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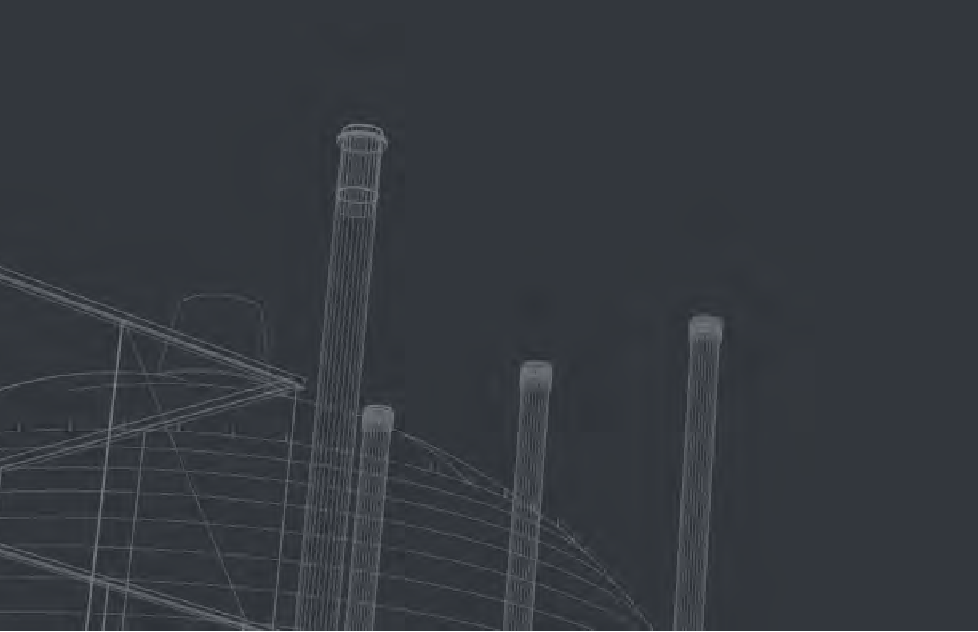
Analysis Fukushima 11032011

In-depth Analysis of the Accident at Fukushima on 11 March 2011

With Special Consideration of Human and Organisational Factors



Fukushima

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1 Introduction and procedure

Following the accident at Fukushima Dai-ichi on 11 March 2011, ENSI initiated an in-depth analysis of the accident which aims to achieve the following objectives:

- In-depth understanding of the sequence of events and the contributory factors
- Derivation of short-, medium- and long-term requirements and/or measures for the licence holders
- Consideration of ENSI's own supervisory work and, as appropriate, derivation of measures
- Verification of the results from reviews by the operators, as per Article 2, paragraph 1, letter c and paragraph 2 of the DETEC Ordinance on the Methodology and Boundary Conditions for Reviewing the Criteria for the Provisional Shut-Down of Nuclear Power Plants dated 16 April 2008 (SR [Systematic Collection of Federal Law] 732.114.5), which stipulates that in case of events at other nuclear power plants classified as INES-2 or higher, the holders of an operating licence (licence holders) must review the design of their own nuclear power plants forthwith and must immediately notify the regulatory body of the results of such review.

In order to do justice to the scope and complexity of this event, a dedicated interdisciplinary analysis team was formed within ENSI. This team comprises experts in the fields of social and organisational sciences, radiation protection, electrical engineering, mechanical/plant engineering, materials technology and systems engineering. As necessary, other sources of expertise were called in to assist, both within and outside ENSI.

It is an undisputed fact that the technically inadequate design of the nuclear plants at Fukushima Dai-ichi, in respect of protection against the tsunami that occurred as a consequence of the earthquake, represents a key factor in the origin and development of the accident. However, only an integral analysis of the accident will be able to clarify how these blatant design defects came about, and why the accident developed as it did. For this purpose, the human and organisational aspects must be taken into account alongside the technical factors. What appeared at first glance to be a technical plant failure triggered by natural events very soon proved to be a complex event in which human and organisational aspects play crucially important parts.

ENSI has given particular consideration to this point in its analysis and, from the outset, has accorded the same status to the human and organisational aspects as to the technical aspects.

The main difficulty with collecting facts in the human and organisational area, including radiation protection, was posed by confirming and verifying the dependability of the available information. ENSI had no direct access to information. For this reason, its analysis is based on generally accessible sources, including in particular information from authorities, operators, expert organisations and (to a considerable extent) media reports.

International analyses to date have provided few detailed statements regarding the aspects of people and organisation. The official reports on the accident (which are still awaited) will play a further part in answering questions that remain open regarding people and organisation, in verifying information that has not yet been adequately confirmed, and/or in testing hypotheses. For the reasons just stated, and on account of the high degree of complexity, ENSI‘s analytical process cannot yet be regarded as complete. This also applies, in particular, to the radiological effects of the accidents.

ENSI‘s analysis takes account of the dramatic circumstances during and after the accident, under which individuals in Japan had to deal with the situation on site in conditions of unimaginable distress. The purpose of ENSI‘s findings and conclusions is not to level criticism at the Japanese players and to distance ourselves from the events; ENSI‘s aim is rather to use the accident as an opportunity to undertake a critical analysis of the situation in Switzerland. Although this report focuses on identifying (presumed) weak points and deficiencies which contributed to the accident and/or which impeded the measures taken to deal with it, it is explicitly not our intention to imply that TEPCO and the Japanese authorities did not do everything in their power to bring the accident under control and/or to mitigate its consequences. It will also be possible to learn lessons from things which „went well“, i.e. factors that helped to prevent the progression and effects of the accident from becoming even worse (e.g. the vast and tireless efforts of the staff in the plant during the days, weeks and months after the inception of the accident). Nevertheless, the current status of information, together with the need to derive the most urgent measures for nuclear plants in Switzerland and all over the world as quickly as possible, have so far prevented (international) analyses from focusing on this important area.

Given the scale and duration of the accident and the number of individuals involved, it must also be acknowledged that only a small number of people were killed or injured, and that the number of individuals exposed to inadmissible doses of radiation has been relatively low. Nevertheless, ENSI takes each and every one of these cases seriously, and we regard it as our duty to learn the necessary lessons from each case.

The procedure for the in-depth analysis is structured in the form of elements that build on one another (see Figure 1). This procedure started with the collection of facts regarding the sequence of events (i.e. a reconstruction of what happened after the earthquake and the tsunami), and also regarding the background and previous history. Insofar as possible, the sequence of the accident was reconstructed on the basis of the available information [1]. Even the official organisations of the Japanese government and/or authorities and the operator, TEPCO (Tokyo Electric Power Company), are (still) not aware of all the relevant data and facts due to the lack of operating data and the very limited ability to inspect the plants up to now; this means that a complete and definitive reconstruction of the accident sequence is not possible as yet. Consequently, many questions arose while the facts were being collected – especially regarding the human and organisational aspects – to which it has (thus far) been impossible to provide answers.

For the purposes of the in-depth analysis, the presumed contributory factors were then collated. This entailed answering two questions: why did the accident occur? And why did it proceed in such a manner? To achieve this, three further questions were formulated in relation to specific key events during the progression of the accident at Fukushima Dai-ichi:

1. **Origin and development of the accident:** Why did a Station Blackout (SBO)[1] occur on 11 March 2011 after the earthquake and the tsunami?

2. **Management of the accident:** Why did damage occur to the fuel assemblies and and why did all the safety barriers fail, with the subsequent release of massive amounts of radioactivity into the environment?

3. **Consequences of the accident:** Why were the plant staff and the public exposed, and why was the environment contaminated?

[1] Description of a „Station Blackout“: Failure of alternating current supplies, with the sub-categories of loss of standard emergency electrical power supplies and total loss of all alternating current supplies (dependent on the basic design of the respective plants and specific back-fitted equipment as applicable). In the case of units 1 to 4 at Fukushima Dai-ichi, this involved a total loss of alternating current supplies.

For each of these three questions, hypotheses were formulated for the presumed contributory factors relating to the areas of organisation, people and technology. Insofar as possible, each of these hypotheses was expressed in specific terms and was substantiated with the help of information from various sources which were as dependable as possible. In the course of this analysis, it was possible to identify numerous relationships and interactions between the factors of influence relating to people, technology and organisation.

On the basis of the presumed contributory factors, it is planned to deduce findings from the accident in the form of „lessons learned". A comparison with the current situation in Switzerland will show how these findings can be applied to Switzerland and which measures can be derived from them, where appropriate.

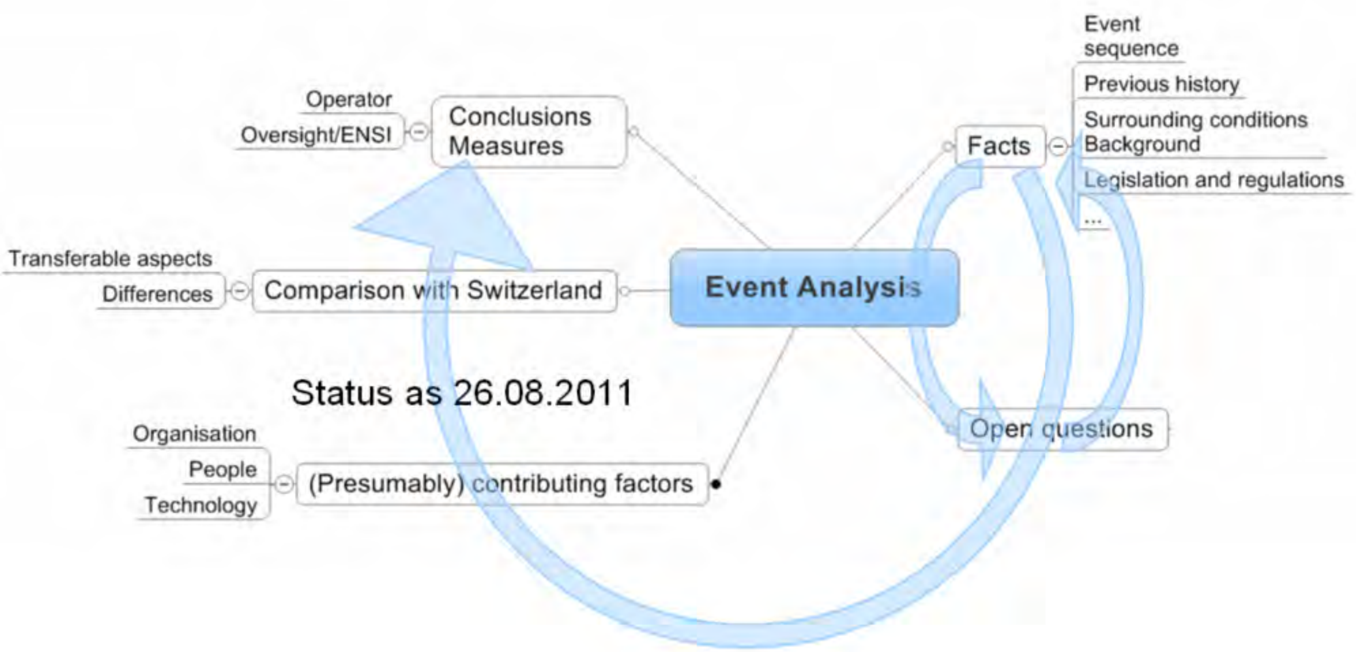

Figure 1: Overview of elements in the analysis by ENSI

2 Background information

2.1 Nuclear supervision and energy policy in Japan

The structure of the Japanese nuclear sector is very complex. A large number of different players – whose tasks, responsibilities and relationships to one another are difficult to grasp – have active roles in the supervision and development of nuclear energy (cf. Figure 2).

