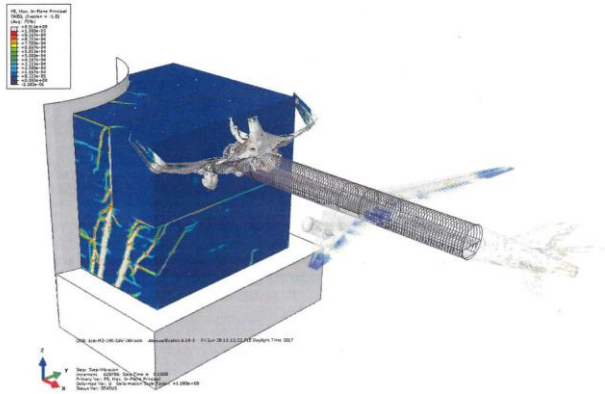
✓ Robustness

Robustness is the capacity of a structure to resist an event for which it has not been explicitly designed

It can be compared to "defense in depth" concept of nuclear safety, but is more specific to Civil Structures that are not allowed to collapse (even is damaged): this concept is already derived in future Eurocode

As this "new concept" is considered as a relevant complement to defense in depth, WS64 PG3 decided to introduce a code modification proposal dedicated to robustness that includes the ageing management activity (because inspection can detect "more than ageing effects")

First output of WS 64 phase 3



- ✓ **Aircraft Crash Protection**

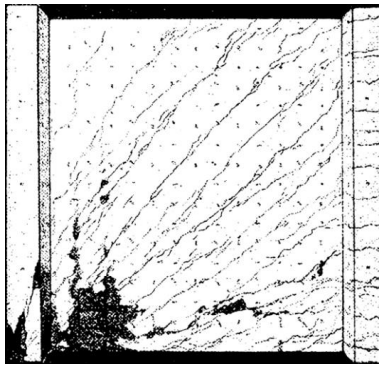
This is in fact a multiple/various set of topics:

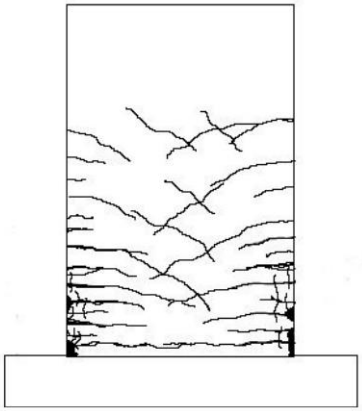
- ✓ **Load characterization**
- ✓ **Material characterization**
- ✓ **Simplified methods**
- ✓ **Acceptance criteria and performance assessment**
- ✓ **Detailed non linear analysis**
- ✓ **Equipment qualification methods and criteria**
- ✓ **Specific effects of very high frequencies**
- ✓ **Detailing requirements**
- ✓ **….**

PG3 is still thinking about the best way to manage all these different « sub-topics » but PG3 will definitively produce 2 kinds of proposal:

- ✓ **Code evolution proposal**
- ✓ **Research proposal**

First output of WS 64 phase 3





✓ **Shear in reinforced concrete structures**

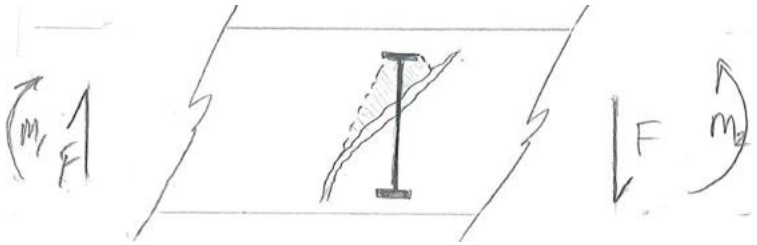
shear resistance of concrete building is a complex topic for many reasons:

