INNOVATION: AHEAD OF THE PACK(AGING)

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ABSTRACT

Customers want the packaging to be more capacious, to accommodate ever hotter materials, to reduce dose rates, to have quicker approvals, not to mention to come in cheaper. On the other hand, Safety Authorities want increased safety, thorough justifications, and essentially no new concepts. To make ends meet, the key is innovation on all fronts. AREVA's Logistics Business Unit has introduced a new concept, internally known as the ID school. It is a unique combination of innovation tools and methods. It blends an all-round technological watch, a system for collecting internal ideas, an extensive R&D program, state-of-the-art research and problem-solving software, a network of experts, an array of innovation methods and dedicated facilities that promote an innovative spirit. These tools apply to engineering, freight forwarding, organization... and favor both individual initiative and teamwork.

This paper describes each of these aspects, stressing the successes and expected benefits to come. It discusses some of the future developments in the ID school concept, and is also a plea to Safety Authorities for looking neutrally, or better favourably, upon innovative features and designs, which often offer safety and radiation exposure benefits. This paper will elaborate on the following three questions: Where are the most crucial needs for technological innovations? What is the role of innovation? How do we make it happen?

WHY INNOVATE AT ALL?

There are many reasons not to stay with the same solutions:

- markets and clients change, new markets open, with different requirements
- regulations change, regulators change – or change their mind on implementation
- regulators innovate faster than industry in their questions
- operational feedback suggests beneficial changes
- technological changes offer new solutions
- competitors are innovative!
- the company is in a process of continuous development.

"If it ain't broken, don't fix it". Why not just stay with the current solutions? The reasons *not* to change are just as numerous and strong:

- obtaining an approval is difficult enough with proven concepts
- changing anything may result in new problems
- designing anything new takes more time
- justification of ageing properties also takes time
- introducing new components will reduce standardization.

At any rate, most of us are faced with pressures to do better, cheaper... Pressure comes first from the customers: they move to higher enrichments and burn-ups, they want to clear their storage ponds earlier; they want to load more fuel in a cask or canister for economies of scale. Of course, fewer shipments is a benefit for safety; but approaching the technological limits for this might not be. Innovation is also what it takes to keep enough safety margins.

Another important factor is the nuclear renaissance, which will increase the number of shipments, but also the number of places where radioactive material will travel. Innovation is needed on the routes, the carriers, the logistics, to help limit CO_2 emissions in the service of a nuclear industry that does just that. Innovative features and designs will offer both high performance systems to customers who have the responsibility of storage and safety, and bring radiation exposure benefits to all the stakeholders.

The needs of technological innovation are important in three domains: equipment design, handling of used fuel and safety justification methodology.

On the design side, optimization of used fuel storage equipment requires innovations. The expectations are a higher payload thanks to new materials (such as metal matrix composites) and optimised geometry for criticality-safety, better thermal evacuation efficiency to accept higher fuel characteristics, resistance to impact of airplanes. Designs are also expected to be optimised for sustainable development. Innovative production methods with a combination of economical and reliable technologies are also a key factor for the customers to accept an used fuel storage system.

The current generation of used fuel transport casks in France will face administrative retirement in a foreseeable future, due to regulatory evolution. The new generation presently in the design phase will face the containment of hotter fuel in the same size and weight envelope. One challenge is heat transfer, where new solutions are needed.

Optimization is needed for fuel loading, cask (or canister) transfer and cask shipping, for tie-down systems. As the competitiveness relies also upon the optimal fuel utilization, a target for R&D is early evacuation. Some key processes like drying to avoid gas build up in cask cavities also require innovative solutions.

Regulatory requirements for safe storage are ever evolving, specifically to reduce dose exposure. To match this, safety justification methods need to be updated and the knowledge of safety margins must be continuously improved. In this improvement process we observe several innovations, for example criticality-safety with burn-up credit, moderator exclusion, evaluation of fuel integrity, analysis of accident conditions with new shock absorbing covers, new calculation models, new evaluation methods of material behavior over many decades.

THE INNOVATION MANDATE

Nuclear utilities – and other nuclear reactors and laboratories as well - require advanced solutions, with increased payload, acceptance of higher discharge burn-ups and easier licensing processes. In the case of used fuel, the expectations from customers affect five key performances:

1. Capacity and economic performance

The first key performance of used fuel management is a higher payload. Added value expected from innovation comes from a greater quantity of used fuel in the cavity of a cask. Increased flexibility of the system can bring added value: for example a better match with the fuel specification. However, adaptation is at odds with standardization, including for operations and overall economics.