Supervision of the safety of nuclear plants was reorganised in 2001 in connection with a reform of the ministries, partly with a view to creating more independence between the entities responsible for supervision and those responsible for energy policy.

Within the administrative system, the following bodies are basically responsible for the development and supervision of nuclear energy:

- Two commissions: the Atomic Energy Commission (AEC) and the Nuclear Safety Commission (NSC), both within the Prime Minister's Cabinet Office.
- Bodies within the Ministry of Economy, Trade & Industry (METI) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT).
- The ministries are supported and/or advised by a series of Advisory Committees and Subcommittees.

Within METI, two different bodies deal with questions related to nuclear energy:

- The Agency for Natural Resources and Energy (ANRE), which is responsible for the development of nuclear energy.
- The Nuclear and Industrial Safety Agency (NISA), with responsibilities which include supervision of commercial nuclear reactors. NISA is supervised and audited by the NSC. It is supported by the Japan Nuclear Energy Safety Organization (JNES).

In the nuclear sector, MEXT includes:

- An organisational unit dealing with the advancement of nuclear technology (research and development).
- A unit which is responsible for the supervision of safety (Science and Technology Policy Bureau, STPB). The STPB's responsibilities include the supervision of research and test reactors.

Following the accident at Fukushima, particular criticism was levelled by the media and official bodies at the regulatory body's lack of independence, and at the personnel overlaps within the nuclear sector between government organisations and the nuclear industry, which lead to conflicts of interest as regards supervision and energy policy. The structure of the organisations involved in supervision, with their interlaced areas of competence and responsibility, was already criticised in 2007 in connection with a review of the authorities' activities carried out by an international team of experts headed by the IAEA (known as an IRRS Mission (IRRS = International Regulatory Review Service)) [8].

Following the accident at Fukushima Daiichi, the Japanese government is planning to remove nuclear supervision from METI and, as a new feature, to concentrate the relevant activities under the direction of the Ministry of the Environment [24].

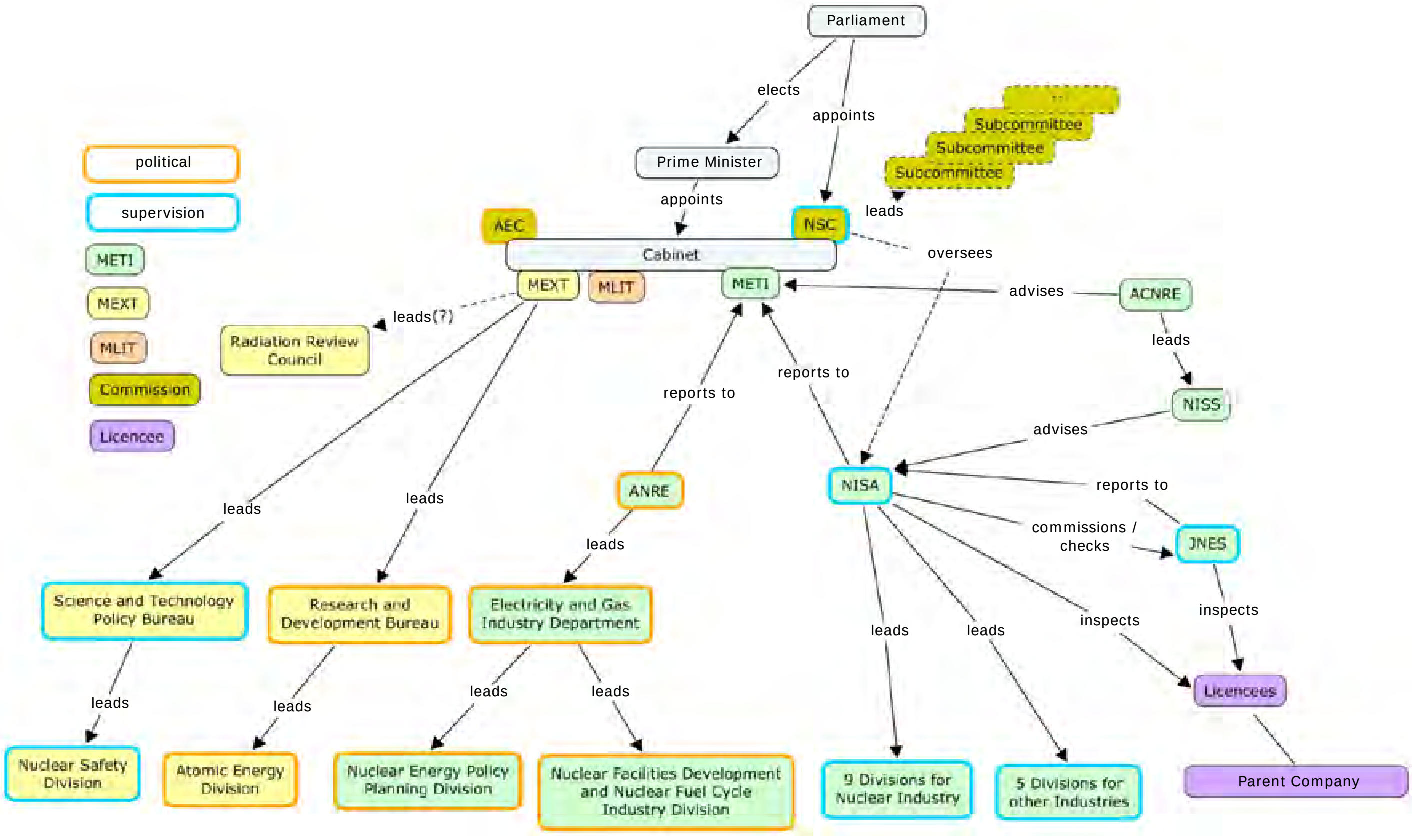

Figure 2: Network of relationships between the government players in Japan's nuclear energy sector

Key

ACNRE Advisory Committee for Natural Resources and Energy
AEC Atomic Energy Commission
ANRE Agency for Natural Resources and Energy
JNES Japan Nuclear Energy Safety Organization
METI Ministry of Economy, Trade and Industry
MEXT Ministry of Education, Culture, Sports, Science and Technology
MLIT: Ministry of Land, Infrastructure, Transport and Tourism
NISA: Nuclear and Industrial Safety Agency
NISS: Nuclear and Industrial Safety Subcommittee

2.2 Legal basis for nuclear supervision in Japan

The legal basis for nuclear supervision in Japan consists of legislation, Cabinet Orders, Ministerial Ordinances and Ministerial Public Notices (see Figure 3). Legislation is passed by parliament. Cabinet Orders are issued by the Prime Minister, whereas Ministerial Ordinances and Public Notices are issued by the responsible ministers in each case.

The main items of legislation regarding nuclear supervision are: the Atomic Energy Basic Act, the Reactor Regulation Act, the Radiation Hazard Prevention Act and the Act on Special Measures concerning Nuclear Emergency Preparedness. Another basis for nuclear energy is provided by the Electricity Business Act, which regulates the entire energy sector in Japan and is not restricted to nuclear energy.

Regulatory Guides are published by the Ministry of Economy, Trade & Industry (METI) and the Nuclear Safety Commission (NSC). METI primarily reviews technical standards drawn up by various engineering companies. 45 technical standards are approved at present. The NSC issues Regulatory Guides for its review of the regulatory body, NISA. Although these Guides are described as internal NSC documents, NISA and the operators are also guided by them.

From an in-depth examination of the NSC's Regulatory Guides, it was noticeable that these documents are worded as recommendations rather than instructional directives. Accordingly, in its report to the IAEA Ministerial Conference, the Japanese government mentions that some aspects of emergency management have an insufficient legal basis, and that the legislative structures must be reinforced. Until now, for instance, the preparation of measures to control incidents that exceed design specifications, known as Severe Accident Management Guidelines (SAMG), is not required by law but is merely recommended.

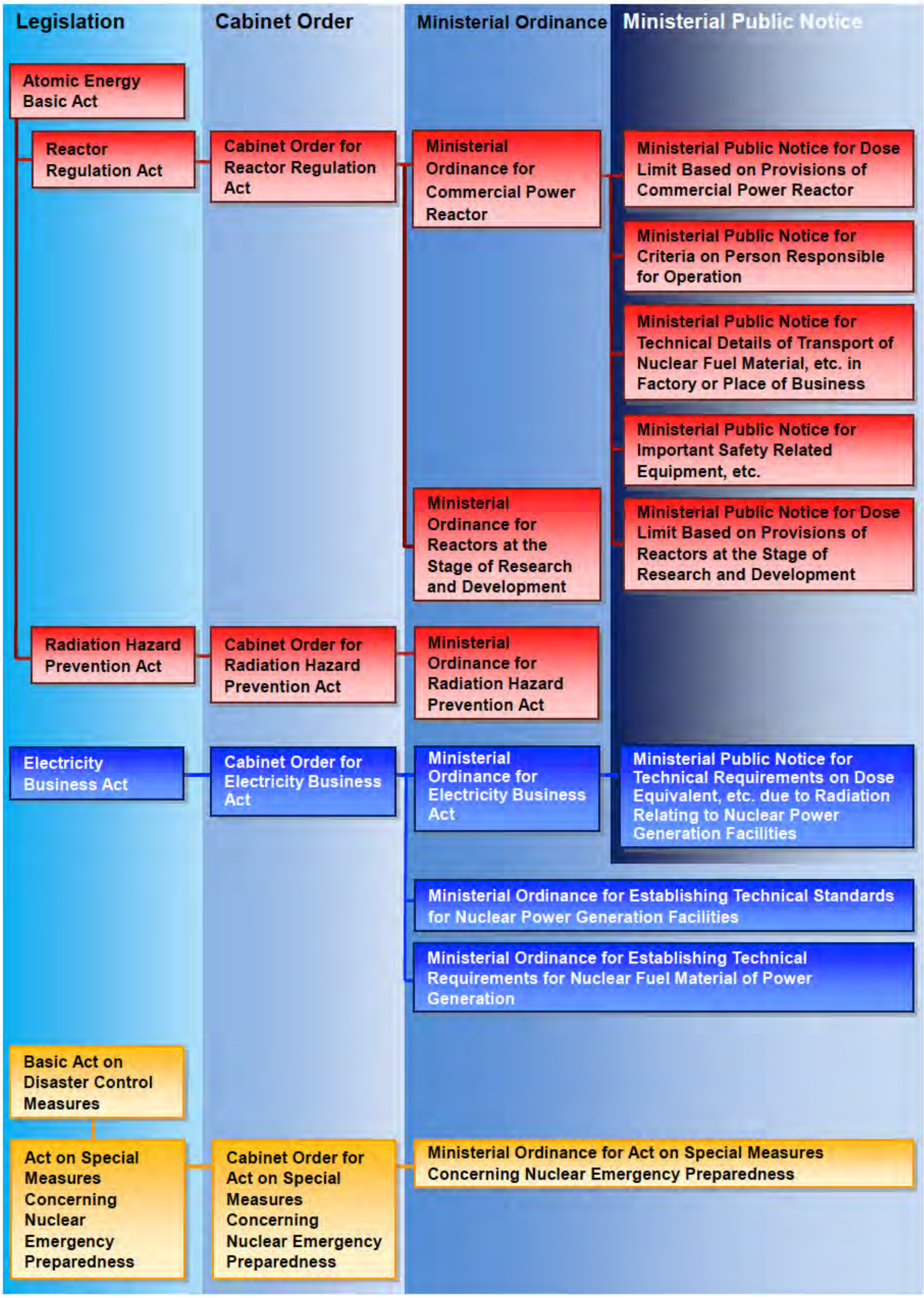

Figure 3: Hierarchical structure of laws on the safety of nuclear istallations in Japan [3]

3. In-depth analysis by ENSI

The current status of the in-depth analysis of contributory factors relating to people and organisation is discussed below. For the technical aspects, please refer to ENSI-AN-7614 Rev. 1.