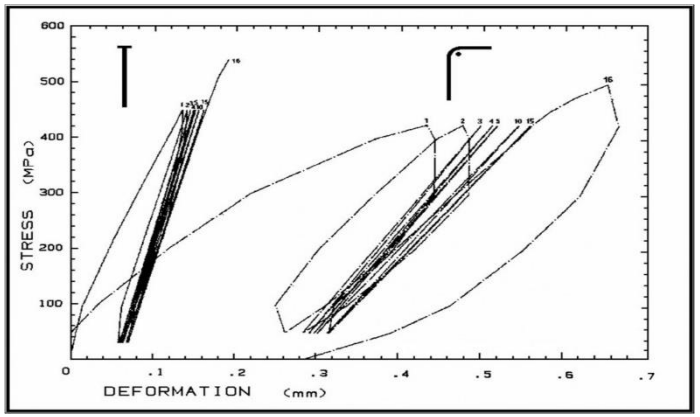
- **The behaviour of the structure is assessed as a whole while shear effects can be local**
- **The effect of concrete cracking has to be managed by « engineering methods » (simplified)**
- **The pure resistance aspect of shear resistant is translated in national codes that are quite different between different countries even if Eurocode is «pushing » to uniformization.**
- **Analysis of "design extension" / "beyond design" conditions is challenging**

As this topic is a large one and it has caught the attention of many other countries, it has been transferred to OECD/NEA/WGIAGE concrete group activities in order to gather more « forces ».

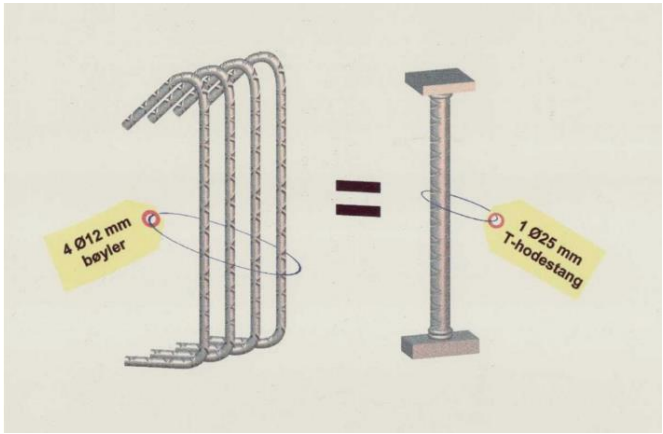
First output of WS 64 phase 3

✓ **Specific detailling topic: headed bars** **« The devil is in the detail »**





As this technology is « too young » to be prescribed precisely, an research proposal in under preparation

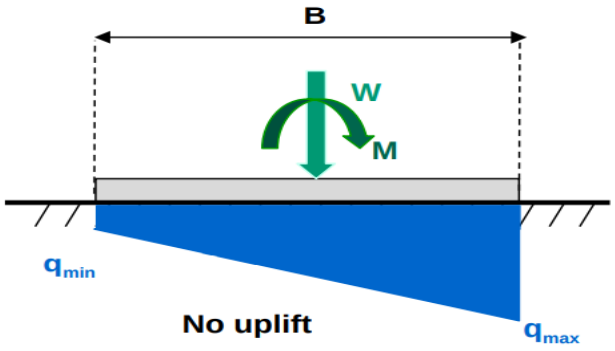


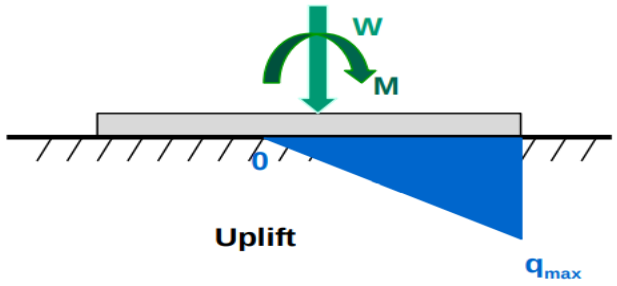
First output of WS 64 phase 3

✓ Uplift of base slab during earthquake

Linear calculation for earthquake engineering is the current practice due to the load taken as a response spectrum: a limit of this pratice is the springs representing the soil that are in tensile situation

The topic is the validity domain of this simplification that lead to a whole set of rules to be satified and alternative methods.