2. Safety and ease of licensing

The safety and justification methodology must take into account the latest scientific developments and publications. There is also a form of competition between authorities to find new modes of failure. Therefore, there is a need for access to updated expertise. Experts from industry and from regulatory authorities should be involved in the innovation process, be familiar with new ideas, and be prepared to evaluate them. Typically, an important issue is the knowledge of long term behaviour of materials and components. As projects and licensing of final repositories are postponed and decisions concerning reprocessing are not yet made, extended duration of used fuel storage is now being considered. IAEA Member States have referred to storage periods of one hundred years and even beyond. Service life for transport casks can exceed forty years. New materials or surface treatments and new experimental or theoretical approaches on the assessment of material behaviour are now being considered. These innovations are necessary and are examined by Authorities.

3. Ease of operation and reduction of doses of operators

The feedback of dose intake from more than thirty years of experience has led to recommendations of a simple and efficient system, and of procedures for closure and shipment. At the same time the standard requirements for acceptable dose issued by regulators are regularly lowered. Solutions having good efficiency for dose reduction are therefore very attractive for the customers.

4. Impact of selected technology for sustainable development

Very often recent dry storage systems have had to comply with objectives of sustainable development. Selection of materials, energy consumption of solutions are compared and innovations are welcome.

5. Impact of selected technology on proliferation issues

Even with the sensitive subject of non-proliferation, the evolution of technology brings improvements to existing systems or develops new interesting solutions.

Environmental aspects, from design to decommissioning, are not often explicitly required, but responsible cask designers factor this in their innovation process.

INNOVATION PROCESS

In order to permanently provide good and economical solutions through innovation, the first action is to define a structured innovation process. Designer teams involved in innovation always follow a defined process. The myth of individual innovation dictates that innovation is natural, and that nothing else is necessary. Experience shows on the contrary that a structure is beneficial, as the production of a team is generally higher than that of an individual, be it a genius. The willingness to structure an innovation process is important. This innovation process allows the maintenance of high performance standards.

A typical process includes four steps:

1- Regular interviews with customers and utilities.
2- Access, capture and reuse of operational feedback and knowledge
3- Creativity and idea generation
4- Selection of ideas

New technologies, improved manufacturing processes, or simple ideas should be screened for significant added value. It is also important to have a communication system (innovation is creation, collaboration, communication).

Methods for creation and expression of ideas

For individual and spontaneous ideas, an idea management data bank is very often implemented in companies, and sometimes they are shared with suppliers or even customers. It is a current bottom-up process which is very effective, as is described below. Often the best ideas come from exchanges between colleagues, discussions, collaborative meetings. That is why it is interesting to establish *creativity groups* and collaborative tools, as explained below.

Role of the top management

Success in an innovation process requires the involvement of top management. Its role is to make the means available, by deciding to appoint people dedicated to stimulate and coordinate innovation (innovation catalysts), to galvanize creativity groups, to allocate a budget for the development of innovative projects, and to put in place incentives (events, awards).

INNOVATION AREAS

What are the innovation areas which should be emphasised with the designer of a cask or of a transport system? We will consider three main technological innovation areas: equipment design, interfaces and handling of used fuel, and safety justification methodology.

Concerning equipment design, permanent effort is made in the technology of baskets for transport and dry storage, or of racks for wet storage, aiming at a higher payload. Metal matrix composites or new materials allow more compact solutions and an optimized geometry for criticality-safety. In the case of casks and canisters, designers are looking for better heat-load evacuation efficiency to accept higher fuel characteristics. Survivability to airplane impact may be required. Designs should be optimised for sustainable development considering availability of raw materials, energy consumption and costs of dismantling. For both transport and storage systems, innovative fabrication methods with a combination of economic and reliable technologies are also a key factor for acceptance by customers and operators.

Concerning loading, transfer and shipment, improvements and optimization are expected for handling fuel and cask, for reducing dose intake, for tie-down on conveyances. As competitiveness also relies upon optimal fuel utilization, a target is early evacuation. Some key processes like drying for avoiding gas build-up in cask cavities also require innovative solutions.

The third innovation area is the justification methodology. Often it is difficult to admit that innovative methods can be used to demonstrate safety. Proven, traditional methodology is preferred. Yet, recent developments in science or modelisation have to be considered. On the other hand, regulatory requirements for safe storage continue to progress, specifically to reduce dose exposure. To match these expectations, safety justification methods need to be updated and knowledge of safety margins must be continuously improved. In this improvement process we observe several innovations, for example for criticality-safety with burn-up credit, moderator exclusion, evaluation of fuel integrity, analysis of accident conditions with new shock absorbing covers, new calculation models, and also new evaluation methods of material behavior for longer periods.

When ideas in each area have been selected through this process, then it is a significant step in establishing an innovation portfolio and to concentrate effort on the selected ideas.

EXAMPLE OF INNOVATION POLICY IN TN INTERNATIONAL

Many engineers are naturally creative but the context is not always favourable. We give hereafter a few suggestions to obtain more innovations. These suggestions come from our experience.

