November 2012

EUROSAFE TRIBUNE

Towards Convergence of Technical Nuclear Safety Practices in Europe

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Source term evaluation
A key to appropriate **emergency management**

When the worst happens: Lessons learned from previous nuclear accidents

SPECIAL FOCUS: THE FOUR CHALLENGES OF THE DUTCH FIRE SERVICES

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Severe accidents & emergency preparedness

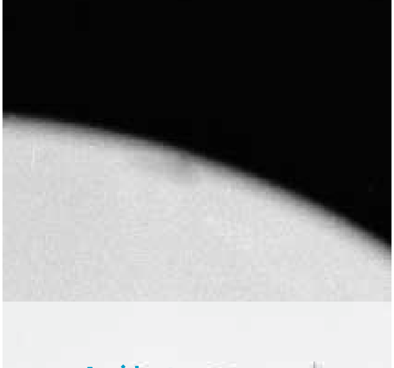
Crisis exercises begin with building scenarios aimed to simulate in the best possible manner accidental sequences that may actually occur in nuclear facilities, drawing upon the feedback from previous exercises and the lessons learned from real events.

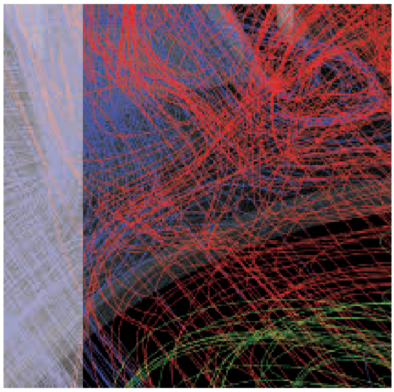
To our readers

Two major lessons emerge from the Fukushima Daiichi accident. The first pertains to the prevention of accidents and, above all, of severe accidents: the defence in depth of current reactors against hazards – in particular natural hazards like earthquakes and floods – could leave them vulnerable to extreme load situations, and it is essential that the feedback from previous events be fully taken into account to upgrade safety levels. To some extent, this lesson also applies to man-made external hazards and internal threats, which could lead to multiple failures of safety systems. The second lesson deals with the management of emergency situations. The idea that placing sufficient emphasis on the prevention of accidents may justify a lesser need for progress in the severe accident management area is dangerously wrong, as experience shows that such accidents may happen nevertheless. Meticulous preparedness for emergency situations and radiological crises is thus essential to mitigate in the best possible way the consequences of a severe accident and minimise its environmental impact.
From these observations emerge four major needs for Europe, a continent which harbours about 1/3 of the NPPs in operation in the world and where a nuclear accident with important radioactive releases would doubtlessly have extensive consequences within and beyond borders, from both an environmental and socio-economic perspective. Firstly, a need for a larger body of experts – at operators, safety authorities and TSOs – who fully understand the consequences of safety systems common failure and who can provide immediate and adequate response to emergency situations inside and outside the nuclear facility. Secondly, a need for skills, to predict and assess source terms, the dispersion of releases in the environment and its radiological consequences, in order to take appropriate measures to protect the population concerned, ecosystems and economic resources. Thirdly, a need for these experts to be directly involved in operational crisis management. This requires a crisis organisation that brings together all the experts and resources necessary to back the operator and public authorities, as well as appropriate training, notably through crisis exercises. Last but not least, a need for harmonisation of practice across Europe as well as enhanced trans-border information and co-operation.
With its new management structure, including notably a Technical Board on Reactor Safety and a Research Group, ETSON, the European network of TSOs is in a position to contribute productively to solving these issues.

We wish you pleasant reading.

Frank-Peter Weiß and Jacques Repussard





● *The general objectives of emergency planning and preparedness are to reduce the risk or mitigate the consequences of a radiation accident at its source and to prevent health effects* ●

Dana Drábová, SÚJB page 10

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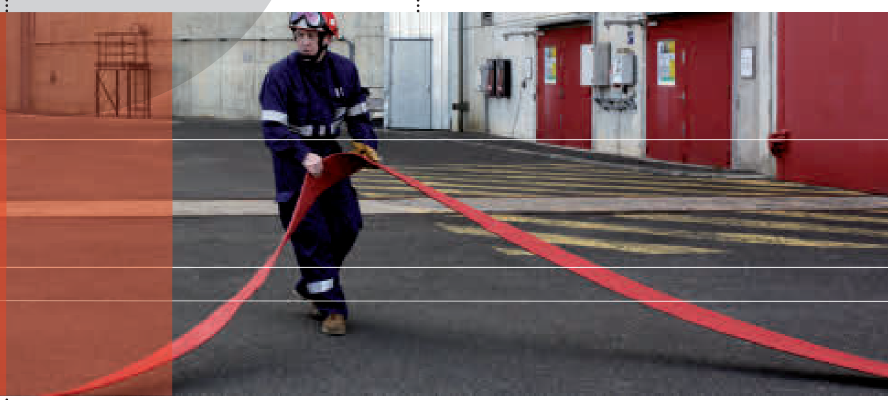


November 2012

The EUROSAFE Tribune express their appreciation to ÚJV for the valuable support provided throughout the design and production of the present issue.

Kaleidoscope

MEETINGS

15-17 December 2012
Fukushima Ministerial Conference on Nuclear Safety organised by the IAEA in Fukushima Prefecture as a contribution to strengthening nuclear safety worldwide. The Conference will provide an opportunity to share further lessons learned from the Fukushima Daiichi accident. More on: www-pub.iaea.org

24-28 February 2013
The annual Waste Management (WM) 2013 Conference to be held at the Phoenix Convention Center (USA) will be devoted to *International Collaboration and Continuous Improvement*. More on: www.wmsym.org

19-21 March 2013
Monitoring in Geological Disposal of Radioactive Waste: Objectives, Strategies, Technologies and Public Involvement in Luxemburg, conference organised by the MoDeRn EURATOM project and the European Commission with special support of the OECD-NEA. More on: www.modern-fp7.eu/monitoring-gdrw-2013/home

21-23 May 2013
Safety of Long-Term Interim Storage Facilities, international workshop organised by the Committee on the Safety of Nuclear Installations (CSNI) of the OECD-NEA and hosted by GRS in Munich. More on: www.oecd-nea.org and www.grs.de

ENSTTI NEWS

3 to 29 June 2013
The Induction to nuclear safety course held in Garching (near Munich) will include specialised courses such as nuclear security, decommissioning and final disposal safety. The 2012 induction course, which was attended by 21 participants from 11 countries, included visits to the Isar NPP as well as to Areva's PKL test facility in Erlangen. More on: www.enstti.eu

The knowledge gained through R&D and the experience feedback from past events are factored into the design of new facilities. In this picture, excavation is underway and earthquake protection pads are installed in view of the construction of the International Thermonuclear Experimental Reactor (ITER) at Cadarache, in the south of France.

SUSEN PROJECT

With the support of the ERDF and as part of the Czech programme titled *Research and Development for Innovations*, SUSEN (Sustainable Energy) has been initiated in the Research Centre Řež (Czech Republic). The project is aimed at developing by 2015 a robust infrastructure for sustainable R&D activities to support Czech participation in European efforts for safe and efficient energy generation in Europe in the 21st century. More at: http://susen2020.cz/en/

Stress tests in the EU's NPPs: ENSREG Summary Report available

The peer reviews of the stress tests have been completed by ENSREG with the endorsement, on 26 April 2012, of the ENSREG Summary Report and of the appended 17 country-specific peer review reports. The ENSREG report, along with the national stress test reports, is downloadable at: www.ensreg.eu/EU-Stress-Tests/EU-level-Reports

Stakes & Goals

Despite the existing technical and organisational arrangements to prevent human and equipment failures, the possibility of a severe nuclear accident that could result in transboundary radioactive releases can never be ruled out. What has to be done inside an NPP when an accident occurs? What organisation, planning, training, etc. is appropriate to cover it? Are the most competent people actually involved in real crises? What are the needs for change in organisations with a view to providing optimal response? These are some of the questions addressed from different perspectives on the next pages.

When the worst happens

What has to be done inside a NPP when a severe accident occurs? Martin Sonnenkalb, Head of Department at GRS' Reactor Safety Research Division, and Thibaut Van Rompuy, Safety Analyst at Bel V, provide a historical perspective on the development of severe accident management across the world from Three Mile Island to Fukushima Daiichi.

Maintaining critical safety functions in operation: a long-time struggle

After the severe accident at Three Mile Island Unit 2 in 1979, initiatives were undertaken in many countries to expand and enhance the NPPs safety by Accident Management provisions. A first development was the creation of *Emergency Operating Procedures* (EOPs) for NPPs that also would be effective if the plant operators could not diagnose the event, or if they diagnosed it wrongly. It led to the concept of *Critical Safety Functions* (CSFs) – such as sub-criticality and sustained cooling of the reactor core, integrity of the reactor pressure vessel (RPV) and the containment – to be fulfilled irrespective of the understanding of the event. The associated procedures were called *symptom-based procedures*, as they are derived from observed symptoms rather than from recognised events.

After the severe accident at Chernobyl in 1986, the initiatives where further enhanced and the focus was enlarged on the mitigation of severe accidents by developing measures and guidance (*SAMG = Severe Accident Management Guidance*), often including hardware modifications and backfittings. Most of the *Severe Accident Management Programmes* (SAMP) developed in Western Europe today (see box p. 8) are based on these earlier developments of US owners groups, especially related to SAMG. > **Feed and bleed** < measures to guarantee or re-establish core cooling before core degradation started have been developed and provisions have been made to easily allow the use of mobile injection systems with diverse water sources. Also, diverse power supply systems have been installed to prevent long-term station blackout situations. Typically, besides the SAMG implementation, some additional mitigative measures related to (at that time) well-known severe accident phenomena have been progressively developed, such as filtered containment venting systems in order to prevent long-term containment overpressure, or the installation of passive autocatalytic recombiners (PARs) or igniters to prevent hydrogen combustions challenging the containment integrity. The associated accident management procedures and guidelines were often developed in parallel and documented in special "handbooks", typically for use by the Emergency Response Organisation (ERO) and Technical Safety Organisations (TSOs).

Feed and bleed
A procedure aimed at cooling down a reactor core by pumping water into the vessel (*feed*) and letting it cool the fuel by boiling. But in many scenarios the system pressure stays at too high a level to pump in any water, and the vessel has to be vented/depressurised to the containment atmosphere (*bleed*) early enough to bring pressure down and allow cooling water being fed into the vessel.

Level 1 and 2 PSA
The Probabilistic Safety Assessment (PSA) consists of a set of analyses to assess the risks involved in a complex industrial system such as a nuclear power plant in terms of frequency of undesirable events and their consequences. There are three levels of PSAs, depending on the consequences assessed: Level 1 addresses the sequences leading to a reactor core meltdown and quantifies their frequency. Level 2 addresses the type, extent and frequency of releases outside the containment due to core meltdown accidents. Level 3 addresses the consequences of these releases in terms of dosimetry or contamination.