3.1 Origin and development of the accident

Question 1: Why did a Station Blackout (SBO) occur on 11 March 2011 after the earthquake and the tsunami?

3.1.1 Organisational factors

3.1.1.1 Operator's safety culture

Hypothesis: Deficiencies regarding the development of a learning organisation

Two key features of a safety-oriented organisation are a fundamental attitude of critical analysis and review, and a readiness to improve continuously in matters of safety, i.e. to learn from the experience of other organisations as well. This feature was not present to an adequate extent in the case of the operator, TEPCO. In its report for the IAEA dated June 2011, the Japanese government refers to the necessity of building up a suitable new safety culture in this context [2].

National and international occurrences in nuclear plants were not given sufficient attention by the operating organisation, TEPCO, i.e. external findings were not adequately incorporated into the cycle of continuous improvement by means of appropriate measures. In 2007, this was confirmed by the recommendation of the IRRS team, according to which NISA was to ensure that the operators would establish effective processes to take account of international operating experience. In the opinion of the IRRS team, there was also potential for improvement regarding the use of the national database containing detailed information on occurrences kept by JANTI (Japan Nuclear Technology Institute) in order to exchange experience at national level [8].

What has been said above about the inadequate consideration given to national and international occurrences also applies to the insufficient attention paid to the current state of scientific and technological knowledge regarding the use of calculation methods (specifically in the field of probabilistic safety analyses, PSA), and to warnings issued by Japanese scientists about the earthquake hazard at the Fukushima Dai-ichi site [2].

Hypothesis: Operator's unfavourable corporate culture

Signs that nuclear plant operators are adequately meeting their responsibilities for safety include the complete and correct representation of the plant's actual situation and the implementation of safety reviews in accordance with regulations. Omissions and falsifications at the Fukushima Dai-ichi plant were already known in 2002. TEPCO itself confirmed 16 cases of discrepancies or omissions in the safety review that were reported to NISA between 1986 and 2001 via the anonymous reporting system that it operates [2].

Over time, a culture that favoured falsification and concealment apparently became established within the TEPCO corporation. Especially worrying is the following fact: In 2004 TEPCO had publicly communicated an action plan against falsifications. Nevertheless, 10 days before the earthquake, and shortly after receiving a licence for a 10-year lifetime extension for Fukushima Dai-ichi Unit I from the regulatory body NISA TEPCO sent NISA a document reporting that (contrary to information provided previously) 33 safety-relevant components had not been inspected [29]. NISA consequently attested that the operator's maintenance management was inappropriate and that the quality of the inspection work was inadequate. It requested a new maintenance plan from TEPCO (by 2 June 2011). These repeated cases of falsification and concealment, spread over many years, indicate insufficient assumption of responsibility for safety and suggest that the safety culture at TEPCO developed in a problematic manner [2].

Hypothesis: Conflict between safety and cost efficiency

In its 2010 annual report, TEPCO states that it reduced the frequency of inspections of its equipment as part of a cost-cutting programme. This reduction is justified by the results of detailed analyses. This possible contributory factor should be mentioned in connection with the inadequate maintenance of the plant described above [6].

3.1.1.2 Strategy and practice of government supervision

Hypothesis: Insufficient independence of the regulatory body

Section 2.1 mentions the complex network of intertwined relations between the various organisations involved in nuclear supervision. NISA (the Nuclear and Industrial Safety Agency), the regulatory body, is part of METI (the Ministry of Economy, Trade and Industry) and is supervised by the NSC (Nuclear Safety Commission, part of the Cabinet Office). The areas of development and supervision of nuclear energy were separated (and assigned to ANRE and NISA respectively) within METI when the governmental reform was implemented at the start of the last decade, but both areas report to the same Minister, which entails potential conflicts of interest. The Japanese government also acknowledges that this arrangement is problematic. For this reason, the government has decided to make NISA independent of METI and to incorporate it into the Ministry of the Environment [2], [24].

There are numerous media reports about several job changes by holders of high-ranking positions between ministries and operating companies in the past. This practice, which can obviously lead to conflicts of interest, is referred to in Japanese as „amakudari“ (descending from heaven, i.e. civil servants move into private industry after they retire) or also „amaagari“ (ascending to heaven). The personal relationships between policy-making bodies, authorities and operators have created a closely-knit nuclear energy community and have led to a lack of transparency in decision-making structures. To the outside observer, at least, it is not always clear where and by whom decisions are actually taken, and/or how independently they are reached. One indication of NISA‘s lack of de facto independence, for instance, is the disclosure of the identity of an anonymous reporter by NISA to TEPCO; at the end of the 1990s, this individual entered violations by TEPCO in connection with safety reviews into NISA‘s anonymous reporting system. At the time, NISA justified this step on the grounds of lack of legal protection for the reporter [30].

Despite the government reform of 2001, in the course of which NISA achieved de jure independence, the above remarks suggest a non-transparent („informal“) culture of supervision, which made it especially difficult for NISA to carry out its supervisory function to an adequate extent and with the required independence, and therefore to implement its own requirements consistently by way of enforcement.

Hypothesis: Structural deficiencies in the overall supervision system

One of the problems with the overall system of nuclear supervision in Japan is that the roles and responsibilities of the Japanese supervisory bodies are unclear. The supervision system is split into a large number of bodies and is highly complex (see Figure 2). This problem was already addressed in 2007 by the IRRS Mission, which recommended clarification of the roles of NISA and the NSC in connection with drawing up guidelines and directives. An analysis by 15 scientists from the Atomic Energy Society of Japan (AESJ) also concludes that the unclear roles and responsibilities of the supervisory bodies substantially impeded communication during the accident at Fukushima [7]. The Japanese government has already decided to standardise nuclear supervision [2].

In addition to the lack of clarity regarding roles and responsibilities, it is also the case that NISA was insufficiently empowered to carry out its supervisory function. The IRRS Mission recommended that greater efforts should be made to build up a pool of qualified technical experts in the long term. It would be difficult to ensure continuity due to the rotation of jobs every two or three years, and the lack of full-time positions. Moreover, NISA is only able to carry out inspections in the plants within time windows that are announced in advance. For these reasons, the IRRS team recommended that NISA's inspectors should be guaranteed unimpeded access to the plants for inspection purposes at all times [30].

As a country that is poor in raw materials, Japan has focused the strategy of its energy policy heavily on the use of nuclear energy. The development of nuclear energy has also received strong direct support from the Japanese government. For example, the state also participates indirectly in a newly-established enterprise (International Nuclear Energy Development of Japan, JINED), which aims to promote Japanese nuclear technology on an international basis [30]. The municipalities where the nuclear power plants are sited rely on financial support from the government and the nuclear power plant owners, so they are subject to long-term dependency [32]. Critical opinions on nuclear safety issues were lost in the construct or ignored. According to media reports, for example, complaints by the public that operators of nuclear power plants were underestimating the earthquake hazard had little chance of success [31].

Hypothesis: Insufficient supervision

In 2007, the IRRS Mission team submitted several recommendations to improve supervision of the plants in operation [8]; in the light of the Fukushima accident, the deficiencies underlying these recommendations emerge as suspected contributory factors:

- As a new feature, the periodic safety review (which has only been required since 2003) should also be submitted to NISA in the form of a written summary.

- Rather than starting to monitor the ageing of systems and components by means of separate ageing management only after 30 years of operation, NISA should require and assess such monitoring on the basis of safety reviews at an earlier stage.

- The development of requirements and supervision for the human and organisational areas should be driven ahead. In contrast to the technical area, there are no clear shutdown criteria for the areas of operational management and organisation.

Press reports mention that supervision has essentially comprised a review of the documents submitted by the applicant. NISA, it is said, has not adequately ascertained the correctness of the information stated by carrying out its own inspections and checks. The IRRS Mission also considered that the regular interaction between NISA and the operators was in need of improvement [8].

In view of the impression created by the accident at Fukushima Dai-ichi, deficient and/or excessively superficial review of protection against earthquakes/tsunamis by the authority should be assessed as a central shortcoming in supervision. The tsunami hazard in particular was assessed using unsuitable methods, and it was not examined critically by NISA [2]. According to press reports, the scanty documents submitted by the operator regarding the earthquake and tsunami hazard were not subjected to adequate critical examination by the authority [33].

One key reason for the official acceptance of the condition of the plant in terms of protection against earthquakes and tsunamis was the non-binding nature of the requirements in the legislation and the guidelines. In 2002, the Japan Society of Civil Engineers (JSCE) drew up recommendations regarding the consideration of tsunamis in design, but these recommendations were not binding for the operators. The operators were also free to choose the assessment method. Studies on probabilistic safety analyses (PSA) were undertaken by the operator only on a voluntary basis and were not adequately developed for cases of infrequent natural events [2]. It should also be mentioned that the statutory approval process for the construction of new nuclear power plants is not linked to compliance with requirements for beyond design incidents. According to the statutory requirements, there is no need to take account of such incidents because operational safety should be guaranteed by the design, and by preventive protective measures. The government is planning a complete revision of the legislation and guidelines on nuclear safety, including the measures for dealing with severe accidents [2].

3.1.2 Human factors

In contradistinction to the organisational factors already described, the following section considers psychological phenomena and behaviours on the part of the humans involved, which may have helped to make it possible for the Station Blackout (SBO) to occur after the earthquake and the tsunami. However, not all aspects of these two areas can be clearly demarcated. Psychological phenomena naturally play a part at both individual and group level (i.e. at the level of the organisation).

