Progetto europeo EDEN: la Thematic Demo sull'ispezione 3D laser in un reattore nucleare

Il progetto europeo EDEN rappresenta uno sforzo senza precedenti, da parte della Commissione Europea, a supporto delle attività di Ricerca e Sviluppo nel settore CBRNe. Sulla base dei risultati e delle lezioni apprese in precedenti progetti nazionali e internazionali, EDEN ha l'obiettivo di portare a un livello superiore di integrazione strumenti e pratiche atti a prevenire e ad affrontare situazioni di emergenza. Le soluzioni ricercate saranno validate sul campo tramite esercizi di simulazione di situazioni il più possibile simili alle condizioni reali. L'ENEA è attualmente impegnata in uno di questi esercizi dimostrativi, indicati nel progetto come Thematic Demos, dedicato alla realizzazione di uno scanner 3D per ispezioni avanzate negli ambienti acquosi di un impianto nucleare (serbatoio e vasca di stoccaggio). Il presente contributo definisce le linee guida di questa azione, programmata per il prossimo Settembre 2015, che pone l'ENEA all'avanguardia nella ricerca sui metodi innovativi di ispezione per l'industria nucleare. Viene inoltre fornita una breve descrizione del concetto e della struttura del progetto europeo EDEN, al fine di contestualizzare meglio l'azione descritta.

The European EDEN project: Thematic Demo on 3D laser inspection in a nuclear reactor

The European EDEN project marks an unprecedented effort of the European Commission to support Research & Development actions in the field of CBRNe. Building upon the results and lessons learnt in previous national and international projects, EDEN aims at bringing to a next level of integration tools and practices for preventing and facing emergency situations. The solutions sought will be validated through in-field exercises with simulated situations resembling real conditions as far as possible. ENEA is leading one of these exercises, indicated in the project as Thematic Demos and devoted to the realization of a 3D laser scanner for improved inspection in the wet environments of a nuclear facility (nuclear vessel and storage pool). The present contribution outlines the guidelines of this action scheduled for September 2015, which puts ENEA at the forefront of the research in the field of innovative inspection methods for nuclear industry. A short description of the EDEN project concept and structure is given for better framing the action.

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The EDEN project as a whole

The accidental or deliberate release of CBRNe materials are low probability events that can have a significant impact on citizens and society. Whenever and wherever they occur, they usually require a gradual and multifaceted response as they tend to provoke severe and unexpected physical, psychological, societal, economic and political effects that might also easily cross the borders inside and outside the EU.

Research activities are essential to develop new instruments and tools that the end-users can activate for successfully managing the four phases of the emergency management, which include Mitigation, Preparedness, Response, and Recovery.

The European Commission has strongly backed the efforts that the private and public sectors are carrying on to secure Europe a leading position as provider of hardware, methodologies and practice for handling emergency situations.

Within the Seventh Framework Programme (FP7), which covered the 2007-2013 period, the European Commission has sustained the theme Security, and CBRNe in particular, as a pillar of its institutional action to promote the European development through research. Many of the main projects are still under completion and at their final stage. Among them, PRACTICE (Preparedness and Resilience Against CBRNe terrorism Using Integrated Concepts and Equipment [1]) and DECOTESSC1 (DECOTESSC1 - Demonstration of Counter Terrorism System-of-Systems against CBRNe phase 1 [2]) are worth mentioning as they mark a considerable progress with respect to the default situation, characterized by a fragmented structure in terms of technology, procedures, methods and organization at the national and EU levels.

As a final act of the FP7 the European Commission has funded an integrated project, EDEN (End-user driven Demo for CBRNe), with an unprecedented economic effort.

The EDEN project [3] will leverage the added-value of tools and systems from previous R&D efforts and improve CBRNe resilience through their adaptation and integration in complex multinational/agency CBRNe operations. The EDEN project stems from the clear understanding that successful CBRNe resilience requires a global System-of-Systems approach.

EDEN recognises that "Systems of systems" has a different meaning for different countries and protection agencies and the concept of the EDEN project is to provide a "toolbox of toolboxes" (ToT), from a virtual EDEN Store, to allow different stakeholders to have a common certified set of applications available and pick the capabilities they deem important (or affordable) from them.

This concept will allow a high degree of interoperability at the differing levels of capability that each country may have. The benefit of EDEN concept is that integration is immediately applied at the application level.

The EDEN Store concept allows capabilities to be shared and consistently provided and accessible to multiple stakeholders. It will gradually build up a common capability that will span across the European boundaries. It will also share the burden of development and allow for lessons to be learned and applications to be enhanced based on the learning. Most importantly, it provides for interoperability, which is paramount in cross-boundary incident management.