After Chernobyl, the focus was placed on the mitigation of severe accidents.

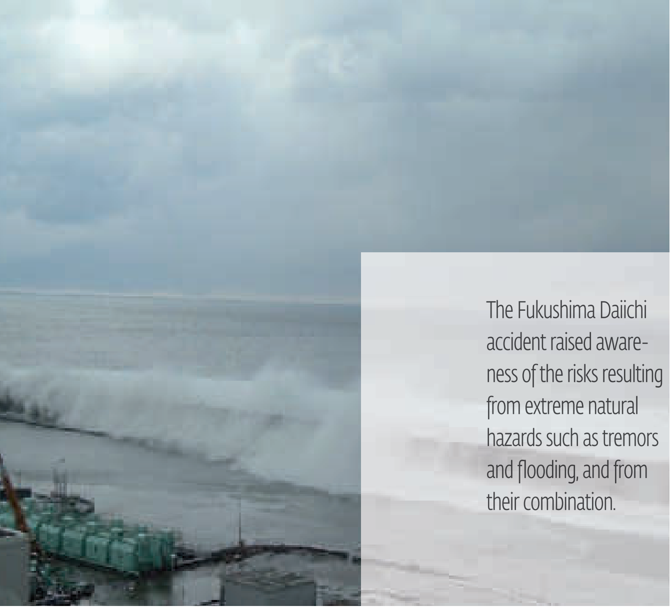
Various aspects of life in the territories contaminated by the fallouts from Chernobyl, particularly in Belarus.

Going beyond the design basis: lessons learned from Fukushima Daiichi

The development of severe accident management strategies requires insights and understanding of complex physical and chemical processes and phenomena that are to some extent plant-specific with regard to their occurrence and consequences. The spectrum of initiating events to be considered for LWRs is not different from the ones used in > **level 1 and 2 PSA** < studies. Lessons learned from the Fukushima Daiichi severe accident may lead to the consideration of additional events, especially external ones, or to additional protective measures of components and equipment typically used in SAMPs, such as special filtered containment venting systems designed for severe accident conditions and operable under severe environmental conditions as well as manually without power supply.

In case of an event, the accident management actions are selected using a clear set of criteria that are based if possible on directly measurable physical quantities. Basically, precise criteria are available to the shift supervisor as when to enter the symptom-oriented procedures or event-oriented ones. Alert criteria are typically defined to activate the ERO, which will take over the decision-making in case the event turns into a > **beyond-design-basis accident** < (BDBA) or severe accident.

Beyond-design-basis accident
This term is used as a technical way to discuss accident sequences that are possible but were not fully considered in the design process because they were judged to be too unlikely. Such accident sequences are analysed to fully understand the capability of a design and are an essential component of the defence-in-depth approach used in nuclear safety, since such accidents may have significant consequences - leading into a severe accident with fuel degradation and release of radionuclides, even if their probability of occurrence is very low.



The Fukushima Daiichi accident raised awareness of the risks resulting from extreme natural hazards such as tremors and flooding, and from their combination.

Keeping the plant personnel's decision-making capability in any case: a key imperative

A proper implementation of SAMP has to be an integral part of the overall emergency response management. Therefore, it should be clear by now that high reliability of communication networks between the different members of the ERO at different locations is of utmost importance. Consequently, the impact of any external events, such as extreme weather conditions or seismic events, should be considered when analysing those networks. Moreover, it is essential to ensure that, even in case of e.g. isolation or inaccessibility of the nuclear site, the means necessary to carry out measures and make appropriate decisions remain available to the plant personnel. ✖

Highly reliable communication networks are key to emergency management.

Severe Accident Management Programme (SAMP)

This set of measures and guidance is focussed successively on preventing the escalation of any event into a severe accident, on mitigating the consequences of such an accident, and on achieving a long-term stable state. *Preventive accident management* deals with preventing core damage in the plant whereas *severe accident management* focuses on the mitigation of the consequences of a severe accident, i.e. an accident where core damage was not prevented. The implementation of SAMP in a NPP typically comprises measures, hardware modifications and guidance, which may vary significantly according to the plant design and the regulatory requirements in the country concerned.

3 questions to... Didier Champion

on providing optimal response to an emergency

Emergency Response director at IRSN, Didier Champion draws upon the French TSO's experience to give his views on the challenges and key factor to success in the management of radiological emergency and post-accidental situations.

What is the optimal response to an emergency situation?

As a public expert in charge of supporting public authorities and governmental administration, a TSO such as IRSN must be in a position to work independently from operators, but in a permanent dialogue with operators to fully understand each other's perspectives and ways of working. This dialogue and the information provided continuously by the operator on his own facilities are very important to allow us providing, in an emergency situation, technical assessments that are both accurate and in time with the radiation protection requirements. In this sense, the optimal response to an emergency situation draws upon the most accurate assessments in the shortest possible timespan.

What conditions should be brought together to respond successfully?

Any efficient response to a radiological emergency resulting from a severe accident with core meltdown implies an accurate assessment of the source term, i.e. the quantity, composition and kinetics of the releases. It also implies understanding how the environment itself will influence the fallouts and finally forecasting the potential doses that could be received in a short term by people around the nuclear plant. This last aspect is essential, since the priority is to protect the neighbourhood of the affected facility, the contamination of wider territories becoming an issue in a second phase. Thus, it makes sense to distinguish the management of emergency situations, which concerns limited areas, and the management of post-accidental situations, which potentially concern much larger areas. In this respect, I should point out that it is difficult to reduce the uncertainties on the characteristics of radioactive deposits until in-situ measurements have been performed using mobile laboratories. Therefore, in addition to the data supplied by Météo-France, the French national meteorological service, which provides IRSN with updates on weather conditions and forecasts, IRSN operates its own network of radiological surveillance of the environment and its own mobile labs to analyse quickly the samples collected by its staff. Beyond the acquisition of data, the efficient management of an emergency situation requires different expert skills and tools to be brought together in crisis centres with a view to assessing the situation inside the nuclear plants as well as its consequences in the environment. IRSN activates its crisis centre to perform diagnostics and prognostics used by the public authorities and government to take protection measures for the population.

Considering the present organisational patterns, what progress remains to be made?

Two major challenges were evidenced by the Fukushima Daiichi accident. The first one pertains to the interpretation of the data coming from a damaged facility to assess the situation and the capacity to get these data, rapidly and continuously. The second one concerns our capacity to address simultaneously a great deal of issues with the risk to be overwhelmed by the bulk of work. I think we also need to improve our capability to report on our technical activities both to the government's administration and to the public at large, to help them to really understand and appraise our work. The maps published on IRSN's website are part of our effort to become more didactic, thereby helping non-specialised decision-makers take appropriate steps in an emergency situation.

Preparing for an emergency: a regulator's view

Independent real-time technical assessment in case of a nuclear accident

In such a situation, the role of STUK is to provide authorities at local, regional and governmental levels with recommendations of protective measures that are based on STUK's own analysis of the plant situation and radiological effects. Three major technical means are available in-house for this purpose, starting with an automatic data exchange link with the nuclear power plants to monitor the plant safety functions. The two other means are the automatic monitoring of the radiation situation throughout the country and several calculation tools to evaluate the possible radiological effects of an accident, with the support of the Finnish Meteorological Institute, which provides STUK with weather information. However, independent real-time technical assessment during an accident would be a challenge, since the TSO would need to have on-line access to the same information as STUK, as is not the case at the moment. The expertise of the TSOs would be utilised in a later phase to evaluate the causes and consequences of an accident.

Tero Varjoranta
Director General
STUK

Are existing emergency planning zones really sufficient regarding the possibility of extended radioactive releases from the different facilities of an NPP? Are the existing emergency decision-making processes sufficiently timely and responsive when analysed for conditions identified at Fukushima Daiichi? For instance, would emergency systems still be functioning despite a large-scale power loss or other disruptions? Do current nuclear plant safety goals adequately reflect the socioeconomic impact of a wide-scale contamination event? The Czech Republic's State Office for Nuclear Safety (SONS) reviewed these questions and many others under Dana Drábová's conduct as part of the reassessment of the management of nuclear emergency situations.

In the Czech Republic, the response to nuclear or radiological emergency situations is based on a national emergency organisation, emergency plans, staff training that includes periodic exercises and standard countermeasures to assure the protection of the population. "*The general objectives of emergency planning and preparedness are to reduce the risk or mitigate the consequences of a radiation accident at its source, to prevent serious deterministic health effects and to reduce the likelihood of stochastic effects as far as reasonably achievable,*" recalls

Emergency preparedness exercise: after contamination monitoring, showering is performed to remove residual radioactive particles.

Assess the experience gained in past radiological accidents.

Mrs. Drábová. "*The relevant Czech legislation is fully harmonised with the EU's acquis communitaire,*" she stresses.

Conditions for the efficiency of emergency plans

The first objective mentioned above is achieved by establishing the primary responsibility of the NPP operator. "*This involves the consistent application of the defence-in-depth principle with the final task to prevent or reduce to the possible extent the release of radioactive material and the exposure of both the employees and the public,*" Dana Drábová comments. The tasks concerning the next two objectives lie within the combined responsibility of the NPP operator and the off-site organisations – public authorities and rescue system. Public authorities are responsible for the development of emergency plans, whose main objective is the protection of the population in case of an accident. For Mrs. Drábová, "*the efficiency of emergency plans assumes they have been established before the occurrence of any accident, taking into account the specific features of the facility and of its environment. Based on the list of events likely to induce releases into the environment, some so-called envelope scenarios are selected and their consequences are assessed.*" The comparison of the consequences to reference levels for which protective actions are recommended indicates the area where actions may be required.

The need for a comprehensive reassessment of emergency management

The Fukushima Daiichi accident has brought into focus a difficult issue. Until then, nuclear emergency planning was generally based on the assumption that regional infrastructure and support capabilities remain more or less intact and ready to cope with any nuclear emergency that might occur. The tragic accident in Japan revealed a need for a comprehensive reassessment of the capabilities, organisation and training of local, regional and national authorities for off-site emergency management. Deeply involved in this process, Mrs. Drábová observes: "*In the Czech Republic, the reassessment included among others command and communication protocols, robustness and diversity of communication networks, decision-making criteria, capabilities for radiation monitoring, supplies and criteria for administration of stable iodine, etc. It has not resulted up to now in finding alarming gaps or mistakes in the existing arrangements. Nevertheless, there is obviously some space for improvements, concerning notably the robustness of human organisation at the operator, regulatory authority and local authorities.*"

Radiological control of thyroid (top) and whole body counting (above) are performed on supposedly exposed individuals.