Conversely, the organisational factors described above are also closely related to the behaviours of the organisations involved, and to the mental/emotional phenomena that affect them.

Hypothesis: Underestimation of risks

The earthquake and tsunami risks were evidently underestimated. In retrospect, this is an undisputed fact and, at least as regards the tsunami risk, it is confirmed both by the IAEA [8] and by the Japanese government [2]. Moreover, incorrect assumptions were made regarding the maximum possible earthquake strength at the site. The American seismologist Robert Geller, who teaches at the University of Tokyo, stated in the journal „Nature" that the Japanese authorities had the fixed idea that a severe quake was to be expected on the southern Pacific coast of the island nation, and that they underestimated the risk of a serious earthquake in the north-east of the country [34]. The maximum height of a tsunami was also significantly underestimated for the affected locations (see Figure 4) [34].

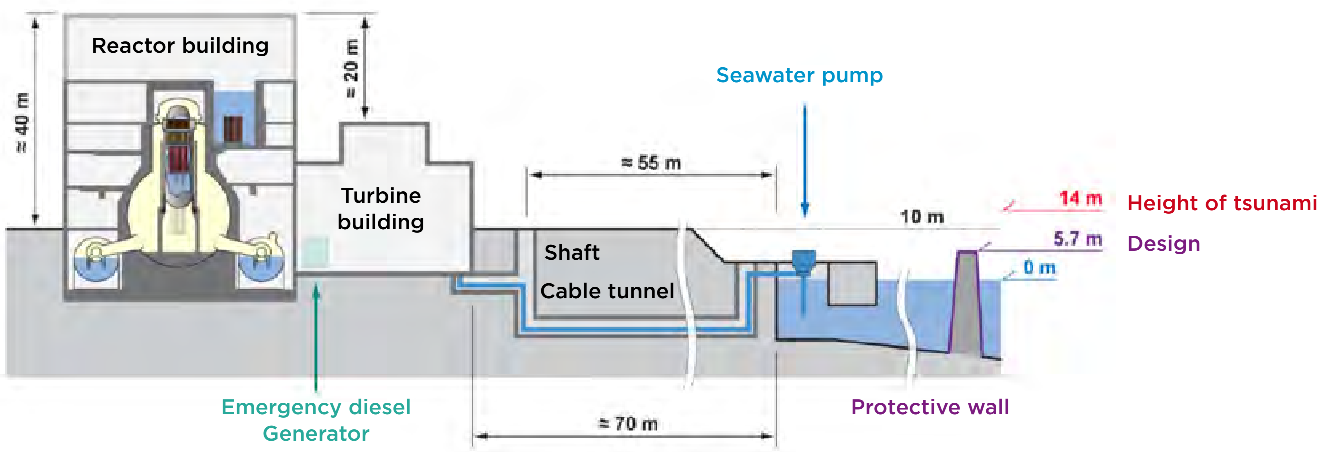

Figure 4: Fukushima Dai-ichi: design, plant and actual height of the tsunami [4]

Figure 5: There are hundreds of marker stones along the Japanese coast bearing the inscriptions:
• „Do not build lower than this stone!“ and/or
• „In case of earthquake, beware of tsunamis!“
(Source: AP, Spiegel Online, April 19, 2011)

Experts and the media consider that this underestimate of the risk is directly related to the methods and bases that are used by operators and authorities in Japan to calculate and/or model these risks, and to the failure to take account of progress over recent decades in the fields of seismology and risk calculation [35], [36]. For example, one criticism made is that the calculation methods used ignored important uncertainty factors (e.g. as yet undiscovered geological deformations or extreme - albeit very infrequent - earthquakes). In addition, probabilistic considerations were not included to a sufficient extent. On the contrary: the calculations were based more on historical data, i.e. on previous events involving earthquakes and tsunamis that are documented (see Figure 5).

Paradoxically, however, it seems that these historical data were not used in their entirety, but merely on a selective basis: in the past, it is highly likely that earthquakes and tsunamis occurred in Japan in excess of the maximum strengths on which the design of the Fukushima Dai-ichi plants was based (e.g. a huge tsunami wave following the Jogan earthquake in 869). However, only those tsunamis occurring after 1896 were taken into account for the design of the plants.

The underestimation of risks can partially be explained by the proven weakness of humans when it comes to the correct assessment of risks. But in respect of the accident at Fukushima, this explanation falls short of the mark. To be specific, it hardly explains why the risks were not perceived and taken into account despite scientific and historical evidence which, in retrospect, is overwhelming. It therefore appears that greater importance attaches to more subtle – yet fundamental – psychological mechanisms which help people to protect their convictions and actions, and hence also their self-worth.

These mechanisms should not primarily be regarded as inadequacies of human nature, but rather as part of the normal adjustments that people must make every day in response to their environment and/or the requirements expected of them. They help people to be and remain capable of taking any action in the first place, and they generally lead to desirable results. In certain situations, however, these fundamental human traits can result in undesirable and occasionally catastrophic effects unless they are cushioned by appropriate organisational measures and overall cultural conditions. It is therefore crucially important for an organisation (operator, authority, etc.) to be aware of these psychological mechanisms, and to implement suitable precautions and stipulate organisational measures so that the (potentially) negative effects of human behaviour can be identified and intercepted, and/or to provide people with a suitable framework of conditions for their actions.

The next section discusses some of the psychological mechanisms which – when considered today – would appear to have played a possible role in the history of events leading up to the accident.

Hypothesis: Disregard of warnings and facts

As has already been described, a series of (potentially) known and documented facts as well as warnings from individual experts and organisations were disregarded. They were not incorporated into the design or back-fitting of the nuclear plants, and they were also given insufficient consideration by the authorities and were not integrated sufficiently into regulatory documentation or supervisory work [2].

In 2005, for example, Professor Katsuhiko Ishibashi of the University of Kobe warned a parliamentary commission about the consequences of earthquakes and tsunamis in respect of the Hamaoka nuclear power plant (which, at the request of the Prime Minister, was provisionally shut down for back-fitting after the accident at Fukushima). In an expert report, the Professor set out the expected progression of an incident after an earthquake and subsequent tsunami. According to media reports, this progression corresponds to the sequence of events which unfolded at Fukushima from 11 March 2011 onwards [37]. Moreover, a Japanese geologist allegedly warned the government that a severe earthquake with a large tsunami wave was to be expected in the north-east of Japan. METI rejected the evidence that was presented and TEPCO also did nothing to improve the protection of the plants at Fukushima against high tsunami waves. It is said that a presentation of the geologist‘s research results to representatives of the Fukushima nuclear power plant was scheduled for a few days after the earthquake and tsunami [37].

But why did such warnings come to nothing?

It must be assumed that psychological suppression or rationalisation mechanisms, together with selective perception, caused newly published and/or produced (scientific) knowledge and facts to be ignored, played down or re-interpreted so that they would not jeopardise previous decisions and actions (or omissions), or cast fundamental doubt over the operation of certain nuclear plants at specific sites. Over recent decades, for example, active fault lines were discovered close to various plants. The plant operators initially tended to downplay these deformations. One case is reported in which the operator repeatedly had to make upward corrections to the data on the length of a newly discovered fault line located close to its own plant. When the operator finally acknowledged the scientists' findings in full, it stated that the plant was designed so that it would withstand an earthquake triggered by this deformation [31].

Another example of rationalisation processes of this sort is reported by Associated Press journalists [36]. In 2007, it is alleged that two TEPCO employees, together with three external researchers, published their approach to the assessment of the tsunami risk at Japanese nuclear power plants in the „Pure and Applied Geophysics" journal. They also recommended that the plants should be designed for the highest tsunami (quote: „at the site among all historical and possible future tsunamis that can be estimated"). However, they immediately qualified this statement again by excluding facts about tsunamis that occurred prior to 1896 from the analysis, because the documented data might be unreliable on account of „misreading, misrecording and the low technology available for the measurement itself". They concluded: „Records that appear unreliable should be excluded" [35].

A further indication of rationalisation and suppression processes is the tendency to use new calculations to confirm original results and statements. A few months before the accident at Fukushima, TEPCO concluded on the basis of its own new calculations that a tsunami wave at Fukushima Dai-ichi would not exceed the 5.7 m mark. A TEPCO construction engineer is quoted as saying: „We assessed and confirmed the safety of the nuclear plants." [35]

Another possible way of evading new knowledge and the higher requirements for safety precautions that it creates was reported by the New York Times [35]. When the authorities started to exert more pressure regarding the seismic design of plants after the Kobe earthquake in 1995, the operators – who were focussing on the construction of a dozen new reactors – defended themselves against stricter regulations. They evaded the pressure by means of delaying tactics, for example by not sending any delegates to meetings on earthquakes organised by the Nuclear Safety Commission of Japan (NSC).
A reluctant approach to external recommendations is also noticeable on the part of the authorities. In particular, it seems as if the recommendations of the 2007 IRRS Mission were only being implemented after a delay. Furthermore, the follow-up mission originally planned for February 2010 was postponed. As far as is known at present, no invitation has yet been issued to the IAEA for this follow-up visit and no definite date has been set [11].

Hypothesis: „Group Think"

The organisational phenomena described here should not only be regarded at the individual level, as defence mechanisms on the part of specific persons; they are also bound to be reflected at collective level, i.e. at the level of the organisations involved (operators, supervisory authorities, policy-making and legal bodies, etc.) and of society as a whole. Against the backdrop of a political and social climate in which very great emphasis is placed on promoting the use of nuclear energy, there is a growing risk that findings and arguments running counter to this trend will be suppressed. This is also demonstrated, for example, by the fact that plaintiffs from the general public who launch court proceedings against nuclear plant operators on grounds of safety deficiencies have virtually no chance of winning their actions in court [31]. It must also be assumed that such trends are favoured by a supervisory apparatus which has little ability to assert itself and must base its work on regulations that fail to cover decisive requirements.

Accordingly, the phenomena described here must also be considered from a socio-psychological perspective. It is difficult for any attention to be paid to new knowledge and warnings brought to the notice of collective bodies (organisations) by external parties. One possible explanation for this is supplied by the phenomenon known in socio-psychology as „Group Think", as described by the psychologist Irving Janis. This concept explains why groups can take extremely unreasonable or even obviously incorrect decisions under certain circumstances, even though the individual group members would never take the same decisions on their own [10].

On the basis of the information available to date, it is impossible to arrive at a definitive assessment of the extent to which Group Think processes actually played a part in the run-up to the accidents at Fukushima (and/or after the accident had occurred). However, statements such as the one cited here by the Chairman of the Nuclear Safety Commission of Japan suggest that such processes cannot be ruled out: „He said the guidelines [referring to the Regulatory Guidelines of NSC on the design of nuclear power plants – editorial comment] were not revised because experts on nuclear power generation are an enclosed group and they tend to avoid vigorous discussions and uncomfortable subjects" [39].