Figure 1: ID SCHOOL$^{\text{TM}}$

A first suggestion is to find or to create an open space for innovation: for example the ID SCHOOL$^{\text{TM}}$. In mid-2009, the management of TN international decided to set up an ID SCHOOL$^{\text{TM}}$, to make available a special room dedicated to innovation. Designers, engineers, or anyone from the company who wish to innovate, through brainstorming or by simply getting out of his everyday environment (usual desk, usual meeting rooms), can organize an innovation group meeting in the ID SCHOOL$^{\text{TM}}$. Small handicraft tools, modelling clay and other building material, web connections, mock-ups, supports for creativity are provided. In the ID SCHOOL$^{\text{TM}}$ the creativity groups gather for brainstorming, invent solutions, check their validity in a creative environment.

An innovation policy calls for methods to stimulate creativity. Consultants propose different creativity tools and methods over the Internet, already tested in various industries and with proven efficiency. Telecommunication and internet companies, the automobile industry offer many successful examples. However our sector is sensitive to safety issues, especially the management of used fuel; and Authorities are decidedly reluctant to evaluate innovations. It is sometimes difficult; but these methods should not be rejected, instead they should be adapted to the time scale and to the specific regulatory environment of nuclear energy. We know many innovation challenges in the field of used fuel management: acceptance of damaged fuels, resistance to airplane crash. An innovation team can be challenged with such issues.

AREVA has developed, and disseminated throughout the group, a special method for an innovation team called the *EFICA method*. This method alternates diverging and converging phases to conclude with a set of innovative ideas and an action plan to develop them. In this method, brainstorming is stimulated by facilitators. These are engineers who receive a specific training. More than twenty EFICA projects have been carried out very successfully by TN International, allowing many new ideas to emerge. These ideas are often implemented in cask designs, and for some of them a patent application is underway.

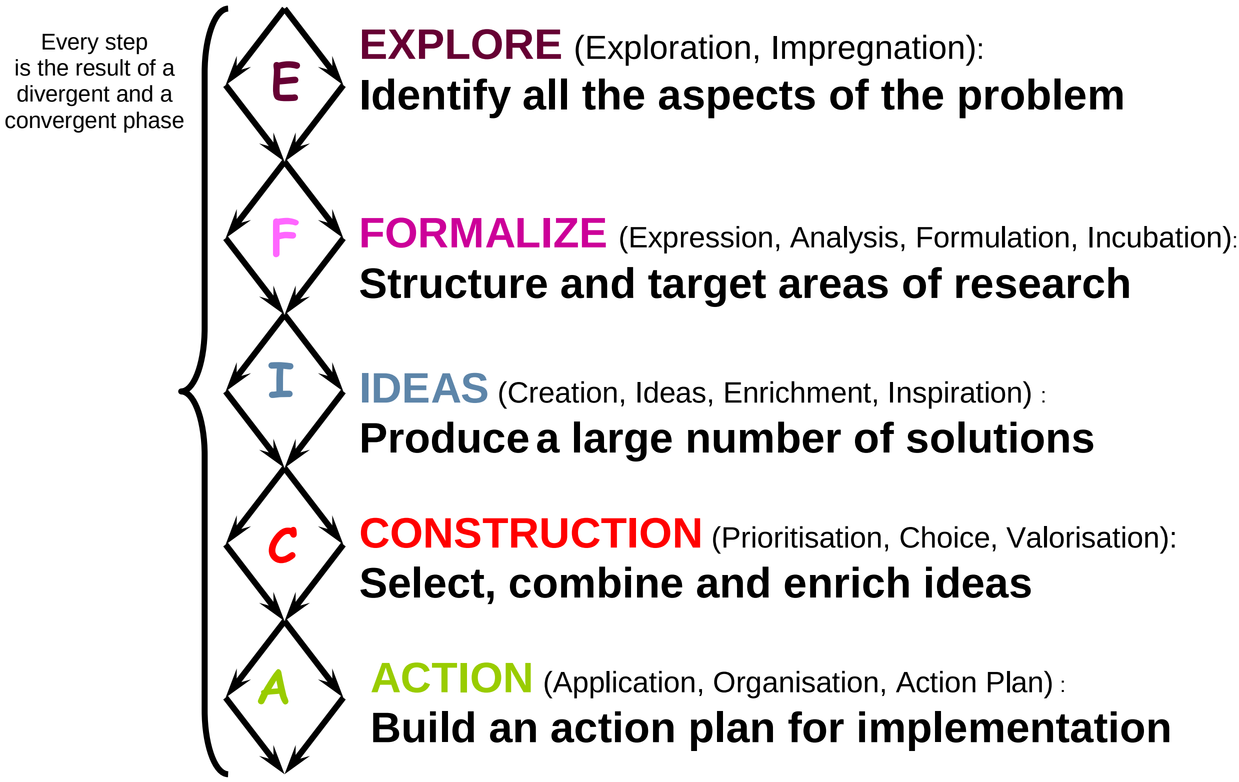

Figure 2: Description of the EFICA method

Another suggestion is an idea management data bank. To catch all interesting ideas, whether they come from groups or from individuals, from organised methods or spontaneously, an *idea management data bank* has been set up at TN International. Ideas can be posted from everyone's computer, using an intuitive software. Each idea is screened for novelty by a specialist in the idea's field, then processed by a high level Ideas Committee. When added value is shown, it is funded as necessary and implemented.