Learning from past radiological accidents to develop harmonised emergency practices

Although emergency management methods are shared worldwide, and information exchange processes have been set up widely between safety authorities for use in the event of an emergency, lessons learnt from the Fukushima Daiichi accident showed again that actual, technical implementation relies upon differing practices leading to incomprehension and confusion, with regard to aspects such as the countermeasures perimeter and the methods for dispensing stable iodine in the event of a nuclear accident. "*As a support to the improvement of emergency preparedness, there should be further international efforts to assess the experience gained in past radiological accidents and to develop recommendations for improvements based on this experience. The efforts should include the development – or refinement – of criteria for worker and population exposure, water and food contamination at different phases of the accident, including conditions for public re-entry into contaminated areas and for return of contaminated land to normal use,*" Dana Drábová advocates. Such international efforts would help harmonise emergency procedures between neighbouring countries and could also improve public trust in the mitigation measures implemented in case of any future major accident. ✖

Learn more about...

THE STATE OFFICE FOR NUCLEAR SAFETY (SONS)

With respect to the legislative requirements for the on-site and off-site emergency preparedness of nuclear installations stipulated by the Atomic Act, its implementing regulations and associated government decrees, SONS is responsible for developing, maintaining and regulating arrangements for preparedness and response for a nuclear or radiological emergency. In the event of an emergency, SONS's main duty is to advise public authorities and the general population on protective measures needed.

More on: www.sujb.cz/en/

Science
& Technology

The management of a severe accident occurring in a nuclear plant aims primarily at mitigating the consequences of a core meltdown in order to provide both the operator's personnel and the neighbouring population with adequate radiological protection. This mitigation requires in-depth understanding of what happens both inside and outside the plant.

Severe accident management applications: filling the half-empty glass

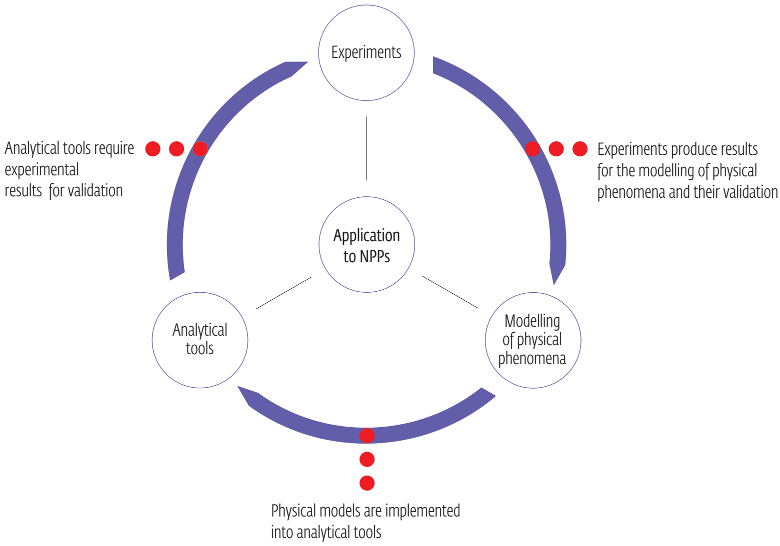
State-of-the-art knowledge on severe accidents allows analysing the progression of an accident, its consequences and the impact of appropriate preventive and/or mitigative countermeasures. In this sense, the glass is half full. But, for Jiří Duspiva, Head of the Severe Accidents and Thermomechanics Department at **> ÚJV <**, these measures have to be analysed together with an estimation of the associated uncertainties and proposed with the corresponding safety margin, leaving the glass half empty. In this respect, an important role of R&D institutes is the elimination of uncertainties, which requires further research programmes. By helping save resources, international collaborations such as the EC SARNET programme play a key role in this process.

As the accident at the Fukushima Daiichi NPP renewed interest in the severe accident issue worldwide, the European Commission decided to perform the so-called stress tests in all EU nuclear countries under ENSREG's aegis. The output from these tests is a set of recommendations for the improvement of units in operation mainly from a severe accident management (SAM) perspective. "*Obviously, a standardised procedure for such retrofits is not conceivable, since the designs of the 138 units in operation across the EU are largely different. Subsequently, the preparation of specific SAM programmes for each NPP requires support from the R&D community,*" Jiří Duspiva advocates, mentioning another important reason for R&D support: the performance of many analytical operations using various computational codes in the preparatory phase of such programmes. Moreover, the lessons learned from the benchmarking performed under the OECD NEA's programme of International Standard Problems revealed the very significant impact of user skills on the quality of the results produced.

ÚJV
The Nuclear Research Institute (Ústav jaderného výzkumu Řež a.s.) is a research and engineering company located in Řež (Czech Republic). It provides utilities and regulatory body (the State Office for Nuclear Safety) with services in the field of safety of nuclear power.

Knowledge gained and limitations

The implementation of computational codes as black boxes – i.e. pouring data into the system and expecting results to be obtained without any particular evaluation and interpretation – showed an absolutely wrong approach, which must be avoided. In this respect, the R&D organisations could provide really important support in preparing the prerequisites to design processes. "*As a support to SAM preparation, many new research activities are necessary, such as analytical studies aimed at identifying the key phenomena involved, the timing of accident progression, and the possible application of coun-*



The principles of R&D in the severe accident area

As evidenced in this figure, R&D processes and applications to NPPs – including severe accident management – are closely related to each other.

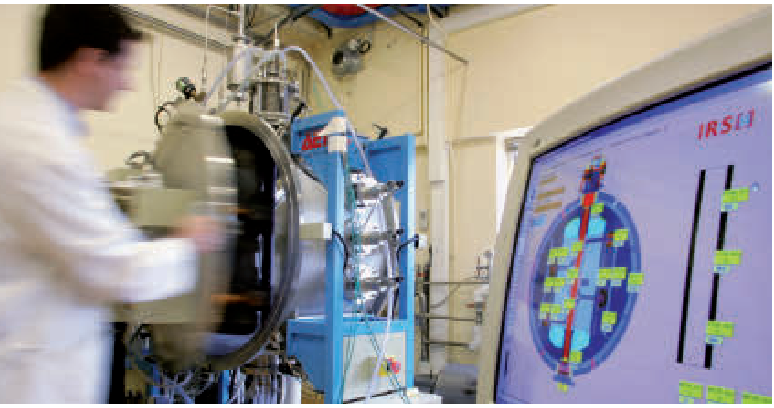
termeasures," Jiří Duspiva points out, adding: *"Such studies started in the EU immediately after the Fukushima Daiichi accident with the aim to support our Japanese colleagues in their decisions at the site. The analytical tools used for those studies are under permanent development, starting a long time ago, and are well validated, but their implementation also showed their [...] limitations".*

If different reactor designs are in operation in the EU, as recalled above, an even larger number of designs are to be found in other parts of the world, using different materials. Unfortunately, knowledge of severe accident phenomenology is available mainly for generic materials, not for specific ones. *"This is the principal area of R&D to be performed in the near future as a support to SAM,"* Jiří Duspiva comments. The gap in specific material knowledge starts with fuel design, where any independent study of material behaviour is a very sensitive issue, because of the fuel designers' and manufacturers' intellectual property. More than ten years ago, the situation was simpler in principle, because two basic alloys were mainly used for cladding. But more recently, each fuel manufacturer has been using a newly developed alloy of its own, whose behaviour can influence significantly the early phase of reactor core degradation during a severe accident.

Performing research to reduce uncertainties

One of the most spectacular aspects of the Fukushima Daiichi accident was the hydrogen detonations that heavily damaged the buildings of units one, two and four. *"Let us recall that hydrogen generation is influenced by cladding material, during the early phase of core degradation in a severe accident, in such a way that it impacts the initial and boundary conditions for the layout of hydrogen removal systems – such as catalytic recombiners – to be installed at power plants as an important measure to prevent hydrogen build-up,"* Jiří Duspiva explains. The interaction of molten corium with the concrete walls after melt-through of the reactor's pressure vessel bottom head could be given as a second example to illustrate a phenomenon where the exact material compositions are key factors that influence their possible behaviour. *"I mean here the composition of the corium with the ratio of oxide and metallic components, but also that of the concrete, because the erosion of siliceous and lime stone concretes is very different,"* he specifies. These are only two examples, but many similar uncertainties exist for different phenomena related to all the phases of severe accident progression, calling for further research.

Source term evaluation, a challenging activity



Why is source term evaluation a pivotal activity for making appropriate decisions in case of a severe accident with radioactive releases outside the nuclear plant containment? What is the state of the art in this domain? How can international co-operation contribute significant progress? Three experts - Peter Líška from VÚJE, Martin Sogalla from GRS and Emmanuel Raimond from IRSN - discuss these questions and many others below.

Peter Líška
Vice-Chairman of the Board, VÚJE

Source term evaluation is of primary importance for appropriate emergency response because, in case of an emergency within a nuclear installation, the radiological consequences in the surroundings will be strongly determined by the accidental release of radioactive material. Consequently, taking appropriate measures to prevent or reduce the detrimental effects of such an event requires to gather, as early as possible, as much information as possible about the release, such as the quantity and composition of radioactive material involved, the start and duration of the release as well as its location. We call the sum of such information the *source term*.

Martin Sogalla
Chief Expert, radiological consequence analysis and emergency preparedness, GRS

In this respect, experience shows that the real problem is with combining the need for both rapid and reliable source term evaluations. On the one hand, a prediction of the source term at an early stage of an accident will be most helpful if it allows taking protective measures – such as the evacuation of a potentially affected area before any release has taken place – with a view to preventing any exposure to radioactivity. But on the other hand, the reliability of information about the further development of an emergency is supposed to increase as the accident progresses. So, a delicate balance is to be found between accuracy and time.

Emmanuel Raimond
Deputy Head of the severe accident Department, Nuclear safety Division, IRSN

I think this is the reason why the consistency of source term evaluations between operators and TSOs needs to be checked. In the initial state of an accident at a nuclear facility, the operator is responsible for source term prediction based on the technical state of the facility and expected evolution. In some national emergency response organisation, the competent national authorities work together with their TSO to evaluate the source term independently. This allows performing comparisons of the results obtained but requires an efficient organisation and procedures to exchange very quickly all technical data on the nuclear facility status. Let me point out in addition that, in case the operator cannot provide appropriate source term information, this task has to be carried out by e.g. the national emergency response centres.

P. Líška — As regards the methods for source term evaluation, I would like to recall that any source term prediction has to rely upon actual data on the plant state. This data will be used to predict the further development of the accident and, should radioactive releases take place, their time, quantity, composition and location. Such predictions usually rely on sophisticated analyses of severe accidents. However, the application of integral computer codes needed for such analyses is too time consuming for rapid assessment if an emergency is taking place.

M. Sogalla — Yes, and to circumvent this difficulty, the results of a plant-specific probabilistic safety analysis (PSA) level 2 can be used, as they provide source terms together with their frequencies and related information about the plant state. QPRO, the tool for rapid source term assessment developed by GRS, uses this kind of information. QPRO is based on a **> Bayesian belief network <** in which actual plant data are combined with pre-calculated PSA level 2 results, yielding within a short period of time optimised source term estimates together with their probabilities.