Hypothesis: Complacency and excessive trust

Another obvious assumption is that a lengthy period without any incidents induced by earthquakes and (in particular) tsunamis could have led to a certain degree of complacency. Consequently, both operators and authorities might not have paid sufficient attention to potential safety deficiencies in the design of nuclear plants and/or may not have reacted as promptly as was required to any safety concerns [33]. The belief that „nothing is going to happen" is also likely to have been reinforced by the fact that earthquakes are virtually an everyday event in Japan, and they usually have no negative effects on nuclear power plants. This tendency to complacency and excessive trust in nuclear technology was confirmed in June 2011 by the METI Minister at the IAEA Ministerial Conference in the following words: „In Japan, we have something called the „safety myth". (...) It's a fact that there was an unreasonable overconfidence in the technology of Japan's nuclear power generation." The result of this was that safety thinking in the nuclear industry was based on weak foundations [40]. This is also reflected by the fact that there has been no review of the design guidelines since 1990. For example, these guidelines explicitly excluded the need to consider long-lasting power failures (quotation: „a long-term power failure can be ignored as emergency back-up systems are expected to supply electricity") [39]. The Chairman of the NSC is quoted by NHK, the Japanese public television broadcaster, as saying that he had not given this statement any attention until the accident at Fukushima, and he regretted his ignorance in this regard.

3.2 Management of the accident

Question 2: Why did damage occur to the fuel assemblies and and why did all the safety barriers fail, with the subsequent release of massive amounts of radioactivity into the environment?

3.2.1 Organisational factors

3.2.1.1 Operator's maintenance and emergency management

Hypothesis: Deficient maintenance management

In 1991/92, a tightness test on the safety containment of unit 1 at Fukushima Dai-ichi was manipulated by introducing additional air [2]. In retrospect, however, whether this action impaired the function of safety systems during the sequence of events in the accident is not possible to answer. The same can be said of the 33 untested components which (according to media reports) TEPCO only reported to the regulatory body after the lifetime-extension of the plant had been granted. At this point, shortly before the accident, NISA attested that TEPCO's maintenance management was deficient, and called for a new maintenance plan by 2 June 2011 [29] (cf. also section 3.1.1.1).

Hypothesis: Delayed decisions

Given the sequence of events [1], it becomes clear that, in technical terms, the seawater feed for unit 1 was ready to operate at a considerably earlier point in time than when it was actually started. Whether the instruction was delayed and, if so, who was responsible for the delay, are questions to which the answers are unknown at present. According to press releases [41], TEPCO headquarters prohibited the supply of seawater into the rector pressure vessel based on its interpretation of the authorities' position to this matter. Nevertheless, the local director of the plant is said to have ordered the feed (for unit 1, approx. 28 h after the tsunami wave arrived). The Japanese government also confirms that the director of Fukushima ordered this measure and that some confusion prevailed in the decision-making chain between the government and TEPCO [2]. Likewise, media reports state that the Prime Minister did not receive all the information required to arrive at a decision. Instead, TEPCO attempted to downplay the accident. The Prime Minister was said to be fundamentally suspicious of a system that consisted of powerful operators and a loyal authority, so he did not have recourse to the communication channels and decision pathways for which provision was made [41]. As a result, it is possible that delays occurred in the decision-making process.

Hypothesis: Inadequate emergency plan

A direct influence on measures to deal with the accident so as to prevent core damage and the release of radioactivity was probably exerted by the available emergency plan with the emergency regulations on dealing with severe accidents, the „Severe Accident Management Guidelines" (SAMG).

This „Emergency Action Plan" was also available at Fukushima Dai-ichi, but it did not give adequate consideration to an accident on this scale.

Even though certain accident management measures did function (manual supply of water via fire extinguishing hoses), the emergency action plan ultimately failed to a large extent [2]. Various aspects contributed to this failure [2]:

- Inadequate emergency procedures for severe accident management measures
- Deficient communication plan between TEPCO's headquarters (Off-site Head Office), TEPCO's site management and/or governmental authorities
- National, external emergency assistance (rescue squads) with logistical support were only able to provide on-site help after some time had elapsed
- Insufficient consideration was given to the simultaneous destruction of large parts of the infrastructure in the surrounding area – availability of heavy equipment for severe accident management measures (see Figure 6)
- Adequately trained staff to deal with an event of this scale and duration were not available
- The members of the emergency team were not given adequate training for an event of this scale and duration during regular emergency exercises

Hypothesis: Staff to implement severe accident management measures were not available or were overcharged

A particular problem arose for the multi-unit plants because several reactors were impacted simultaneously by the accident. There was a bottleneck of qualified staff, who were unable to be present simultaneously at all the reactors affected by the accident. As well as the technical separation of the units, it also seems sensible to set up independent emergency organisations for each reactor unit [2].

Figure 6: Extent of destruction, shown here for unit 4 at Fukushima-Dai-ichi (Source: n-tv online, Sunday 24 April 2011) and roads near the coast (Source: rp-online)

3.2.1.2 Bases of emergency protection and emergency action planning by the authorities

Hypothesis: Deficiencies in the supervision of emergency measures and the underlying legislative and regulatory framework

Measures to bring severe accidents under control were drawn up by TEPCO in 2002 on a voluntary basis. The relevant guidelines were issued as long ago as 1992 and have since been partially updated on only one occasion (1997) [12]. The inadequate development of the emergency measures is attributed in particular to the lack of legislative requirements in the Act on Special Measures Concerning Nuclear Emergency Preparedness [2].

Hypothesis: Omissions in official emergency action planning

The authorities' preparations for an accident of this scale were equally inadequate. The emergency centre at the site (the local Nuclear Emergency Response Headquarters, NERHQ) was not ready to operate due to insufficient shielding and the lack of infrastructure, so it was necessary to switch to a location in the surrounding area [2].

Communication problems also arose between the local NERHQ, the NERHQ, the government (the Prime Minister), the TEPCO Head Office and TEPCO's on-site operational management. As well as the initial failure of means of communication, this was due in particular to the unclear emergency procedures and the related lack of clarity regarding responsibilities [2].

Due to the deficient structures, the Japanese government was unable to adequately coordinate the international assistance that was offered, and was therefore unable to make prompt use of it [2].

3.2.2 Human factors

Hypothesis: Difficult working conditions for the staff

The staff at Fukushima Dai-ichi had to work under extremely difficult conditions after the earthquake and the tsunami (and to some extent, they probably still have to do so at present). Little confirmed information about the actual working situation on site is available as yet, but the pictures repeatedly published by the media send out a clear message.

Difficult physical working conditions:
The physical conditions on site made emergency management and/or the workers' activities more difficult. Due to the power outage, large areas of the plants were in darkness (see Figure 7), including parts of the control rooms; the instrumentation had partially failed and/or the information that was still available was not reliable; communication within the plant and to the outside world was impeded. Only restricted access to systems and rooms was possible due to debris, damaged doors, flooded buildings and plants and the risk of explosion, etc. Work was also made more difficult by the ambient conditions such as high ambient dose rates (ADRs), noise, heat, and high air humidity. There are reports of cases of dehydration and heat stroke due to long periods of working in full protective suits without cooling [13]. In addition, there was a health hazard for staff (which still exists to some extent) due to high exposure to radiation. At the outset, for example, the local emer-

gency centre was not adequately protected against penetration by radioactivity, and this led to an accumulation of impermissible doses of radiation in the case of at least one person [14]. Moreover, the health of those working on site was (and still is) endangered by highly radioactive debris located on the site [15]. Finally, it has been reported that it was initially impossible to fit all members of the intervention teams with dosimeters and protective equipment (masks in particular) in order to carry out the emergency measures [16]. These conditions made it far more difficult to implement planned emergency measures.

Difficult psychological working conditions: It is likely that the psychological stresses under which the staff had to work on site were at least as onerous as the physical conditions [42]. Although this has not yet been confirmed either by official sources or by media reports, it must be assumed that some of the staff were in a state of shock after the earthquake (which lasted for 90 seconds) or after the tsunami, if not before. Another factor was that many employees were afraid for their family members. The employees had no possible way of contacting their relatives and in some cases had to assume that they could have fallen victim to the tsunami or the earthquake. The media also reported individual stories of employees who remained in the plant although they knew that their families had been swept to their deaths by the tsunami [42]. Finally, the staff had to cope with the deaths of several workers in the plant. Two of them drowned in the floodwater in the plant, and were found at the end of March in the turbine building of unit 4 [17].

Figure 7: Working with a total power outage and high exposure to radiation (Source: T-online News, 24.03.2011; Welt-expressinfo online, 25.03.2011)

It is also highly likely that the general conditions under which the staff had to work were extremely difficult for a considerable time. According to media reports, the supply of food for the staff was inadequate in the initial period. It is reported that during the first days, 500 employees slept together on tatami mats in a nearby secondary school, with no showers and meagre rations of food [43]. At the outset, moreover, it is very probable that the staff could not be relieved for a lengthy period, which is bound to have led to over-tiredness or even conditions of exhaustion [42]. Shortage of staff made the emergency measures more difficult.

Another definite psychological stress factor was the need for on-site employees to take decisions and to act without knowledge of the actual condition of the plant (also see below). Likewise, it must be assumed that the situation for the on-site staff became increasingly desperate as time went on, because new and unexpected events occurred repeatedly and many of the measures taken were not successful. In some cases, the staff had to take action against the sequences of accident-related events simultaneously in the different units, and it is likely that they felt that they had lost control of the situation in the plants for a lengthy period.

If we consider the physical and psychological conditions just described, which continued for several weeks and to some extent still persist today, we are bound to conclude that the on-site staff accomplished the utterly impossible and displayed almost superhuman behaviour, regardless of how successful they ultimately were in gaining control over the accident and/or its consequences. Rumours that the staff fled from the plant after the earthquake and the tsunami are largely refuted by media reports. A few of the 900 or so persons present at Fukushima Dai-ichi left the plant due to concern about their families, but most of them remained in the plant.

The evacuation of the staff, except for 50 persons, which took place on 14 March was officially ordered by TEPCO. TEPCO even asked the Prime Minister for permission to withdraw the entire staff. However, this request was vehemently declined by the Prime Minister [41]. At a later stage, the on-site staff was increased again so that the necessary work on the site could be carried out. The precise figures and the numbers of people present on site at different times are not yet available to ENSI.

Hypothesis: Inadequate awareness of the situation

It must be assumed that the on-site staff had no precise knowledge of the actual situation and condition of the plant for long periods [44]. At least temporarily, this is also likely to have resulted in incorrect assessments of the situation. The first incorrect assessment was probably made just a few minutes after the earthquake, following the first tsunami warning issued by the Japanese meteorological institute, and referring to a wave with a height of at least three meters („major tsunami") [18]. Based on this warning, which did not make it possible to foresee the true scale of the expected tsunami, it was probably thought that no special technical measures were occasioned at Fukushima Dai-ichi and that there was consequently no particular cause for concern. The fact that the first version of the plan presented by TEPCO to bring the plant back under control had to be adapted again after a short time, and the estimated time of occurrence of core meltdown in unit no. 1 had to be corrected [45], suggest that the correct assessment of the condition of the plant will prove to be very difficult for a long time to come.