Validation will be through three themed end-user demonstrations (Food Industry, Multi-Chemical, Radiological) cover at multiple hazards (C, B, R, N, E), and multiple phases of the security cycle, multiple tiers of and multiple stakeholders.

The EDEN consortium includes end-users, major stakeholders in the CBRNe domain, and large system integration and system solution providers, including SMEs (Small and Medium-sized Enterprises) that will bring innovative solutions and support integration and RTOs (Research and Technology Organisations) that will further develop EU affordable resilience.

The expected impact from EDEN is to provide affordable CBRNe resilience and market sustainability through the better system integration in real operations and in enhancing the safety of citizens.

The concept behind the EDEN Store is summarized in Figure 1.

End-User needs, as identified with a survey carried out prior to the project start and steadily updated during the project execution, are the main drivers of EDEN. They are the input for the development of the

"Toolbox of Toolboxes", which will include both new and existing tools coming from previous projects.
With a consortium of 39 partners, EDEN gathers most of the principal stakeholders together in R&D activities on CBRNe. The project has a three-year expected duration and the kick-off was on September 1st, 2013. The focal points of the whole project will be three large-scale demonstration actions scheduled at the end of the project, during which the ToT will tested and validated.
The three Demo actions are broken down into:

- Food chain and biological contamination
- Multi-chemical threat
- Radiological threat

Besides them, Thematic Demos include a plurality of scheduled actions, during which specific tools and practices will be tested and validated through in-field exercise. One of these Thematic Demos is led by ENEA and is about the development of a 3D laser scanner for inspection in the wet environments of a nuclear reactor. Wet environments include the vessel containing the core of the reactor and the storage pool for spent fuel rods. To complete this ambitious task ENEA will build upon its proven track record in developing 3D laser scanners for terrestrial and underwater applications. Here the challenge is to develop a device qualified for operating in a contaminated environment, a target that demands specific scientific and technological solutions. Inspections in nuclear reactors are essential for preventing faults, planning repairs and replacing critical components. Although laser techniques for measuring quantitatively fuel rods deformation have already attracted the interest of some research groups [4], so far tests have only been carried out in laboratory. The action ENEA is leading within EDEN aims at deploying for the first time a 3D laser sensor

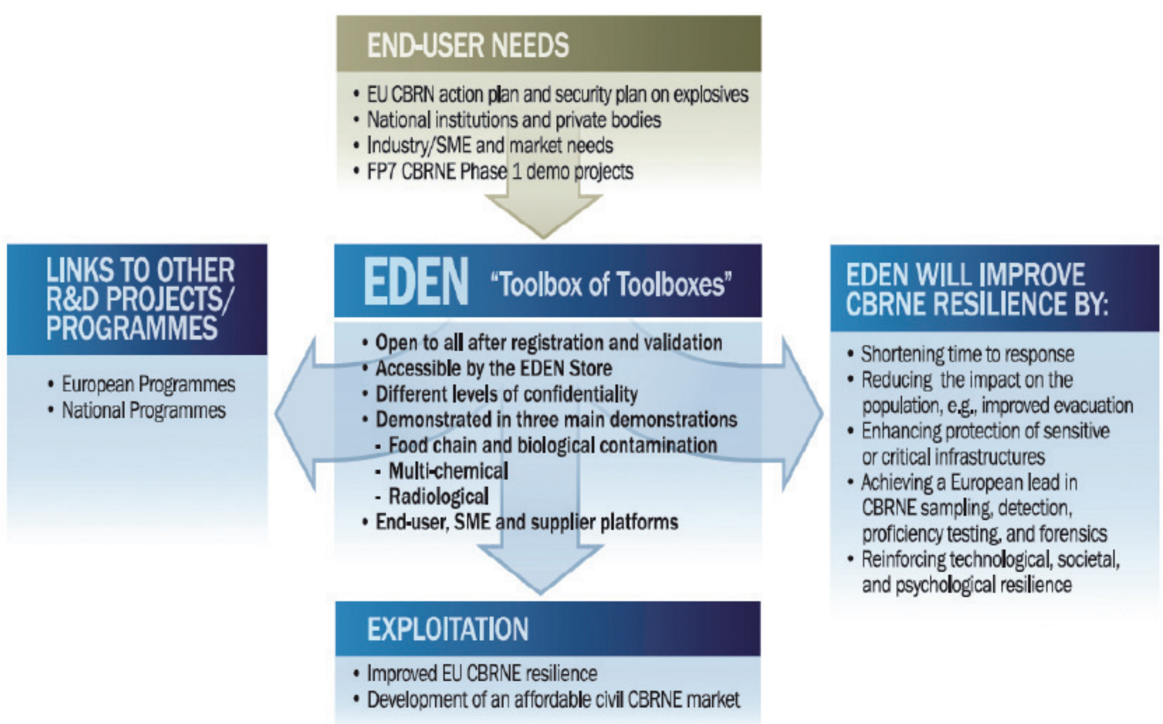

FIGURE 1 The EDEN project concept summarized in a workflow

in the wet and contaminated environment of a nuclear reactor, paving the way for further technological developments in this research field.