P. Líška — With the same purpose, expert systems such as **> ESPRO <** have been developed to provide an early indication of the likely source term characteristic based on the plant status. The resulting source term is chosen from pre-calculated (severe-accident) scenarios prepared using a mechanistic computer code called MELCOR. The system outputs are interfaced with decision support systems such as RTARC, developed by VUJE, or RODOS, developed with the support of the EC's Euratom Framework Programmes. The analysis of the existing expert systems and of our experience with different techniques of artificial intelligence led to the development of an expert system with an operation interpretation module that uses the knowledge bases of either symptom-oriented EPs or EPs used for the evaluation of the source term and the determination of protective measures. These procedures, which are represented in the form of a hierarchical logical Petri net model, include a set of decision diagrams for quick estimation of the source term.

E. Raimond — In France, for PWRs, the method for source term estimation under severe-accident conditions is based on the analyses performed in advance for a reactor unit, drawing upon its known potential leakage of fission products to the environment but also from knowledge obtained from research. At IRSN's crisis centre, the method is based on identification of dominant parameters of accident progression that influence radioactivity releases to the environment. The most important parameters on releases and the source term calculations are performed with the SESAM software. In case a release has already taken place, measurements of radioactive effluents and off-site measurements of radioactivity can be combined with the plant-state data to improve the evaluation of the source term. I think many crisis centres use a very similar approach.

P. Líška — You are right, and special-programme modules such as STERM, developed by VUJE, are utilised for the estimation of source term using the gamma dose rates measurements from fence monitors, which we call the 'first ring'. The values of the measured gamma dose rates are compared with dose rates for a 1 Bq/s release under a variety of different atmospheric conditions which have been pre-calculated using a **> Gaussian-puff dispersion model <** in the current module. The results of an uncertainty and sensitivity analysis were used and data which characterise the location of detectors, the source

Bayesian belief network
As a network of probabilities that captures the probabilistic relationship between variables as well as historical information about their relationships, a Bayesian belief network is a very effective tool for modelling causes and effects in situations where some information is already known and incoming data is uncertain or partially unavailable.

ESPRO
A goal-oriented, rule-based knowledge system, ESPRO is based on emergency procedures developed in VUJE Trnava, Inc. for use by the Emergency Response Centre (ERC) of the Slovak Nuclear Regulatory Authority (NRA).

Gaussian-puff dispersion model
This mathematical simulation of how air pollutants disperse in the ambient atmosphere is performed with computer programmes that solve the mathematical equations and algorithms which simulate the release dispersion. The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from sources such as industrial plants, vehicular traffic or accidental chemical or radioactive releases.

(Left page) Test performed in the Intermezzo oven as part of the BECARRE research programme related to reactor core meltdown.

3 questions to...

Gregory Gromov

on severe accident modelling and mitigation

As the director of the State Scientific and Technical Centre on Nuclear and Radiation Safety (SSTC), the Ukrainian TSO, Gregory Gromov shares the Centre's experience in severe accident analysis. SSTC, who just celebrated the 20th anniversary of its foundation, is a member of ETSON.

When did SSTC initiate work on severe accidents?

In the mid 90s, we started assisting the Ukrainian nuclear regulatory authority in developing requirements on severe accident analysis, as part of the safety analysis report (SAR). With this purpose, we used – like many other countries – the U.S. NRC Regulatory Guide RG-1.70 as a basis for our national regulations on SAR. In addition, we drafted general requirements on severe accident analysis. Then, our next step was to develop SSTC capabilities in the domain of severe accident modelling. Our area of competence has been further extended thanks to co-operation with European TSOs, mainly GRS, and with the U.S. NRC. Nowadays, we have skilled experts and our own proven computer models.

Which models do you use to work?

We implement different codes depending on the analyses to be performed. For severe accident analysis, we use MELCOR, a model we adapted through specific developments to all types of WWER plants operating in Ukraine. For the in-depth review of containment conditions and hydrogen safety, we implement COCOSYS – a mechanistic model developed by GRS for analysing the physical-chemical processes in containments –, and more rarely CONTAIN. For comparative analyses of the in-vessel phase of severe accidents, we use ATHLED-CD and RELAP/SCDAP as an alternative. Last but not least, we use INTERRAS, MACCS, HotSpot, MICROSHIELD and PC COSYMA for assessing the radiological consequences of a severe accident and for supporting the regulator in the emergency response field.

Which future subjects do you advise to work on?

Firstly, I would mention the reinforcement of current regulations so as to include severe accident management provisions in the design basis of NPPs. Historically, regulations were focussed on providing assurance that events within the NPP design basis would not result in severe fuel damage or in substantial off-site releases of radioactive material. Additional emphasis should now be put on the mitigation of severe accident consequences. In particular, defence-in-depth level 4 – which deals with the control of severe conditions including the prevention of accident progression and the mitigation of the consequences of a severe accident – should be reinforced. In think the second direction is the specific consideration of multiple-unit sites with respect to multi-unit accidents, common-cause failures at multi-unit sites, effects from multiple units, etc. Another important direction pertains to severe accident analyses for spent-fuel pools as regards, in particular, the effects of accidents that may simultaneously occur in the reactor pool and in the core. Any specific phenomena should be carefully considered in this domain too. The fourth main direction for future work that comes to my mind is the enhancement of the computer models and severe accident analysis methodology based on data from the Fukushima Daiichi accident. In a broader sense, I think providing synergy between safety and security becomes one of the top-priority tasks. These two areas, which have usually been treated separately, need to be better correlated with a view to ensuring ultimately appropriate co-ordination of the safety and security provisions intended for the prevention of severe accidents, the mitigation of their consequences, and the management of emergency situations.

of release (dimensions of reactor building, sensible heat) and the meteorological conditions (wind direction, wind speed, stability class) were taken into account in these calculations.

M. Sogalla — The source term estimated by the methodology described by Peter is an integral value. The isotopic composition of release is not measured by this approach and can be assumed only on the basis of computational analyses. The results obtained drawing upon sampling, using post-accident sampling systems for instance, are surely useful, but these results are available much later as the data of dose rates from the on-line environmental monitoring system. Therefore, the pre-calculated characteristics of isotopic composition of release are used for a dose projection.

E. Raimond — I would like to address some lessons learned from the accident at the Fukushima Daiichi NPP, as this accident has shown the difficulties that arise when both the operator and the national emergency organisation are unable to provide quickly co-ordinated information on the plant conditions and on the risk of radioactive release. Especially during the beginning of the accident, information concerning the plant state seemed to be too sparse for a precise source term prediction. The most reliable indicator for releases consisted of local dose-rate measurements on the site and in its surroundings. But their interpretation was also difficult due to changing local meteorological conditions...

P. Líška — Let me emphasise that, even more than one year after the accident took place, most of the precise knowledge about the source term is predominantly based on backward calculations which estimate the source term by combining off-site measurements of radioactivity with meteorological information about the dispersal and deposition of radioactive material to the measurement sites. As you well know, such calculations are based on the so-called inverse modelling of the relevant meteorological processes and are therefore sensitive to the accuracy of meteorological data and models used.

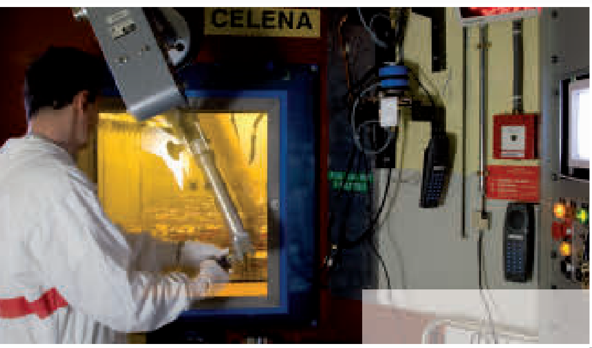
M. Sogalla — To go on with the lessons learned from Fukushima Daiichi, I think the accident has shown how difficult source term prediction can be when the relevant plant information is missing. Thus, the improvement of plant data availability is the most effective way to make source term predictions more reliable in the future. If, however, such information from the plant is unavailable or insufficient – as was the case not only in the Fukushima Daiichi NPP accident, but also in the Chernobyl and Three Mile Island NPP accidents –, the evaluation of the source term will have to rely on backward calculations from off-site measurements or on a combination of off-site and on-site data. Thus, I think the further development of appropriate methods and tools for such tasks and provisions for fast availability of relevant meteorological data will vitally contribute to improve source term evaluations in such a case.

E. Raimond — No doubt, Martin! But let me point out another important thing: the Fukushima Daiichi accident has also shown that the emergency response organisations in Europe can substantially benefit from sharing information and data concerning the source term. This collaboration is especially important when no information about the source term is available from the operator or the country where the accident occurs. The European TSOs have substantially contributed to improve source term evaluation by sharing their knowledge in the early stage of the accident. The enhancement of TSO networking in this field will substantially contribute to the improvement of source term evaluation on a European and international basis.

P. Líška — I totally share this view! And I am glad the NERIS Platform established a forum for dialogue between authorities, TSOs, operators, professional organisations, research institutes,

Learn more about...
GRS & IRSN: a large software library for safety studies

The development of computer codes is key for understanding, by means of simulation, the physical and chemical phenomena involved in nuclear reactor accidents. Therefore, leading TSOs develop and upgrade continuously software systems used internationally through a set of agreements. Developed jointly by GRS and IRSN, the Accident Source Term Evaluation Code (ASTEC) aims at modelling the phenomena conducive to a PWR reactor core meltdown accident up to the potential releases outside the containment. Validated through a series of experimental programmes such as Phébus FP and ISTP, ASTEC is recognised as the European reference software system for severe accident simulation and is used by the SARNET NoE as well as Canadian, Chinese, Indian, Russian, South-African and South-Korean organisations.



(Above) PHEBUS FP experiments aimed to study the phenomenology of severe accidents in PWRs and the behaviour of fission products in case of core meltdown.