✓ Ageing management

Ageing management is a very large topic, even if we take only the « physical ageing »

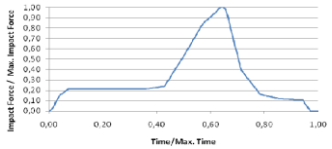
In WS 64 a code evolution proposal had been produced so that AFCEN has launched the redaction of a whole part dedicated to ageing, but the text is not available yet, so some typical items have been reviewed in detail during the workshop such as spent fuel pool ageing

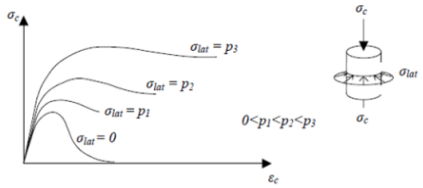
This topis has been merged with robustness on order to reinforce ageing management activities

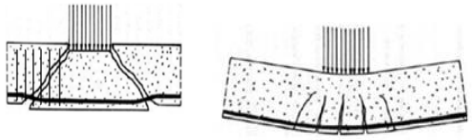
Airplane Crash (APC) Protection

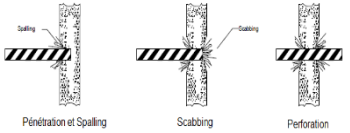
The scope of APC protection in a design code

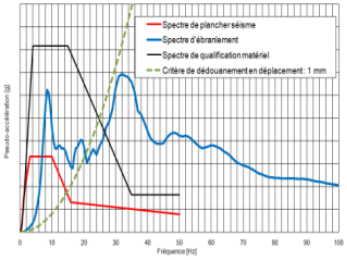
- 1/ **General explanation** and requirements related to the consequences of projectile impacts on civil structures (**soft/hard impacts**, **direct/indirect** effects)
- 2/ Material behavior and properties (steel and concrete) and **acceptance deformaton criteria** in the non linear domain
- 3/ **Local/global** mechanical effects due to « deformable » projectiles
- 4/ Local mechanical effects due to « **semi hard** » projectiles
- 5/ Effect of shock **induced vibrations**
- 6/ Recommandations to build and validate a **FE model** to study local&global consequences of APC