It is impossible at present to make definitive statements regarding a whole series of issues because insufficient information is available. For example, it is not possible (as yet) to assess the adequacy of the staff's behaviour in planning and implementing the emergency measures. Moreover, it is impossible to say at this stage whether the existing regulations were followed. Nevertheless, it can already be stated that the conditions described are likely to have made emergency management considerably more difficult. The accident at Fukushima Dai-ichi impressively confirms that emergency management must not be regarded as a purely technical matter that is confined to the availability of technical measures and resources. The physical and psychological stresses, and the overall organisational conditions under which people have to work in an emergency, must also be taken into consideration.

3.3 Consequences of the accident

Question 3: Why were the plant staff and the public exposed, and why was the environment contaminated?

3.3.1 Organisational factors

3.3.1.1 Protective measures for the operating staff and the intervention teams

Hypothesis: Inadequate protective measures for the operating staff and the intervention teams

Although the authority had increased the dose limit from 100 to 250 mSv for those staff deployed to deal with the accident who were exposed to radiation for occupational reasons, the limit may possibly have been exceeded in the case of two persons, with a whole body dose in the range from 200 to 580 mSv [19]. These possible breaches of the limit values for the whole body dose, which consists of exposure in the radiation field and the incorporation (bodily uptake) of radioactive substances – mainly radioactive iodine – could be an indication that protective measures for the staff were inadequate at the start of the accident. Full protection masks with active carbon filters would have prevented the inhalation of I-131, which contributes significantly to the whole body dose.

Serious contamination of persons occurred on 24 March 2011 in the case of two employees working in the turbine building of unit 3. Due to inadequate protective equipment, direct contact with water polluted by beta-emitters caused contamination of the individuals' feet and legs, causing partial body doses of up to 3 Sv in both cases. The highly uncertain nature of the dose information prompts ENSI to conclude that there were difficulties regarding personal dosimetry.

Japanese health organisations criticised the deficient monitoring of doses for the operating staff and the intervention teams, and the increase in the limit for the whole body dose from 100 to 250 mSv [20].

Shortcomings in radiation monitoring for the staff are explained by the flood-induced destruction of many personal dosimeters and the initial difficulties with measuring radiation on the plant site [2]. It is obvious that neither the local authorities nor the ministries' offices were adequately prepared to measure ambient dose rates or to determine concentrations of radioactivity in the air. ENSI is unable to understand why only incomplete information from the operator on ambient dose rates (ODL) was available, with no measurements by independent authorities.

3.3.1.2 Information and protective measures for the general public

Hypothesis: The general public was inadequately informed

Although the evacuation of the public from the more immediate vicinity of the plant was quickly initiated by the authorities, there is criticism of the inadequate information supplied to the public and the local authorities in the (wider) surrounding area regarding the likely development of the accident and its impact on the exposure of the public to radiation. During the acute phase, the public was not adequately informed about potential exposure to direct radiation and the ingestion of radioactive substances. Likewise, the public was not briefed sufficiently about the personal protective measures to be applied. Reasons that can be cited for this include the organisational problems mentioned below and the non-availability of destroyed means of communication [2].

Hypothesis: Inadequate protective measures for the public

At the start of the accident it was not clear who actually bears the main responsibility for protecting the public in case of an emergency. This was principally due to the complex supervisory structures and the large numbers of supervisory bodies involved [2].

Even though the evacuation of the public in the areas surrounding the Fukushima Dai-ichi plant took place quickly, the evacuation zones were not sufficiently adapted to the prevailing local radiation contamination. At the outset, the measures were not based on the guidelines of the International Commission on Radiation Protection (ICRP) and the IAEA [2]. One example of this is the very late evacuation of the village of Iitate, which is situated outside of the 30-km radius to the north-west of Fukushima Dai-ichi.

Likewise, the evacuation zones were not initially determined on the basis of propagation calculations by the system envisaged for this purpose, i.e. SPEEDI (System for Prediction of Environmental Dose Information) [2].

The monitoring organisations in the province of Fukushima only have one device available, which can measure about ten persons per day, to handle the announced whole body measurements of the affected members of the public (about 200,000 people) in order to determine potential instances of incorporation caused by inhalation or ingestion of radioactive substances [21].

3.3.2 Human factors

Hypothesis: Inadequate knowledge of the radiological situation and stress-induced errors

As outlined in connection with the explanations of contributory factors in the organisational area, the reporting on personal doses – although still incomplete – suggests that several individuals received doses of radiation that were above the applicable limit values for them. In official statements, this is attributed in part to the initial lack of an adequate number of electronic dosimeters and to disruptions in the recording of measured data, as well as to major problems with measuring radiation on the plant site during the first days following the accident. In the case of the employees of an external company whose legs were contaminated by radioactive water on 24 March 2011, it must also be assumed that the staff were working without knowledge of the actual radiological situation and/or that they had assessed the situation incorrectly. TEPCO assumes that they took the values measured on the previous day as their basis and were not aware of the changed working conditions despite the alarms from their dosimeters [22].

Another example of avoidable incorporation is the incident which took place on 13 June 2011: an employee working outside the unit 2 reactor building only realised after completing two hours of work that he had forgotten to fit a filter to his full protection mask [23], although the consequences in this case were minor with a committed (effective) dose of 0.5 mSv.

Even if the incidents of avoidable exposure to radiation, contamination and incorporation reported here are individual cases, they must nevertheless be included in the analysis. From the individual perspective, it must be assumed that errors are favoured in situations such as this. In the cases described, for instance, dosimeter alarms were not heeded or individuals forgot to fit the active carbon filter.

Since the basic assumption has to be that errors are committed, especially under the conditions in which staff were working to cope with the accident at Fukushima, it is essential to consider the cases of exposure to radiation, contamination and incorporation described here from an organisational perspective as well. In so doing, it is necessary to examine whether the company's own staff and third-party personnel, as well as the intervention teams, were adequately trained and whether they were sufficiently prepared for the individual tasks that had to be performed. In the case of the employees who were contaminated on 24 March 2011, TEPCO gave an assurance that its own staff and third-party personnel had received fundamental instruction on the recognition of a dosimeter alarm [22]. Whether these individuals had ever worked previously in a radiation field with open radioactive substances and whether they had understood the instruction are matters which, in ENSI's view, cannot currently be clarified. It therefore seems legitimate to question the organisational measures taken to protect the employees, including the general training measures and the specific preparation for the tasks to be undertaken (e.g. in the context of „pre-job briefings"), and also to ask whether the organisation of the on-site radiation protection was suitable in order to cope with an accident of these dimensions. In this regard, particular emphasis should also be placed on the need for organisational measures that are appropriate to human behaviour traits (especially in extreme situations).

It has to be assumed that the Japanese and international authorities and the operator, TEPCO, will follow up the issue of staff training and preparation in the course of further investigations and analyses.

4 Conclusions

The findings presented in this report must be regarded as provisional results from the analysis. It will take months or years to carry out the analysis, before all the lessons from the accident at Fukushima can be learned and implemented. A large number of the (presumed) contributory factors that have been identified thus far are hypothetical in nature. This is because, on the one hand, it is still difficult at present to fully verify the dependability of the information that has been gathered – in particular as regards the areas of people and organisation (including radiation protection). A substantial part of the information available to date was taken from media reports. So far, it has been impossible to undertake a comprehensive review of the correctness and completeness of this information. It is also to be expected that it will never be possible to have all of the information confirmed by official reports. On the other hand, it will be equally impossible to verify a number of hypotheses, especially those relating to the history prior to the accident, since no direct causal link can be established between individual events in the past (e.g. the non-availability of systems due to deficient maintenance) and the accident. The accident can be explained only by the very specific conglomeration of events and circumstances, and their specific coincidence, but not by linear, causal concatenations of events and circumstances. For these reasons, the precise role of each of the identified contributory factors in the causation of the accident cannot be conclusively proven.

ENSI's analysis has yielded the following results:

- The (presumed) contributory factors identified to date range across the areas of people, technology and organisation with a variety of interlinked relationships and/or interactions. This applies to the origin and development of the accident, the measures taken to deal with it and its consequences. This report focuses on the results in the area of people and organisation.

- The (presumed) contributory factors identified in the area of people and organisation relate to the operator (TEPCO) as well as to political and official bodies.

- Organisational aspects that relate to the safety culture of the operator, TEPCO, and the structural deficiencies of the entire system of nuclear supervision in Japan, as well as the underlying psychological mechanisms that form the basis for human behaviour, contribute towards an explanation of the technical shortcomings in the run-up to the accident.

- Crucial importance attaches to the human and organisational aspects of emergency management in connection with measures to deal with the accident (e.g. emergency sequences, procedures, decision-making and communication pathways, training and deployment of staff, etc.). The influence of the difficult physical and psychological working conditions on the performance ability of staff in emergency situations must be considered in depth, and must be taken into account for the planning of emergency actions by operators of nuclear plants and by the supervisory authorities (assumption of a worst-case scenario).

As regards the further steps in the analysis, it is important to continue considerations as to how the identified contributory factors could materialise in the first place, i.e. which fundamental mechanisms and phenomena provided the basis for them. The accident at Fukushima can be attributed in particular to a design error. Therefore, the design of Swiss nuclear power plants must undergo renewed critical analysis against the particular backdrop of the knowledge gained in Japan. But above and beyond the review of the design of nuclear power plants, the decisive question is: How could it come about in Japan that an inadequately designed plant did not undergo adequate back-fitting during its long period of operation? The (presumed) contributory factors identified by this report in the area of people and organisation already supply a major contribution towards a differentiated consideration of the conditions and complex combinations of circumstances which led to the accident at Fukushima and/or influenced its progression. However, the search for explanations must give even more thorough consideration to the fundamental human and organisational mechanisms that underlie the behaviours, omissions and errors described in this report. Mechanisms of this sort have already been tentatively addressed in the report. Why were the deficiencies in design and supervision – which appear so obvious in retrospect – not identified at an earlier stage? Why did the plants at Fukushima not have better protection against tsunamis, although it was known that very high tsunamis had already caused major destruction in Japan in the past? Why were the operators and authorities not better prepared to cope with an accident of this sort?