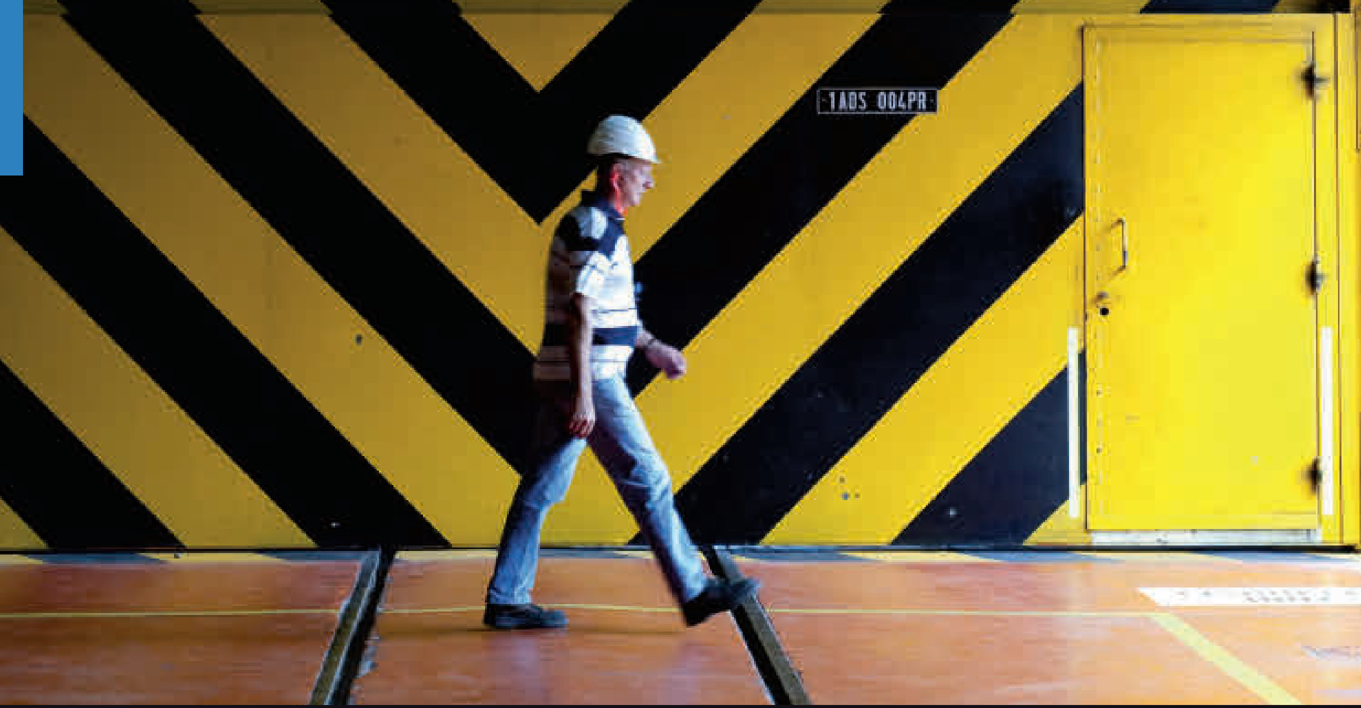
(Right) Facility devoted to fire and airbone contaminant dispersion experiments.

universities, non-governmental organisations (NGOs), consultants, national and local stakeholders at local, regional, national and European levels. The platform also supports,through partnership at each level, projects devoted to preparedness in the field of nuclear or radiological emergency response and recovery. It initiates and co-ordinates networking activities to share experience and to contribute to a better harmonisation in Europe. Moreover, the NERIS platform promotes the maintenance, development and adaptation of existing tools and methods for nuclear or radiological emergency response and recovery.

E. Raimond — Let me add a concluding remark, saying that, after the Fukushima Daiichi accident, the NERIS platform established close co-operation with Japanese TSOs and a wide range of stakeholders to share their experience at the NERIS workshops and research and development projects. ✖

Methods & Organisations

From the stress tests performed on the nuclear facilities after the Fukushima Daiichi accident, it became clear that appropriate methods and organisational patterns had to be developed by operators to better protect the core safety functions of nuclear reactors. Questions arose also pertaining to the effectiveness of emergency organisation and response in situations with severely damaged infrastructure…



Getting prepared for an emergency: an American perspective

US President Jimmy Carter on his visit at TMI shortly after the March 28th, 1979 accident.

The U.S. Nuclear Regulatory Commission (NRC) began its operations in January 1975, with a mission as an independent regulator with its sole focus on protection of public health and safety and the environment from commercial applications of nuclear technologies. Recognising from its inception the value of Emergency Preparedness (EP) actions to provide defence in depth and complement preventative and mitigative actions by the operator, the NRC draws upon the lessons learned from each severe accident to improve its response capabilities, as explained by Jane E. Marshall, Branch Chief, Coordination Branch, Division of Preparedness and Response, Office of Nuclear Security and Incident Response.

One primary change in response has been to increase the priority of the international, national, state, and local coordination.

WHAT IS THE NRC'S ROLE IN THE U.S. NUCLEAR EMERGENCY AND CRISIS MANAGEMENT ORGANISATION?

The National Response Framework presents the guiding principles that enable all response partners – communities, tribes, States, the Federal Government, and private-sector and nongovernmental partners – to prepare for and provide a unified national response to disasters and emergencies. As described in the Nuclear/Radiological Incident Annex to the National Response Framework, the NRC is the Coordinating Agency for radiological events occurring at NRC-licensed facilities and for radioactive materials either licensed by the NRC or under the NRC's Agreement States Programme. As Coordinating Agency, the NRC has technical leadership for the national government's response to the event.

WHAT KIND OF STEPS DOES THE NRC TAKE IN THE EVENT OF A NUCLEAR EMERGENCY SITUATION?

In response to an event that could threaten public health and safety or the environment, the NRC activates its incident response programme, providing expert consultation, support, and assistance to State and local public safety officials responding to the event. Once the programme is activated, teams of specialists are assembled at NRC's Headquarters Operations Centre and Regional Incident Response Centre to obtain and evaluate event information and to assess the potential impact of the event on public health and safety and the environment.

WHAT IS THE PRIMARY FOCUS OF THE NRC DURING RESPONSE?

It is to assess plant conditions, evaluate protective action recommendations, support off-site officials, coordinate with federal partners, and inform news media. While responding to an incident, the nuclear power plant operator – who is responsible for taking any mitigating actions to protect the public, and making recommendations to off-site decision makers for protective actions – is required to send specified plant parameter data such as temperatures, pressures, flow rates, and meteorological conditions that the NRC response teams use to ensure that the operator's actions are safe and deliberate.

WHAT CONCEPTS, METHODS, TOOLS OR EXERCISES DOES THE NRC RELY UPON TO ASSESS INDEPENDENTLY THE PROTECTIVE ACTIONS TAKEN BY THE NPP OPERATOR?

First of all, the NRC requires the performance of a full-scale exercise at least once every two years that includes the participation of government agencies. These exercises are performed in order to maintain the skills of the emergency responders and to identify and correct weaknesses. They are evaluated by the NRC inspectors and > **FEMA** < evaluators. The NRC and FEMA determine the two-year evaluated emergency preparedness exercise requirements for nuclear power plant operators and state and local governments. In this manner, both onsite and offsite emergency preparedness capabilities are adequately evaluated. In the event of an accidental radiological release from a nuclear power plant, the NRC uses RASCAL (Radiological Assessment System for Consequence AnaLysis) dose modelling software to perform its independent dose assessments.

FEMA
The Federal Emergency Management Agency (FEMA) has the primary federal responsibility with respect to offsite (State and local) emergency plans associated with the nuclear power plants. It works closely with the U.S. NRC to ensure a co-ordinated emergency planning and response.

HOW DID THE SEPTEMBER 11, 2001, ATTACKS IMPACT EMERGENCY PREPAREDNESS?

As the result of reviews conducted in the wake of these attacks, the NRC staff recognised that malevolent events differ from radiological events due to a deliberate planned hostile action to maximise damage and loss of life and that emergency preparedness response to such events may be challenging. The NRC issued Bulletin 2005-02, "Emergency Preparedness and Response Actions for Security-based Events," which recommended enhancements that power reactor licensees could make to their EP programmes and also sought information on how licensees had modified their programmes to address the current threat environment.

HOW WERE THE LESSONS LEARNED FROM FUKUSHIMA DAIICHI FACTORED INTO THE NRC'S POLICY/PRIORITIES IN MITIGATING SUCH ACCIDENTS?

The NRC's Incident Response programme has been working to improve its response capabilities after the Fukushima Daiichi incident. One primary change in response has been to increase the priority of the international, national, state, and local co-ordination. This includes dedicating more response resources to communicating with the international community and organisations, coordinating with other U.S. federal government agencies, and informing state and local governments and members of the public.

As part of the comprehensive complementary safety assessment (CSA) process launched in France in the wake of the Fukushima Daiichi accident, EDF submitted reports to ASN for each of its 19 nuclear sites, for a total 58 standardised PWR units (see box), in September 2011. Drawing upon the subsequent analysis, EDF was able to confirm the existence of adequate margins within the current safety basis and the anticipation of many of the lessons learned from Fukushima Daiichi as part of the safety reassessment process, especially those regarding flooding hazard, earthquakes and mitigation of severe accidents through filtered containment venting, hydrogen recombiners, etc. As a result, EDF put forward additional measures, taking into account potential severe situations beyond previous assumptions. Michel Debès, in charge of international relationships at EDF Engineering and Generation division, explains how these measures will further improve the safety level of EDF's NPPs.

EDF's nuclear reactor fleet

58 PWR reactors on 19 sites
Three standardised series:
900 MW (34 units), 1300 MW (20 units), 1500 MW (4 units).
Total power: 63 GWe.
2011 output: 421 TWh.
One new 1650-MW EPR plant under construction at Flamanville (to be commissioned in 2016).

CSAs of EDF's nuclear fleet and lessons learned

The periodic safety reassessment process is a major tool to reassess the capability of the plant design and the robustness of organisations to prevent severe accidents.

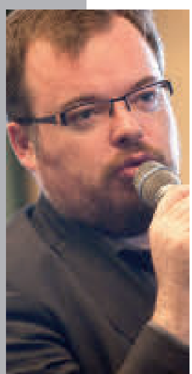
Taking into account extreme external hazards to strengthen defence in depth

The CSA process confirmed the current good safety level and adequate safety margins for all NPPs (*). Additional measures have nevertheless been put forward against external hazards, such as the reinforcement of NPPs' protection against extreme earthquake and flooding conditions; the protection of electrical switchyards against flooding; the strengthening of supports and anchorages; the enhancement of cooling water and power supply capabilities through the addition of water reserve (basin, underground table...), of back-up cooling water supply and one back-up diesel generator on each unit.

Concerning the mitigation of core melting risks with a view to avoiding long-term consequences, it includes the reinforcement of the ultimate containment venting filters' protection against earthquake to limit external releases. A 'hardened safety core' of equipment and materials has been defined for protection against extreme external hazards, with the aim to limit large-scale releases. Moreover, an additional 'resilient' line of defence is being implemented through a national 'Rapid Nuclear Action Force' (French acronym: FARN) prepared to interventions within 24h on any site that might be concerned, along with adequate logistics and strengthening of on-site crisis management capabilities. The objective is to maintain or restore reactor cooling, so as to avoid any significant release, with capabilities to re-inject water into the facility, to

Enhancing defence in depth with a hardened safety core

The progressive upgrades of nuclear facilities resulting from the periodic safety reviews and the operating experience feedback have allowed them to cope with strongly degraded situations significantly better than at the time they were commissioned. However, one of the lessons learned from the Fukushima Daiichi accident is that it is necessary to enhance the capacity of nuclear power plants to cope with rare and cataclysmic events. In order to assess the overall robustness of the plants against such events EDF has used methods whose simplicity does not allow, according to IRSN, considering at this stage the values of global margin factors put forward by the operator as reliably reflecting the robustness of facilities against hazards. In order to determine effective robustness, it is thus necessary to identify the weakest elements, which can be a very difficult task. Thus, in order to obtain the effectiveness of post-Fukushima measures, IRSN has proposed to further strengthen the defence-in-depth approach by protecting the structures, systems and components (SSCs) aimed at ensuring critical safety functions against hazards significantly higher than those considered as design basis for the facilities. These SSCs will make up a "hardened safety core" to ensure ultimate protection.