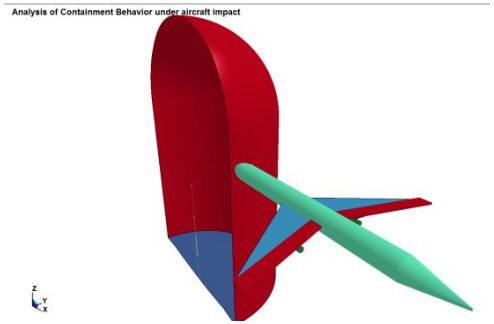








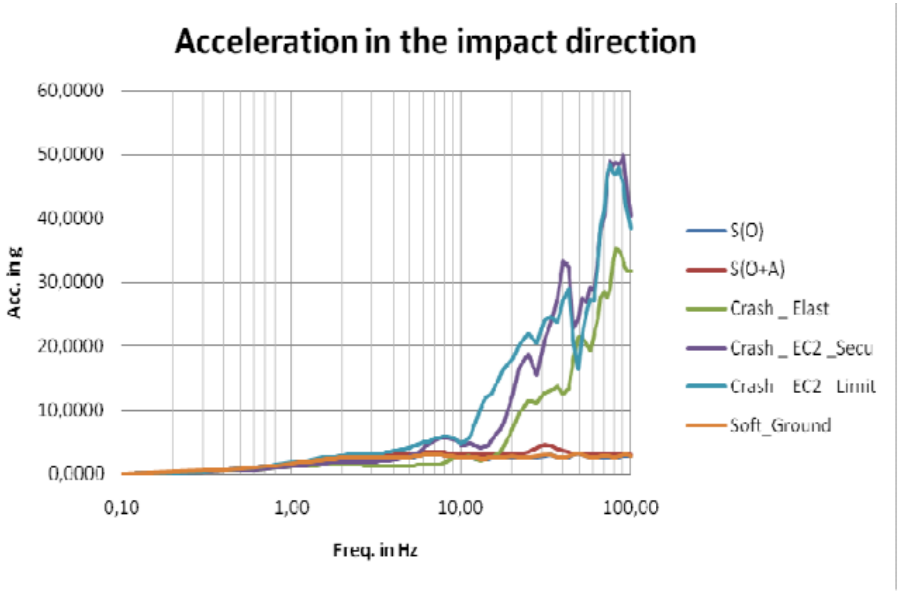
Airplane Crash (APC) Protection

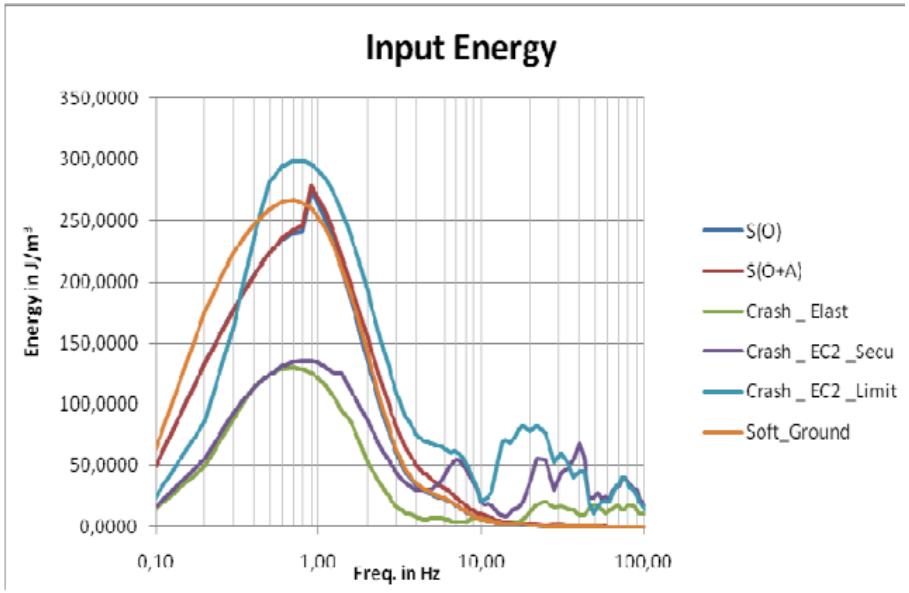


- ✓ The main difficulty is the **equipment qualification**
- ✓ **Originally** this qualification was **based on seismic qualification** and the huge experience in earthquake engineering that allowed to reach a "first step"
- ✓ However, earthquake engineering is not exactly similar to "APC engineering", in particular **accelerations** from APC may be huge in numerical value, but without significant energy content
  - ➢ so new concept **for acknowledging energy content** appeared and there is a need for some Research before implementation

Research proposal

Aircraft crash





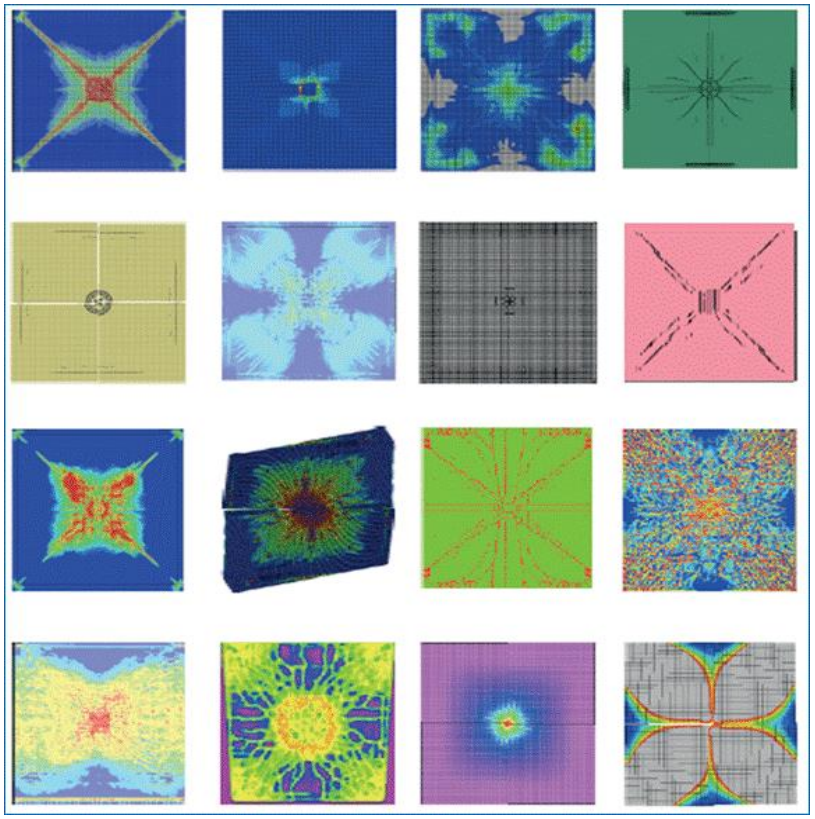
No correlation between acceleration level and potential damage energy