After implementation and use of these innovation tools, innovation in TN International has become a company-wide skill. Some of the results of this innovation policy for design and fabrication of fuel storage equipment are:

1. High performance design solutions for sub-criticality
The general trend towards high burn-ups for LWR fuels (typically 60 000 MWd/tHM for EPR™ reactor) leads to higher fissile contents which means either higher U-235 enrichments (5%) or higher plutonium contents for MOX. Sub-criticality is guaranteed by the basket geometry and the material. Compacity is one of the major criteria for the design of evolutionary casks: as the mass and volume of packaging are generally limited due to various interfaces (transport limitations or facility interfaces), there is a real challenge to design high capacity baskets. Therefore, a family of boronated alloys has been developed for use in the baskets: boronated stainless steel plates or metal matrix composites, formed by casting or sintering.

All characteristics (composition, mechanical) have been studied, including the homogeneity of boron contents and the resistance to corrosion in boronated water; and they are satisfactory. Boralyn™ with 15% B_4C is an example of high performance materials for sub-criticality: it can be used for the structural resistance of the baskets. There is also the new Boron Metal Matrix Composite (MMC) material with an aluminium matrix and up to 25% B_4C.

2. Innovation in containment closure
A new type of fluorocarbon O-ring gaskets has been developed and qualified to keep the guaranteed leak rate for a large range of temperatures. The long term behavior at high temperature of EPDM O-ring gaskets has been studied with innovative methodology, it is now possible to obtain a curve of temperature versus time-limit for EPDM O-rings.

3. Mitigation of hydrogen risk
For the mitigation of hydrogen risk in the cavity of dry storage casks, a catalytic recombiner has been developed and qualified, with a sufficient capacity to stabilize the hydrogen concentration below its flammability limit. Cooperation with French research institute IRCELYON has led to the development of this solution.

4. Complete range of high performance neutron shielding materials
TN International has developed high performance neutron shielding materials (formulation and manufacturing methods) resistant to fire tests (self extinguishing) : TN Vyal B™, TN HYPOP™ and BORA™ for sub-criticality. These materials are adapted to different thermal environments. Depending on the temperature of use, the designer can choose the most adequate product.

5. Solutions for thermal and structural management
For a given metallic containment vessel containing a given number of used fuels, the necessary thickness of neutron shielding material increases by 20% when the burn-up of uranium fuel increases by 15%, and by 50% if we change from uranium fuel to MOX fuel. Innovations have brought a better heat evacuation system to compensate for the negative effect of thermal insulation by the neutron shielding material (polymers are generally low heat-conductive materials): thermal

conductors, fins, new aluminium heat exchangers, special surface treatments, and gap reduction between cask inner wall and basket).

6. Used fuel dry storage systems
The most significant results of the innovation policy of TN International is the new generation of dry storage systems which includes most of the above described innovations. These new dry storage systems TN® DUO and TN® NOVA are presented in other papers.

CONCLUSIONS
The role of innovation in radioactive material transportation is to bring important benefits in term of performance, safety and public acceptance, while simultaneously supporting the dynamic perspective of the entire nuclear industry.

Those in charge of developing new transportation systems should not be reticent to research, foster and adopt innovative solutions. Well-aimed innovation will give them the competitive edge they need. The teams will be better motivated. Innovation is an advantage from the start.

Innovative solutions can be developed by R&D teams outside of the pressure of current projects; they can be tested, and form a portfolio of solutions available off-the-shelf. The presentation in papers and otherwise of this portfolio can be a way of engaging the Competent Authorities, in order to give them an advance taste of our next casks and of their safety features. To show that we have safe and secure solutions is beneficial for the whole nuclear activity. Obviously, the intellectual property of any breakthrough has to be protected by a patenting policy.

It is uncertain that you can improve safety by using solutions developed forty years ago. It is still possible today to design safer, cheaper, more efficient casks, while reducing your environmental footprint. The industry should be innovative, Competent Authorities should give a chance and a benign eye to justified and demonstrated innovation, so that you and everybody else will reap the benefits.

With innovation, which is a long-lasting process, the nuclear industry, and especially the back end part of the fuel cycle, is looking towards the long term and is preparing a future with less CO_2 emissions. That is our commitment at AREVA TN International.