Frédéric Ménage
Deputy manager
Nuclear safety division – Safety assessment, IRSN

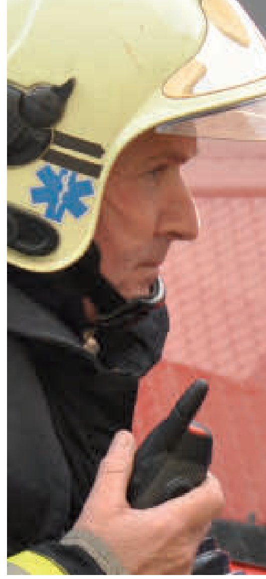
implement pumping or electric devices (using 'plug & play' connections), and to deploy large-scale equipment for protection, intervention and control. This emergency deployment is to remain in place a couple of days after recovery of autonomy, so as to manage the situation (water provision, effluent processing etc...) over time. An industrial modification program for the nuclear fleet has been submitted to the ASN in June 2012, to be examined for the end of 2012. Short-term modifications (FARN, temporary mobile equipment, etc.) are underway; longer-term actions will be consistent with long-term operation safety objectives and with the related modifications. Regarding the EPR advanced design being built at Flamanville – which features already an improved robustness with respect to severe accidents –, a 'hardened safety core' has been defined which mostly uses SSC as implemented in the initial EPR design. Some limited modifications have been introduced in order to increase self-autonomy, such as building leaktightness, water reservoirs, additional electrical or mechanical connections, flooding protections, mobile water supply means, fuel pool instrumentation...

An effective safety management throughout the NPPs' lifecycle

Beyond the construction of NPPs, a nuclear program requires the ability to efficiently manage, over the entire plant lifetime, normal, incidental and accidental situations, to maintain a comprehensive knowledge of design issues and to carry out comprehensive periodic safety reassessments, which together enable long-term operation of NPPs. The Fukushima Daiichi accident has confirmed how important it is, for an operator, to be capable of mastering both operation and design issues over a plant's lifetime.

The second challenge is the enhancement of safety features with the aim to reduce potential radioactive releases to the environment, also in the long term. For existing NPPs, which are built to operate several decades, the periodic safety reassessment process is a major tool to reassess the capability of the design and the robustness of organisations to prevent severe accidents, and should one nevertheless occur, to mitigate its consequences. The goal is to guarantee the absence of long-term contamination of large territories, while taking into account experience feedback and the knowledge gained, as regards notably extreme natural events.

(*) **Learn more:**
the corresponding 7,000 pages are posted on ASN's website: www.asn.fr



The management of nuclear & radiological emergency situations is carried out with different organisation patterns from one country to another. Hans De Neef, from the General Directorate Crisis Centre of the Federal Ministry of Internal affairs, Christian Vandecasteele, Co-ordinator Nuclear Emergency Planning at the Federal Agency for Nuclear Control and Didier Degueldre, Branch Manager Fire Protection, Accidents & Emergencies at Bel V explain how the Belgian organisation involves all safety experts in a comprehensive emergency response organisation.

Emergency response *made in Belgium*

The organisation set up in Belgium for the management of emergency situations at federal level is described in the Royal Decree of 31/01/2003. "*In such cases,* explains Hans De Neef, *the Governmental Crisis & Coordination Centre (GCCC) activates three emergency management groups to facilitate and organise the national emergency coordination: the Federal Coordination Committee in charge of the strategic coordination and the decision-making processes, the Evaluation Cell in charge of assessing the emergency situation and advising the Federal Coordination Committee, and the Information Cell in charge of the information of the public about the situation and the decisions made. If suitable, the Federal Coordination Committee could also*

Exercise with local fire brigade (Beveren, Belgium).

decide to activate the Socio-economic Cell to assess the social and economical consequences of the emergency situation." The emergency management set up in case of nuclear or radiological emergencies relies fully on the emergency arrangements explained above. "*But due to their impact on the public, they are managed at national level, based on a particular emergency response plan,*" Christian Vandecasteele stresses.

The specificity of the nuclear/radiological emergency response plan

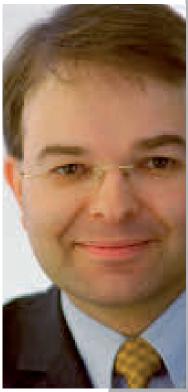
Aimed at co-ordinating the actions towards protection of the population and the environment for the Belgian territory in the event of a nuclear accident or any other radiological emergency situation that could lead to an overexposure of the population or to a significant contamination of the environment, this plan published in 2003 as a Royal Decree establishes the tasks that the various departments and organisations would have to accomplish if the case arises, each within their legal and regulatory competences. Hans De Neef recalls that "*in the case of a nuclear or radiological emergency situation, the Federal Coordination Committee directs the off-site operations, under the authority of the Minister of Internal Affairs*" and that "*the implementation of the actions decided at federal level and the management of the intervention teams are under the leadership of the Governor(s) of the province(s) concerned, with the help of the Mayors concerned.*"

Evaluate the potential consequences and gather field radiological information

The *Evaluation Cell* is composed of experts from different organisations such as the Federal Agency for Nuclear Control (FANC), Bel V, the

Empirical research on crises: the three major lessons learned from Fukushima Daiichi

The first lesson is that three isolated events – an earthquake, a tsunami and a nuclear accident – can concatenate into a multiple disaster. Such 'domino-effect' scenarios have been neglected so far, since analyses were often limited to single events for capacity reasons. Even in Japan, only the supposedly greatest single risk, i.e. earthquake, was considered in the planning, but not the correlated risk of a "tsunami". Otherwise, the emergency generators would probably have been configured differently. The second lesson is that extreme events with a very low probability of occurrence – e.g. once in 100,000 years of operation – were usually disregarded as a 'residual risk' by crisis research scientists. Conversely, risks with a much lower probability of occurrence were paid far greater attention, because they were supposed to occur earlier. If the focus is increasingly placed, in the future, on the possible extent of damage, the comparably low probability of occurrence will lose importance, even in the case of nuclear plants. I think the third lesson learned from Fukushima Daiichi is that crisis analyses are limited mostly to the breakdown of the system itself – e.g. a nuclear power plant – with the subsequent failure of the redundant emergency systems being disregarded. For instance, at Fukushima Daiichi, the measuring equipment was not operational because of a failure of the emergency power supply, while the fire fighters' vehicles were swept away by the tsunami. Slightly exaggerating, I would say future crisis and contingency plans should be focussed first and foremost on the breakdown of emergency systems themselves.



Frank Roselieb
Managing Director of the Krisennavigator (Crisis Navigator)
Institute for Crisis Research
(a spin-off of the University of Kiel)

In Belgium, nuclear or radiological emergencies are managed at national level, due to their major impact on the public.

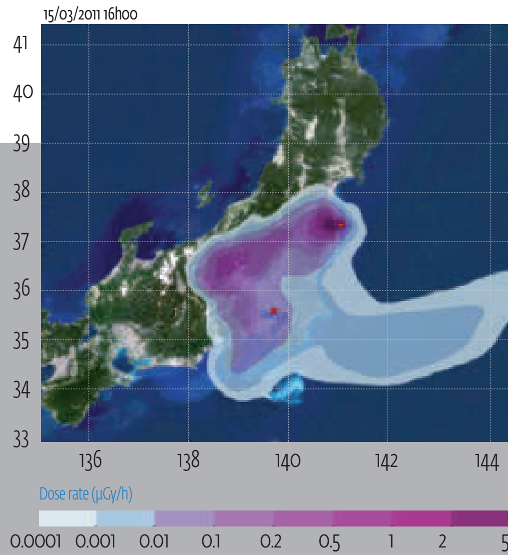
National Meteorological Institute, the technical and radiological support bodies. Didier Degueldre explains their role: "*They are tasked with assessing all information received from the affected installation and other sources of information. They evaluate the installation status and its estimated time evolution in order to assess the real or potential consequences of the situation with a view to issuing advice on protective measures for the population and the environment.*" The protective measures strongly depend on the time elapsed since the event's occurrence and encompass sheltering, evacuation, stable iodine intake, access control, food ban, relocation, environment decontamination, water and food controls as well as medical care.

The *Evaluation Cell* is supported by a *Measurement Cell* in charge of gathering field radiological information: monitoring of external radiation of the air and of the deposits, sample measurements, etc. "*In the current organisation, the* Evaluation Cell *gathers all the necessary capabilities and expertise to perform a global assessment of the situation independently from the operator of the affected nuclear installation or plant,*" Christian Vandecasteele points out. With this purpose, the cell includes members from various and complementary bodies, thus covering a wide spectrum of knowledge and skills pertaining to the nuclear installations, the radiological impact of radioactive releases (including atmospheric dispersion modelling), radioecology, etc. The described organisation gives the *emergency management groups independent assessment and response capabilities*. However, in the context of an emergency, the presence of a representative of the affected licensee acting as a liaison officer with the on-site emergency response organisation allows speeding up, improving and facilitating the technical and radiological assessments needed to issue advice on protective actions for the population and the environment.

Bel V, an integrator in the Belgian organisation

Commenting on the particular role of Bel V, Didier Degueldre emphasises: "*As the TSO of the Belgian nuclear safety authority, its role fits perfectly with the integrated technical and radiological assessment approach, as it sends two representatives to the* Evaluation Cell *of the GCCC. One participates in the technical assessment of the affected installation or plant, in close co-operation with the licensee and other technical experts, the other in the assessment of the real or potential radiological consequences, in close co-operation with other radiological experts*". ✖

Giving a basis for appropriate decision-making



The management of emergency situations is first and foremost a race against time and uncertainty. Hence, any method aimed at providing the authorities in charge with precise forecasts on the development of an accidental situation inside an NPP and on its radiological consequences for the environment plays a crucial role as a support to making strategic choices in the area of the protection of the population, as explains Olivier Isnard, an expert in modelling the source term and the movements of contaminated air masses at IRSN.

We implement a method called the 'mark tracer'.

What are the needs for evaluating the radiological consequences of a nuclear accident?

There are three basic needs: firstly a model or a source of measure of the radioactive release to the atmosphere; secondly, a model or measure of the meteorological conditions where radionuclides will travel through the atmosphere. Thirdly, the topographical data of the territory concerned : are there any mountains, rivers, or the sea, which will affect mainly the flow and the way the radionuclides will be deposited on the ground. These three main inputs allow building a model of the atmospheric transfers. Let me point out that models of the transfer have to be made at different scales very quickly for different reasons: firstly, because the atmospheric transfer of radioactivity is a fast process – contamination can spread over an entire hemisphere within days –, and secondly because crisis management requires strategies to be developed both locally, to protect the population living near the affected nuclear plant, and globally, to predict which countries may be impacted and when.