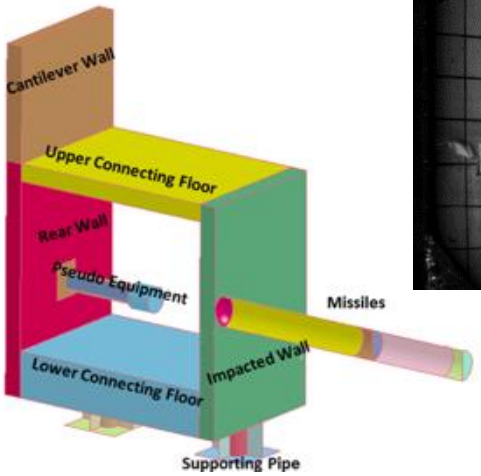
Figure extracted from Rouzau-Herve-Secourgeon-Barré SMIRT 2013 paper

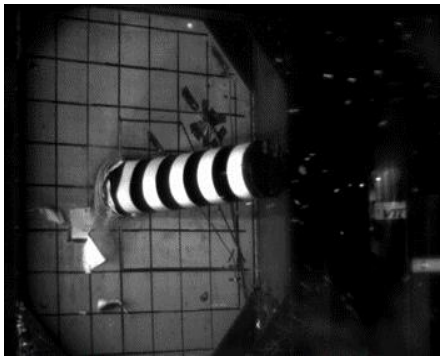
Research proposal

Aircraft crash

A large research program has already been performed at international level on the framework of OECD/NEA/WGIAGE (IRIS 1, IRIS 2, IRIS 3)







Experimental campaign performed in Finland (VTT) and numerical simulation performed by many different countries

Research proposal

Aircraft crash

But even if this research activities (OECD/NEA/WGIAGE IRIS 1 to 3) have been a great success, the whole engineering community involved in aircraft crash protection agrees to launch a further step focusing on the effect of high frequencies

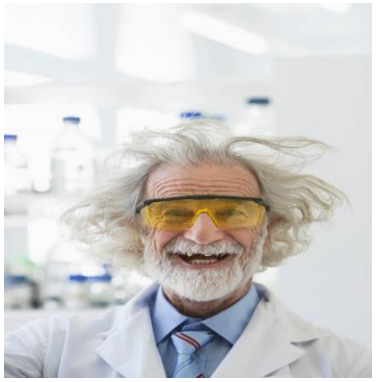
This tendency is a logic one due to the huge benefit taken from earthquake engineering that ends in the range of « medium » frequencies compared to aircraft crash effects

The perimeter will be defined by very specialists in order to find the area where outcome is really expected.

$$F_{impact} = Fc.(x(t)) + \dot{x}^2(t).\frac{\partial \mu(x(t))}{\partial x}$$

$$\frac{\partial \mu(x)}{\partial x} = \frac{1}{V_{impact}}.F_{impact}(x)$$

$$t_{eq} = \frac{\partial \mu(x)}{\partial x} \times \frac{1}{\pi D.\rho_{alu}}$$



First Conclusions

WS 64 PG3 has been very active until now and many topics will lead to either a code evolution proposal or research proposal

The main output of this workshop for PG3 is definitely the aircraft protection for which many sub-topics are now « on the table »

For the research point of view the effects of high frequencies of aircraft impacts versus the « inadequate » aspect of acceleration concept is a field that has to be deeply investigated.

Prospects for CEN/WS 64

- ✓ **Prospects for CEN/WS 64 Phase IV**
  - ➢ Maintain the effort undertaken by CEN/WS 64 since 2011, with the assessment of AFCEN codes against the variety of industrial and regulatory practices across Europe
  - ➢ Increase the involvement of European Regulators and TSOs
    - To share the understanding of the technical grounds underlying the design and construction rules, and consider their adaptation to various national regulations
    - To further facilitate the assessment of nuclear reactors based on AFCEN codes
    - To make AFCEN codes a reference for the assessment of nuclear reactors which can be based on various other standards
  - ➢ Consider new topics in the development of harmonised requirements and rules across Europe (Small Modular Reactors, Advanced Manufacturing techniques…)
- ✓ **Project plan under preparation**
- ✓ **Phase IV kick-off in 2023**
- ✓ **Call open for participation (utilities, vendors & suppliers, regulators and TSOs…)**
- ✓ **If interested, please contact CEN/WS 64 Chairman: lucien.allais@cea.fr**

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Thank you for your attention