It would definitely not suffice to imply that individual decision-makers in Japan were merely irresponsible or committed deliberate errors of conduct. It must be assumed that basic human and organisational mechanisms (behaviour-shaping mechanisms, [25]) are also among the underlying factors. Such mechanisms and external conditions can have a strong impact, and may have the effect that facts which appear to be self-evidently obvious in retrospect are not identified or are suppressed, rationalised or explained away beforehand. It is also possible that over a lengthy period of time, gradual changes in perceptions and practices occur that are recognised with hindsight as obvious major changes, but which are difficult to identify at an earlier stage because they „creep in“ (Drift into Failure, cf. [26]). Phenomena of this sort must be regarded as inherent characteristics of socio-technical systems. These behaviours reflect the constantly necessary adaptations in people and/or the socio-technical systems within which people operate, in response to changing conditions (cf. e.g. Hollnagel [27]). These mechanisms affect all the players, from the operator and the regulatory body and/or political bodies all the way through to society as a whole. It is the responsibility and duty of all players in the nuclear industry (operators of nuclear plants, governments, supervisory authorities and expert organisations, etc.) to understand the potential and actual effects of these mechanisms and to accommodate them in their organisations by means of appropriate structures and processes, and with the help of a culture that is safety-oriented and mindful. These mechanisms cannot be eliminated by simple and case-specific measures such as new regulations or the further automation of technical systems, because there will repeatedly be new and unexpected situations that were not foreseen by any engineer or regulatory body. Rather, the organisations must have the ability to cope with the unexpected. They must be resilient, i.e. they must be capable of adapting before, during and after changes and disruptions, so that they can maintain control at all times, under expected and unexpected conditions alike [28]. Although the effectiveness of many of the mechanisms described here cannot be fully proven in specific cases, it is nevertheless important to deal with them as the further analysis of the accident at Fukushima proceeds. This is the only approach that allows a full consideration of the applicability of the accident to Switzerland so that the relevant lessons for Switzerland can be learned.

5 Further procedure

The following areas of action regarding the issues of safety culture and emergency management were identified on the basis of the (presumed) contributory factors related to people and organisation. As part of its supervisory activities, ENSI will conduct a specific review of the situation for these areas of action in Switzerland. For this purpose, ENSI has formulated a series of specific findings. A comparison with the actual situation in Switzerland will show which of these findings are applicable to Switzerland and what measures can be derived from them, where appropriate.

It is still necessary to clarify the radiological effects of the accident (see question 3). ENSI will deal with this aspect in more detail in a separate report. Once the personal dosimetry data are available, ENSI will also carry out an analysis of the instances of exposure to radiation that actually occurred.

Safety culture
(Origin and development of the accident, see question 1)

The framework of organisational, official, political and social conditions and the underlying mechanisms of human behaviour and of the functioning of organisations must be taken into account when assessing the events in Japan, and they must be included when considering the applicability of these events to the situation in Switzerland. The nature of their impact and their (potential) effects on the safety of nuclear plants must be identified and understood. It is the responsibility and duty of every organisation in the nuclear sector, and specifically of the operators of nuclear plants and the supervisory authorities, to understand the potential and actual effects of these mechanisms and to take account of them in their organisations and/or actions by means of appropriate structures and procedures, and with the help of a culture that is safety-oriented and attentive.

ENSI is carrying out a detailed review to determine whether the events in Japan lead to new knowledge regarding the safety-oriented development of organisations that were as yet given insufficient consideration in previous supervisory practice and regulations of ENSI, and also in ENSI's own organisation. In this context, account must also be taken of the nature and impact of the overall system (i.e. the interaction of all the players involved, from the industry-side organisations, the regulatory body and the political bodies through to society as a whole).

Emergency management
(Measures to deal with the accident and its consequences, see questions 2 and 3)

The events at Fukushima clearly demonstrated that emergency management plays a decisive role in influencing the progression of a severe accident. For this reason, all the bodies involved must accord correspondingly high priority to emergency management by operators and authorities (supervisory authorities and local authorities as well as international organisations). In addition to the technical aspects of emergency management (e.g. the availability of technical equipment to initiate emergency measures), crucial importance also attaches to the human and organisational aspects (e.g. emergency sequences, procedures, decision-making and communication pathways, training and deployment of staff, etc.). In particular, the necessary attention must also be paid to the organisational measures to protect on-site staff against impermissible exposure to radiation while they are dealing with the accident. A central factor here is that the aim is not merely to plan and prepare for measures to cope with the broadest possible range of expected events.

In addition, it is necessary for considerations to include the ability of the participating organisations to deal with unforeseen events in which the planned measures do not work. Knowledge available to date also suggests that the working conditions for the staff present on site after the accident at Fukushima were extremely difficult in both physical and psychological terms. The impact of such conditions on the performance ability of individuals in an emergency situation requires in-depth consideration, and it must be taken into account by operators of nuclear plants and by the supervisory authorities when planning emergency actions.

Based on the assumption of a worst-case scenario, ENSI will review the extent to which findings from measures to cope with the accident at Fukushima influence the existing requirements for emergency management in respect of the operators and of ENSI itself, and ENSI will initiate improvement measures as and when this is necessary.

6 List of abbreviations

AEC	Atomic Energy Commission
AESJ	Atomic Energy Society of Japan
AN	Memo
ANRE	Agency for Natural Resources and Energy
ENSI	Swiss Federeal Nuclear Safety Inspectorate
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	International Nuclear and Radiological Event Scale
IRRS	Integrated Regulatory Review Service
JAIF	Japan Atomic Industrial Forum, Inc.
JANTI	Japan Nuclear Technology Institute
JINED	International Nuclear Energy Development of Japan
JNES	Japan Nuclear Energy Safety Organization
JSCE	Japan Society of Civil Engineers
METI	Ministry of Economy, Trade & Industry
MEXT	Ministry of Education, Culture, Sports, Science and Technology
NERHQ	Nuclear Emergency Response Headquarters
NHK	Nippon HosoKyokai, Japan Broadcasting Corporation
NISA	Nuclear and Industrial Safety Agency
NRC oder U.S.NRC	United States Nuclear Regulatory Commission
NSC	Nuclear Safety Commission
NYT	New York Times
ODL	Ortsdosisleistung
PSA	Probalistic Safety Analyzes
SAMG	Severe Accident Management Guidelines
SBO	Station Blackout
SPEEDI	System for Prediction of Environment Emergency Dose Information
STPB	Science and Technology Policy Bureau
TEPCO	Tokyo Electric Power Company

Fukushima

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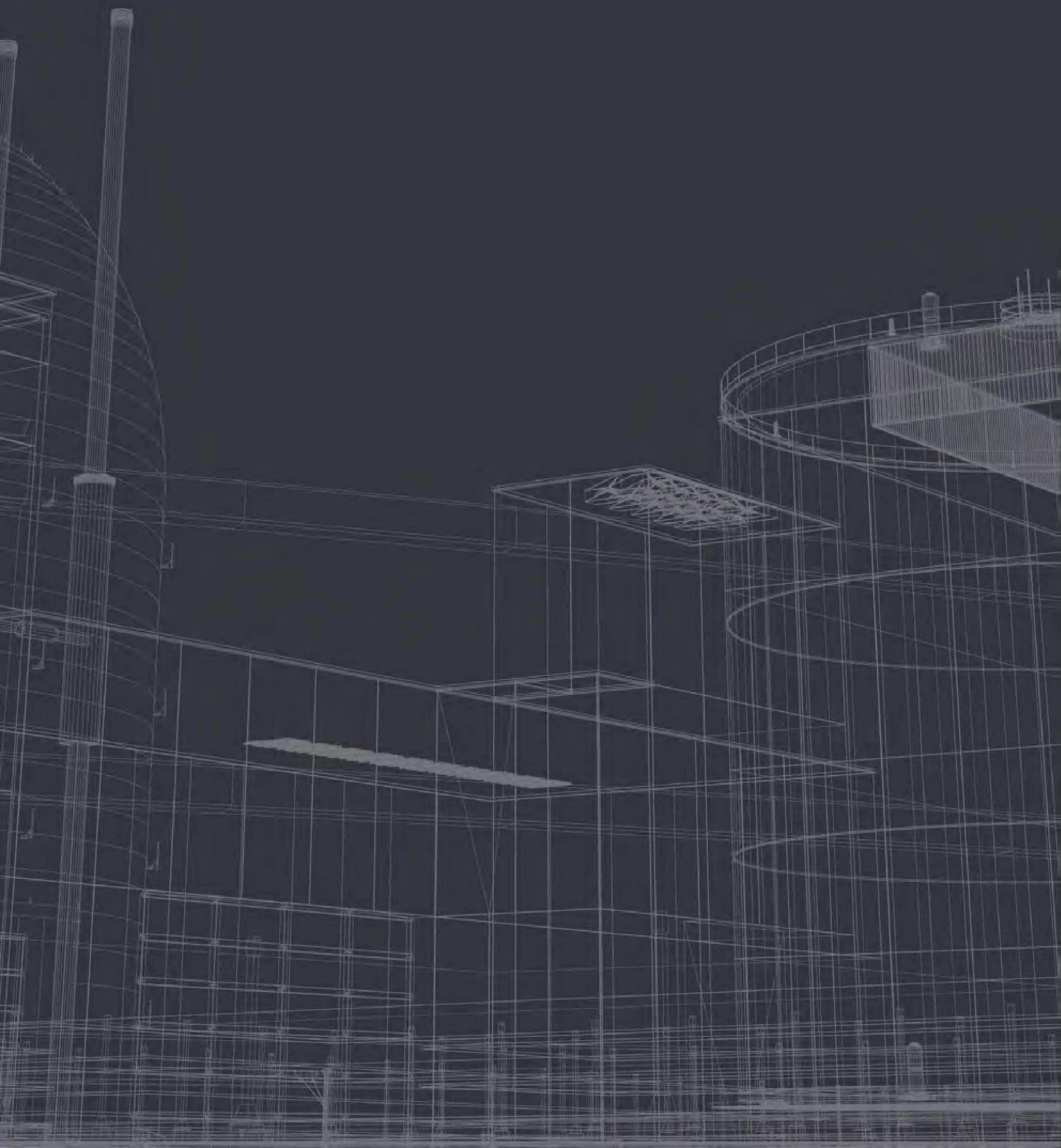

7 References

1 Ereignisabläufe Fukushima Dai-ichi und Daini infolge des Tohoku-Chihou-Taiheiy-ou-Oki Erdbebens vom 11.03.2011, ENSI-AN-7614 Rev. 1, Eidgenössisches Nuklear-sicherheitsinspektorat ENSI, 2011-08-26

2 Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, - The Accident at TEPCO's Fuku-shima Nuclear Power Stations -, Nuclear Emergency Response Headquarters, Government of Japan, 2011-06-18 kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html

3 Convention on Nuclear Safety, National Report of Japan, Fifth Review Meeting, Government of Japan, September 2010

4 Das schwere Tohoku-Seebeben in Japan und die Auswirkungen auf das Kernkraft-werk Fukushima-Dai-ichi, Bernhard Kuczera, Internationale Zeitschrift für Kernenergie, Sonderdruck aus Jahrgang 56 (2011) Heft4/5, April/Mai

5 Lessons Learned from TEPCO Nuclear Power Scandal, Speech and Presentation-Tokyo Electric Power Company (TEPCO), 2004-03-25 tepco.co.jp/en/news/presen/pdf-1/040325-s-e.pdf

6 Annual Report 2010, Optimal Energy Services, Our Focus in Value Creation, Tokyo Electric Power Company (TEPCO), Juli 2010 tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2010-e.pdf

7 JAIF Earthquake Report No. 77: 18:00, May 10, Japan Atomic Industrial Forum Inc. (JAIF), 2011-05-10 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1305023353P.pdf