Once the atmospheric dispersion has been modelled, how can the radiological consequences of the releases are assessed?

At IRSN's emergency centre, we have a first technical team in charge of analysing the damaged facility and a second one tasked with the evaluation of the radiological con-

Radioactivity measurement on samples as part of a crisis exercise.

sequences on man and the environment, with a view to helping the government services take appropriate protection measures for the population. We have developed a method called **> 3D3P <**, which means 'triple diagnosis, triple prognosis', aimed at assessing the reactor state, forecasting the situation and evaluating the source term, the latter becoming an input for the technical team in charge of the radiological consequences of the accident.

Has the 3D3P method already been implemented in an emergency situation?

We used this method to monitor the situation of the three damaged reactors at Fukushima Daiichi for instance. To evaluate the source term on BWRs – a technology that is not implemented in the French reactor fleet –, we made some hypotheses to adapt the methodology and to simplify the problem, so as to reduce the time span necessary for calculations. First of all, we decided to represent the three units in one single unit and we assumed a 45%-core meltdown for this unit. Then we assumed a continuous leakage of this containment at a certain flow rate, taking into account a retention factor from the aerosols coming up from the suppression pool. At this stage, it is very important to have the right correlation of releases in time with the right meteorology to evaluate the source term during the response. We implement a method developed specifically for this aim, which we call the 'mark tracer'.

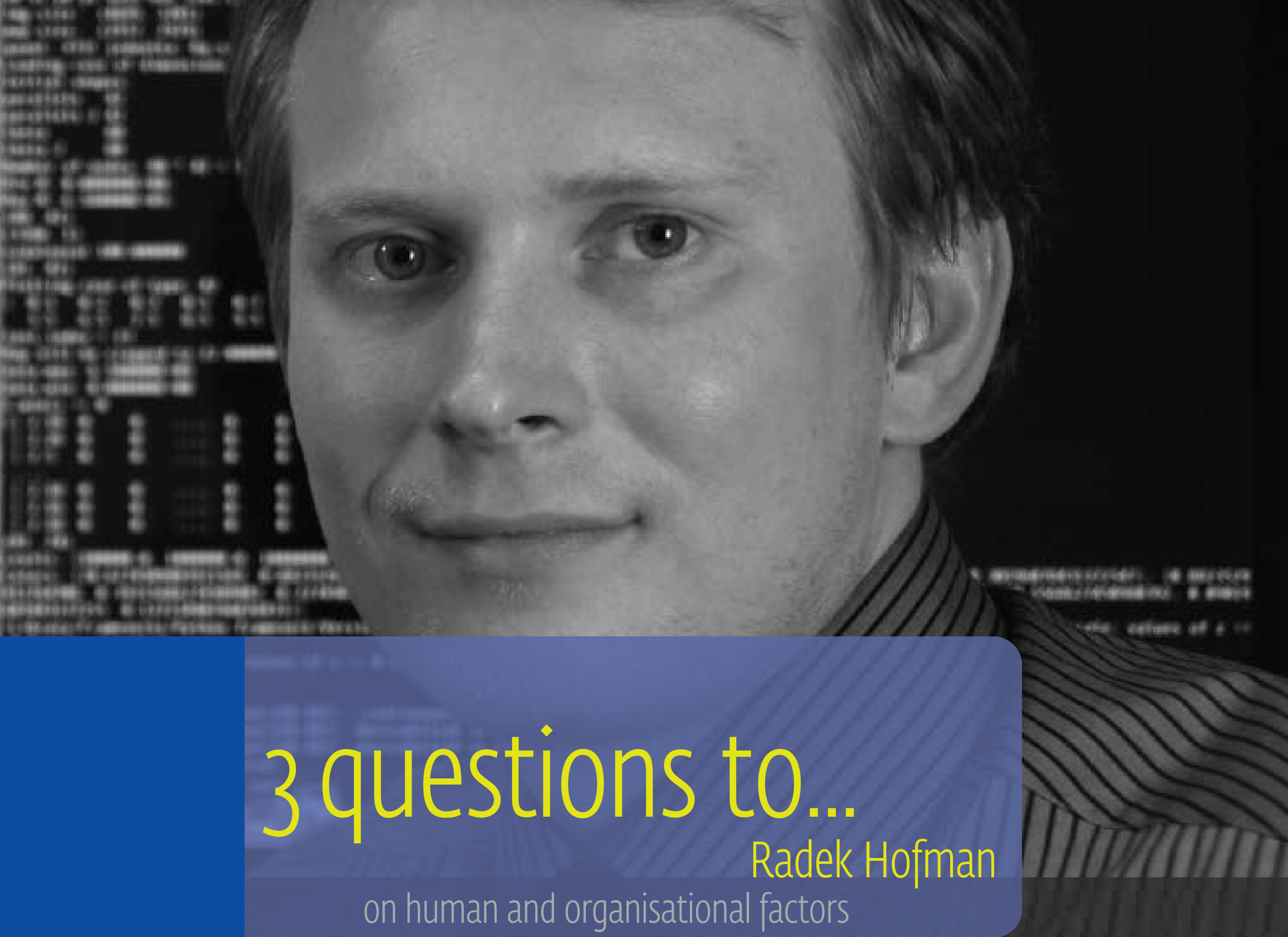
How does the 'mark tracer' method operate?

It consists in taking a radionuclide – for example caesium – as a tracer to construct an hourly release from the damaged reactors using the dispersion model and comparing data modelled and measured in particular locations of the territory. To model contamination dispersion in an appropriate manner, up-to-date meteorological data are absolutely needed. This is why IRSN signed a partnership with Météo-France, the French national meteorological service, who provides IRSN every six hours with operational forecasts at the scale of France, Europe and the World. The IRSN emergency centre used Météo-France's *Arpège* outputs to generate dispersion evaluations with a 0.5-degree resolution – i.e. a square of 50 km side length – worldwide and another model named *Arome*, to generate evaluations with a 2.5 km resolution locally. This very narrow grid allows the precise modelling of the releases, which is then compared with the dose rates measured around the nuclear plant and in the environment.

3D3P
In this working method, '3' stands for the three barriers that separate the radioactive material, which constitutes the fuel, from the environment, a diagnosis of each barrier being performed every 60 to 90 minutes. Based on this triple diagnosis, a prognosis is performed for each of the three barriers to derive a scenario for the future.

What progress is expected in the forthcoming years?

A major advance will be the possibility to encapsulate highly complex physical models in computer simulations. Another source of progress is the current replacement of our environmental monitoring stations with state-of-the-art technology and an increased number of stations to better cover the French territory. Last but not least, we'll be able to reconstitute precisely the source term – and thereby the accidental sequence – in a damaged plant using the measurements performed in the plant's environment, with a view to confirming whether or not a given computer model is valid. ✖



3 questions to...

Radek Hofman

on human and organisational factors

A postdoc at the Institute of Information Theory and Automation of the Czech Academy of Sciences, Radek Hofman specialises in mathematical modelling of environmental processes, Bayesian filtering and software development for decision support. He received the Czech Nuclear Society's award for his doctoral thesis titled *Application of Advanced Data Assimilation Methods in Off-site Consequence Assessment*.

What is the basic principle of data assimilation methods?

Also known as 'statistical inference', data assimilation (DA) refers to a group of methods used to estimate the state of a dynamic system by combining multiple information sources. Typically, the numerical model of a system under investigation thus is corrected with observational data. In case of an accident with off-site consequences, DA can be applied to estimate the true scale of the accident with a view to improving the reliability of decision-making and countermeasure planning. One of the most challenging tasks is the prediction of the spatial and temporal distribution of radionuclides during the early phase of an accident where they propagate in the form of a radioactive plume. This can be simulated using an atmospheric dispersion model. However, partial ignorance of meteorological conditions and source term together with inherent model errors due to the wrong conceptualisation of atmospheric phenomena hinder us from obtaining accurate results. In such circumstances, DA allows us correcting the model using sparse measurements from a stationary radiation-monitoring network (RMN) and mobile groups. This problem has been already addressed using different methods based on point-wise estimates and filters for parameterised densities, and we attempt to solve it using sequential Monte Carlo. The resulting method, based on simultaneous propagation of multiple dispersion models, can answer the questions asked by decision makers – e.g. "What is the probability of exceeding a given threshold of deposition in a particular location?" *– in a more informative probabilistic manner. The associated disadvantage, a high computational complexity, is becoming a minor issue with the development of increasingly powerful computers.*

Was DA implemented to the Fukushima Daiichi situation?

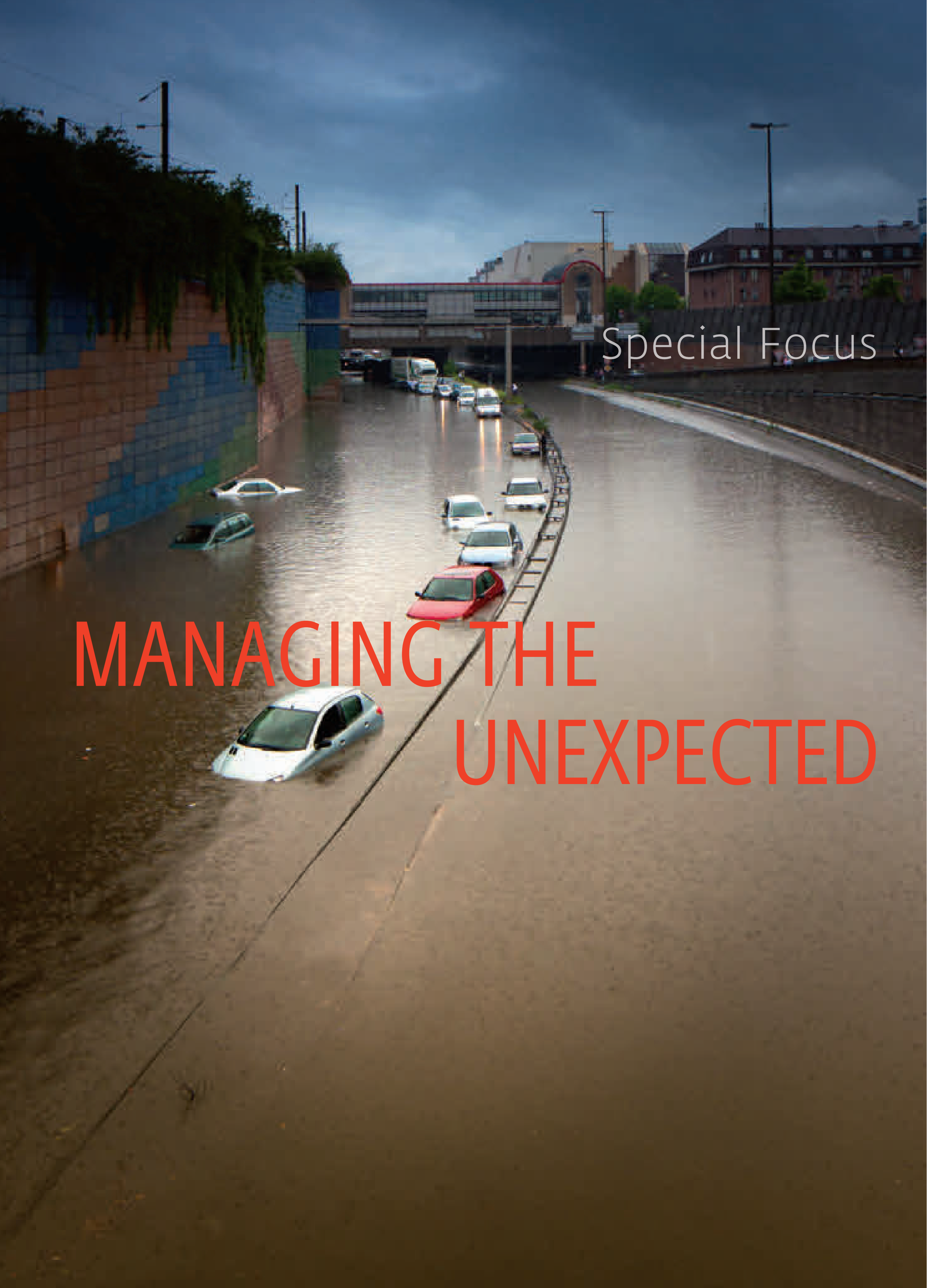
DA has been already applied to the retrospective analysis of the Chernobyl disaster and some other accidents and tracer experiments. In the case of Fukushima Daiichi, a wide array of radiological measurements is accessible on the web site of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). These data, together with available meteorological data, were already used in several studies focused on the estimation of the source term.