Thematic Demo on improved inspection in a nuclear reactor using 3D laser scanning technique

This action is about the demonstration of a new 3D laser scanner for the surveillance of the deterioration condition of nuclear fuel rods. The device will be immersed inside the storage pool and/or in the reactor pool for inspecting the fuel rods remotely.
Despite the numerous existing typologies of nuclear reactors (Boiling Water Reactors, Pressurized Water Reactors, TRIGA research reactors, etc.), the common physical forms of nuclear fuel is cylindrical, with the fuel pellets inserted into metallic tubes.
Cladding is the outer layer of fuel rods, standing between the coolant and the nuclear fuel. It is made of a corrosion-resistant material with low absorption cross-section for thermal neutrons, usually Zircaloy or steel in modern constructions, or magnesium with a small amount of aluminium and other metals for obsolete reactors. Cladding prevents radioactive fission products from escaping from the fuel mixture into the coolant, contaminating it. Usually fuel rods are grouped into Fuel Assemblies (FAs), forming the core of a nuclear reactor (Fig. 2).

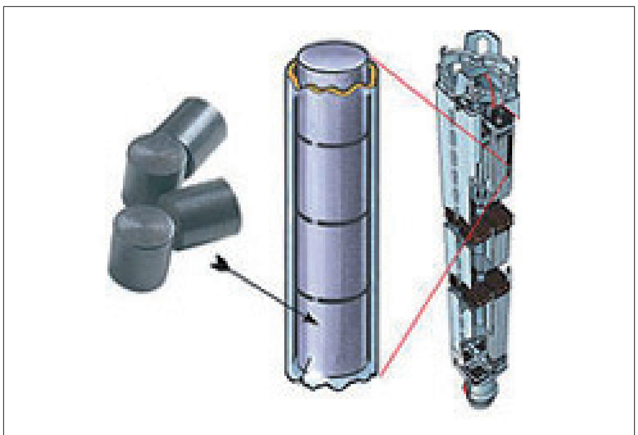

FIGURE 2 From fuel pellets to rods and assembly
Source: http://www.skb.se

During normal operations the fuel rods of nuclear power reactors are subject to internal stresses, which may lead to large dimensional changes or gross failure. Blistering, swelling and cracking are the most likely effects with which can lead to serious consequences. So far, deformations on fuel rods are inspected through a visual test.
Some optical technologies have been proposed but none of them has reached the necessary level of development to be applied in situ for the evaluation of rods integrity. The operation of a measurement device inside the vessels and pools of nuclear reactors, or in fuel storage facilities demands innovative solutions in terms of qualification to operate underwater and/or in radioactive, and/or contaminated environment. All these requirements have to be met without compromising the system performance.
The scenario for this Thematic Demo takes inspiration from several past real events, where an alert state was raised inside a nuclear facility as a consequence of deformations in one or more fuel rods.
For instance, on December 2012 Japan's nuclear regulatory authority confirmed a trouble with the fuel rods stored in a spent nuclear fuel pool at the Tokyo Electric Power Co.'s Kashiwazaki-Kariwa plant. A pair of fuel rods came into direct contact as a result of deformation in the bundle of fuel rods, leading the Nuclear Regulation Authority to determine that the fuel had likely been loaded into the reactor core "in an abnormal situation." An alert 1 level was then issued.

Purpose of the scenario

The exercise aims at both simulating the decisional flow for managing the deployment of an innovative inspection tool inside the storage pool, or the reactor pool of a nuclear reactor, and testing the reliability of the instrument and its performance. The technology of 3D laser scanner is gaining ground as an improved inspection tool for structural monitoring in several disciplines ranging from cultural heritage to Oil and Gas industry. The deployment of the device inside a sensitive area like a nuclear reactor plant comes with specific issues to take into account. Technical issues include the capability of the deployed device to withstand radiation doses compatible with the time required for acquiring the 3D model with the necessary spatial resolution. If the measurement is carried out in the storage pool on a neutron irradiated fuel rod, the gamma dose rate is expected to be of the order of 3kGy/h. In case of detection inside the reactor pool of the nuclear reactor, higher dose rates are expected. The scenario is intended for realizing a deployment condition of the sensor as closer as possible to the real situation. This also includes managing the decisional flow during the routine inspection campaign, with particular regard to actions to do in case a major fault is detected.

The undetected occurrence of cracks and deformations in the nuclear fuel rods is one of the main effects leading to critical situations in a nuclear power plant. Fuel swelling and thermal stresses are the main detrimental effects a fuel rod undergoes during its lifecycle.