8 IAEA: "Integrated Regulatory Review Service (IRRS) to Japan", Bericht IAEA-NSNI-IRRS, 2007-12-20

9 IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami, International Atomic Energy Agency (IAEA), 2011-06-01 iaea.org/newscenter/focus/fukushima/missionsummary010611.pdf

10 Sozialpsychologie, Aronson, E. , Wilson, T. D. & Akert, R. M., 4. Auflage. München, Pearson Studium, 2004

11 Convention on Nuclear Safety National Report of Japan for the Fifth Review Meeting, Government of Japan, Septem-ber 2010 nsc.go.jp/anzen/shidai/gen-an2010/genan053/siryo2-3.pdf

12 Presentation "Summary of Safety Regula-tion in Japan", Nuclear and Industrial Safety Agency (NISA), 2011-05-24 nisa.meti.go.jp/english/files/en20110526-1-1.pdf

13 JAIF Earthquake Report No. 104 18:00 June 06, Japan Atomic Industrial Forum Inc. (JAIF), 2011-06-06 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1307352120P.pdf

14 Press Release (May 02,2011), Report on investigation of cause and development of preventive measures regarding exposu-re exceeding dose limit to radiation dose engaged person at Fukushima Daiichi Nuclear Power Station to NISA, Tokyo Electric Power Company (TEPCO), 2011-05-02 tepco.co.jp/en/press/corp-com/release/11050211-e.html

15 JAIF Earthquake Report No. 105 18:00 June 07, Japan Atomic Industrial Forum Inc. (JAIF), 2011-06-07 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1307442268P.pdf

16 JAIF Earthquake Report No. 98 18:00 May 31, Japan Atomic Industrial Forum Inc. (JAIF), 2011-05-31 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1306833181P.pdf

17 Seismic Damage Information (the 92nd Release), Nuclear and Industrial Safety Agency (NISA), 2011-04-14 nisa.meti.go.jp/english/files/en20110416-7-1.pdf

18 Tsunami Information (Estimated Tsunami arrival time and Height), Japan Meteorological Agency, 2011-03-11, 14:49 jma.go.jp/en/tsunami info_04_20110311145026.html

19 Press Release (Jun 03,2011), Status of Evaluation Exposure Dose limits of TEPCO employ–ees at Fukushima Daiichi Nuclear Power Station (Continued Releases), Tokyo Electric Power Company (TEPCO), 2011-06-03 tepco.co.jp/en/press/corp-com/release/11060311-e.html

20 JAIF Earthquake Report No. 116 18:00 June 18, Japan Atomic Industrial Forum Inc. (JAIF), 2011-06-18 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1308388162P.pdf

21 JAIF Earthquake Report No. 100 18:00 June 2, Japan Atomic Industrial Forum Inc. (JAIF), 2011-06-02 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1307006763P.pdf

22 Press Release (Mar 25,2011), Result of the investigation on exposure to radiation of work-ers from cooperative companies at Unit3 in Fukushima Daiichi Nuclear Power Sta-tion(March 25, 2011), Tokyo Electric Power Company (TEPCO), 2011-03-25 tepco.co.jp/en/press/corp-com/release/11032503-e.html

23 JAIF Earthquake Report No. 112 18:00 June 14, Japan Atomic Industrial Forum Inc. (JAIF), 2011-06-14 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1308042843P.pdf

24 JAIF Earthquake Report No. 175 12:00 August 16, Japan Atomic Industrial Forum Inc. (JAIF), 2011-08-16 jaif.or.jp/english/news_images/pdf/ENGNEWS01_1313463676P.pdf

25 Management in a Dynamic Society: A Modelling Problem Rasmussen, Jens Safety Science, 27 (2/3), pp. 183-213 (1997)

26 Drift into Failure, From hunting broken components to understanding complex systems, Dekker, S.W.A., Aldershot, UK: Ashgate (2011)

27 Barriers and Accident Prevention, Hollnagel, Erik, Aldershot, UK: Ashgate (2004)

28 European Organisation for the Safety of Air Navigation (EUROCONTROL), A White Paper on Resilience Engineering for ATM, 2009 eurocontrol.int/esp/gallery/content/public/library/A%20White%20Paper%20Resilience%20Engineering/A_White_Paper_Resilience_Engineering.pdf

29 Japan Extended Reactor's Life, Despite Warning, New York Times, 2011-03-21 nytimes.com/2011/03/22/world/asia/22nuclear.html

30 Culture of Complicity Tied to Stricken Nuclear Plant, New York Times, 2011-04-26 nytimes.com/2011/04/27/world/asia/27collusion.html

31 Japanese Officials Ignored or Concealed Dangers, New York Times, 2011-05-16 nytimes.com/2011/05/17/world/asia/17japan.html?ref=japan

32 In Japan, a Culture That Promotes Nuclear Dependency, New York Times, 2011-05-30 nytimes.com/2011/05/31/world/asia/31japan.html

33 AP Exclusive: Fukushima tsunami plan a single page, Associated Press, 2011-05-27

34 Forscher: Japan schätzte Bebengefahr falsch ein, Österreichischer Rundfunk ORF, 2011-04-14 science.orf.at/stories/1681378/

35 Nuclear Rules in Japan Relied on Old Science, New York Times, 2011-03-26 nytimes.com/2011/03/27/world/asia/27nuke.html?_r=3&hp

36 AP IMPACT: Nuclear plant downplayed tsunami risk, YAHOO! News, 2011-03-27

37 Die Warner, die nicht gehört wurden - Ausland: Japan im Ausnahmezustand, Tagesanzeiger, 2011-03-28 tagesanzeiger.ch/ausland/die-tsunami-katastrophe/Die-Warner-die-nicht-ge-hoert-wurden/story/20980711?dossier_id=885

38 The geologist who predicted Japan‘s tsunami, The Week, 2011-04-12 theweek.com/article/index/214132/the-geologist-who-predicted-japans-tsunami

39 Madarame: Plant guidelines should be fully revised, NHK World, 2011-06-05 www3.nhk.or.jp/daily/english/05_23.html

40 ‘Safety Myth’ Left Japan Ripe for Nuclear Crisis, New York Times, 2011-06-24 nytimes.com/2011/06/25/world/asia/25myth.html?ref=japan

41 In Nuclear Crisis, Crippling Mistrust, New York Times, 2011-06-12 nytimes.com/2011/06/13/world/asia/13japan.html?ref=japan

42 Letters From Fukushima: Tepco Worker Emails, Wall Street Journal, 2011-03-28 blogs.wsj.com/japanrealtime/2011/03/28/letters-from-fukushima-tepco-worker-emails/

43 Economy Sends Japanese to Fukushima for Jobs, New York Times, 2011-06-08 nytimes.com/2011/06/09/world/asia/09japan.html

44 Tepco weiss nicht, was abläuft, Tagesanzeiger, 2011-03-22 tagesanzeiger.ch/ausland/die-tsunami-katastrophe/Tepco-weiss-nicht-was-abla-euft story/24725993?dossier_id=885

45 Core of reactor 1 melted 16 hours after quake, The Japan Times, 2011-05-16 search.japantimes.co.jpcgi-bin/nn20110516a1.html

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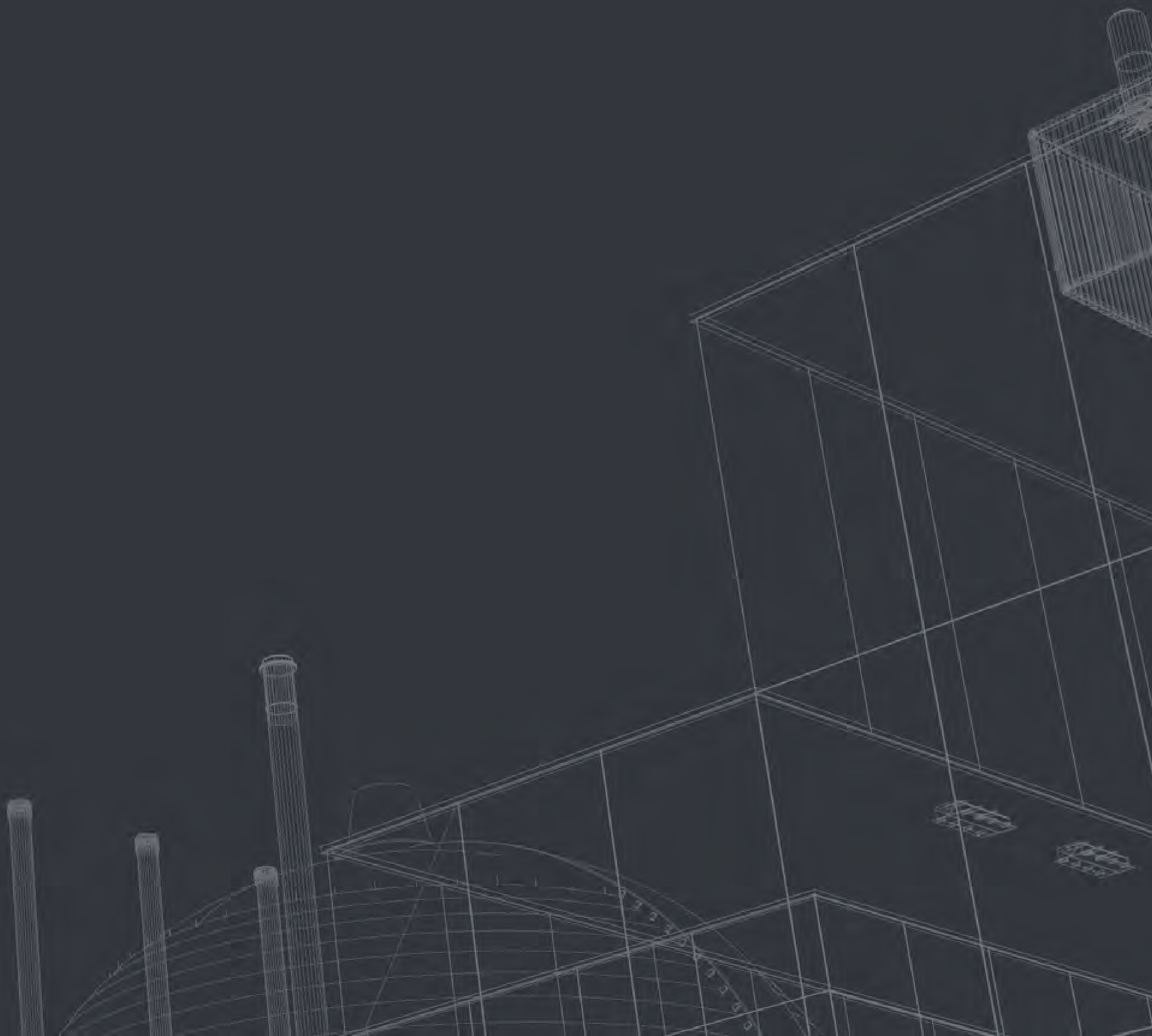

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Swiss Federal Nuclear Safety Inspectorate ENSI

Issued by
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Phone +41 (0)56 460 84 00
Fax +41 (0)56 460 84 99
info@ensi.ch
www.ensi.ch

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