Can data assimilation be applied to any kind of accidental situation?

DA can be applied whenever it is beneficial or necessary to combine data from different sources. The generic character of the methods allows their modification for non-radioactive pollutants and accidents, e.g. releases of chlorine from industrial facilities or spreading of a toxic agent in urban areas. Moreover, we do not have to restrict just to the data collected from a RMN or mobile groups. Currently, we are developing an algorithm for the navigation of unmanned aerial vehicles – called 'drones' – equipped with measuring devices as an alternative source of observations. As the drones can be deployed on demand and autonomously navigated in order to maximise information gain, their application seems to be a promising way how to obtain data from areas not covered by a stationary RMN.

Special Focus

MANAGING THE UNEXPECTED



A car accident with trapped casualties, a head-on train collision, a fire on the 7th floor of a high-rise building, forgotten house keys, an explosion and fire at a chemical plant, a fire on board a classic yacht, an evacuation of over 10,000 civilians from a flooded area, people stuck in elevators, the search and rescue for the survivors and the victims under the debris after an earthquake. These are only some examples out of the infinite variety of incidents fire fighters may encounter in their daily work ■ ■ ■

■ ■ ■ Taken one-by-one, those incidents cannot be trained for specifically, since all possible scenarios cannot be figured out, nor can all specific procedures be laid out. The real world presents us with scenarios on a daily basis that are more improbable than the weirdest scenarios one could mastermind. So, how to get prepared? By taking up the four challenges of fire fighters.

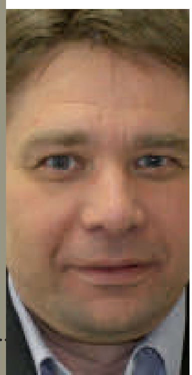
THE FOUR CHALLENGES OF THE DUTCH FIRE SERVICES

Never take anything for granted

For Marjan J.G.W. Heijman, Programme Manager specialising in crisis and disaster management at the Dutch Fire Service and Disaster Control, safety management starts with engineering rules aimed at minimising the risk of accidents and pulling up lines of defence against potential incidents: "*For the fire services, the next steps are to conceptualise the remaining risks, to develop worst-case scenarios and to remain aware that there will always be scenarios one could not imagine or predict in advance. To question every assumption is the main issue here and this is our first challenge. We cannot afford to take anything for granted.*" Contingency plans often rely heavily on the availability of communication channels under all circumstances, whereas practical experience shows that, in a major incident, communication channels become quickly overloaded or even do not work at all. During the Fukushima Daiichi disaster for instance, radio and television communications went down.

More troublesome are reassurances delivered by industrial facilities. When it comes to tackling the different aspects of the safety conundrum, owners and managers are sometimes prone to

The advantage of the cold crucible technology *for the experimental study of physical properties of molten corium for modelling severe accidents: The induction melting of materials in cold crucible (IMCC) is a method that combines induction heating and skull melting. The IMCC technology compounds two main advantages which allow achieving a purity level of the molten material equal to – or in excess of – the purity of the initial components, and obtaining overheating temperature in the range of 1,000°C and above. Therefore, the IMCC technology is well adapted to the investigation of the fundamental properties of high-temperature melts, as it provides useful knowledge to draw e.g. phase diagrams that allow, among others, considering the functional purpose, the development strategy and the characteristics of a new type of materials, i.e. the sacrificial materials used in corium localisation devices for the modelling of severe accidents in new-generation NPPs. There are only a few laboratories across the world where such investigations can be carried out. One of them is now being set up at the Research Centre Řež, in the Czech Republic, in the framework of the Sustainable Energy (SUSEN) project, financed by the European Regional Development Fund.*



Igor Poznyak
Head of the Laboratory
Nuclear Fuel Cycle department
Research Centre Řež plc

Question every assumption; keep it simple; learn from each other; take civilians seriously.

underestimating risk and ignoring the 'impossible'. Questioning their reassurances may seem like questioning their integrity but is nonetheless necessary.

Complex solutions means new problems

Because of the wide variety of incidents – and the yet unknown ones –, the fire services use the 'all hazards method' and prepare for contingencies in a generic way. This provides a firm base during operations, since only a small number of objects and scenarios require specific preparedness. "*It is fundamental to connect every scenarios to daily routines and frugal formulas,*" Mrs. Heijman stresses, adding: "*Complexity and deviations from daily routine are our enemies. Simplicity allows specific routines being easily adopted and executable under pressure.*" The fire services' second challenge for routines as well as for organisational structures thus is *keep it simple*. The lesson learned from operations and major exercises is that every bit of additional complexity multiplies the problems that are already there.

Open-mindedness and a sense for organising

It is impossible to train people for each specific contingency plan; training therefore must be more generic, i.e. focussed on the main processes instead of on all possible scenarios. "*Therefore we need to identify these processes,*" Mrs. Heijman explains "*and set up generic plans whenever possible. To this end, the use of computerised simulation technology can be a valuable addition to hands-on physical training. In regional and national databanks we have a large variety of training modules for our local trainers to use and build upon.*" Unfortunately, the effective use of these readily available modules is some-

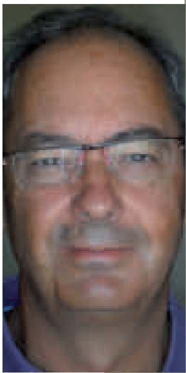
Training must be focussed on the main processes instead of on all possible scenarios.

Simplicity allows specific routines being easily adopted and executable under pressure.

times limited due to the ever-lurking 'not invented here' syndrome within the fire services. This takes us to *learning and learning from each other* being the fire services' third challenge. Learning from each other assumes both open-mindedness as well as a sense for organising. Fire fighters are used to public exposure, as they invariably operate in the street's arena, under the lamplights of the ever-present traditional and social media. Under such circumstances, discussing good tactics as well as failures is no easy thing, all the more where liability can be at stake. The management of every incident is evaluated within the team on daily routine, while meaningful incidents are assessed by the fire service itself as well as by one or more of the Dutch independent bodies dedicated to safety, reporting overtly to the authorities. Ultimately, the Dutch Fire Service and Disaster Control (NVBR) assesses the actions taken by a 'learning arena', as was done for instance after the large chemical plant fire at Moerdijk in 2011.

Risk communication, a meaningful way to raise the population's awareness

As serious incidents or disasters can be managed neither by one department nor by professionals alone, co-operation between services and with civilians is necessary. Victims and passers-by are the first ones on the spot of the calamity and the first ones to act. In the Fukushima Daiichi accident, civilians came into action long before the government did. After the rescue teams' arrival, civilian support was crucial to perform and continue the operations. Therefore, the fire services' fourth challenge is to *take civilians seriously* during the preparations as well as in the execution of the operations, as Marjan J.G.W. Heijman explains: "*This calls for more openness in crisis communication. In practice, authorities and executives are reluctant to give full disclosure as a measure to prevent widespread panic or other troubles. In our experience, civilians seldom panic but easily get suspicious when information seems to be manipulated or obfuscated, as evidenced by the Fukushima Daiichi disaster and other major*



"When a severe accident occurs in a nuclear power plant, highly complex mitigation has to be performed inside and outside the plant in a race against time that requires high-level preparedness. Limiting the consequences of the accident is primarily the operator's responsibility, however TSOs are directly involved, notably to perform real-time technical assessment of the situation as a support to decision-making by public authorities. I think independent assessment requires firstly top-notch expertise to analyse quickly and accurately data that are collected in harsh conditions. Such a level of expertise cannot be achieved without intensive training and practice. The second condition for independent assessment is the availability of advanced technical resources such as computer models to help experts provide especially accurate diagnoses and prognoses, a particularly difficult task due to the complexity of accidental scenarios and the extent of the associated uncertainties."

Ramón de la Vega
Head of Emergency and Security, Spanish Nuclear Safety Council (CSN)

Co-operation between services and civilians is necessary to manage serious accidents.

incidents." New media such as social networks just magnify this effect. To foster emergency preparedness among the population, it is sound to communicate about what kind of scenarios can occur, how to prepare oneself and what can be done in case of an emergency. This openness is to be continued whenever a major incident or disaster actually takes place, as properly informed civilians will act primarily to the benefit of themselves and others.

A national knowledge centre for emergency services to ask

The fire services in the Netherlands can only grow in maturity from taking up these challenges. Co-operation between the so-called 'Safety Regions' and with the national authorities contributes to this growth. In the nuclear domain, the Safety Regions formed an alliance to found a National Centre on Nuclear Emergencies with a view to refining their knowledge and skills, and to establish a national knowledge centre called *Centrum Kernongevallenbestrijding Veiligheidsregio's* (CKV) emergency services can turn to with their queries about nuclear scenarios and incidents.

The reference levels established through on-going radiological monitoring of the environment around nuclear facilities provide a useful basis to allow comparisons in case of radiological emergencies.

COMING NEXT...

The enhancement of robustness in nuclear safety

This issue will provide different insights into how nuclear facilities can be made more resistant against internal and external loads – in particular extreme or combined natural loads –, based notably on the outcome of the European stress tests, in relationship with the prospect of long-term operation advocated by many utilities. More on: www.eurosafe-forum.org

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The Eurosafe Tribune

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Towards Convergence of
Technical Nuclear Safety Practices in Europe