If not timely detected these effects can lead in the worst cases to cladding breaches, which result in the release of fission products into the coolant, and even in fuel washout in the most severe cases. Such an event requires cleaning the primary coolant circuits and increases in outage time, and can have significant operating and financial impacts on the affected plants. IAEA reports [5] that during the 1994-2006 period in PWRs, an average of 13.8 out of 1000 FAs were found faulty with leaks (Fig. 3).

The deployment of a 3D laser scanner inside the storage pool, and eventually in the reactor pool of the nuclear reactor, allows to reduce the downtime of planned or emergency inspections. Data can help the decision making process by the personnel appointed to run the plant during routine maintenance campaigns but also in the case of critical situations arising from emergencies.

The proposed methodology marks a significant improvement with respect to the current state of the art for assessing fuel rods deformation with most of the practices based on the inspector's skill rather than on quantitative and reliable data.

Scenario outline

TRIGA RC1 is a nuclear reactor for scientific purposes, with a limited power (1 MW) and not connected to the electrical grid, it being not intended for electricity generation. The reactor itself is located inside a research centre and does not resemble the operational environment of a big nuclear power plant. Nevertheless, the TRIGA RC1 nuclear reactor is well representative, despite its size, of all the issues that could emerge from an inspection campaign on fuel rods. The decisional flow leading to the deployment of the inspection sensor does not differ significantly from that in place in real high power production plants. From a technical point of view, the limited dimension of the storage pool and of the reactor pool makes the

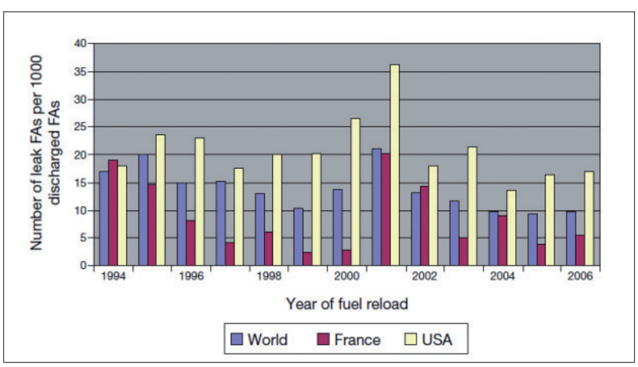

FIGURE 3 IAEA figures on FA found fault with leaks after inspection
Source: IAEA

FIGURE 4 The TRIGA RC1 nuclear reactor

actuation of the 3D laser sensor in TRIGA RC1 more challenging than in a production plant (Fig. 4). This adds greater significance to the scientific-technical value of the demonstration action.

The event as a whole is intended for demonstrating that improved inspections with a remote laser system can be carried out in the sensitive area of a nuclear reactor, even without turning the plant off. This has deep implications when the scenario is rescaled to real power plants, which face high operative costs for each on/off cycle. The main benefit is the possibility to increase the rate of the inspections, their affordability and reliability. One of the distinctive features of the 3D laser scanner is the possibility to compare images taken at different times.

The simulated event during the exercise envisages a fabrication fault in one fuel rod that causes it to blister, or otherwise the occurrence of a deformation in the rod during the normal operation of the reactor. The laser device will detect this anomaly and the rod removal can be planned.

The fuel rods in TRIGA are made of a ternary alloy of Zr-U-H and are 72 cm in length with a diameter of 3.73 cm (Fig. 5).

First laboratory measurements and computer simulations show that 3D models of the rods can be acquired with a sub-millimetric spatial resolution with a sensor-target distance of 5 meters. This level of accuracy is appropriate for the inspection sensibility as required by end-users.

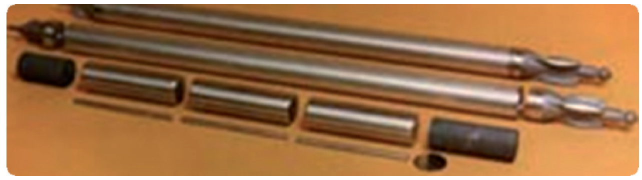

FIGURE 5 The TRIGA Fuel Rods

Conclusions

A vibrant research activity is underway at ENEA for carrying on, on September 2015, a Thematic Demo in the nuclear reactor TRIGA, demonstrating the capability of a 3D laser scanner to detect deformations in a fuel rod immersed in a wet contaminated environment. The action is supported by the European Project EDEN and the results will be evaluated by a panel of experts selected by the project coordinator from the list of the End-Users interested in the proposed technology. The synergetic collaborations between ENEA researchers with different skills and fields of competence have been instrumental to set up the exercise and will be the winning factor for its successful completion.

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