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**NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

**NEA/CSNI/R(2008)14
Unclassified**

Working Group on Integrity and Ageing of Components and Structures (IAGE WG)

Sub-group on the Integrity and Ageing of Concrete Structures

**A DECADE OF CSNI ACTIVITIES IN THE AREA OF AGEING OF NUCLEAR POWER PLANT
CONCRETE STRUCTURES**

The enclosed CD-ROM contains the Proceedings of the CSNI Workshops on Prestress Loss, NDE in Concrete, FE Analysis of Degraded Concrete Structures, Instrumentation and Monitoring and Repair.

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the OECD member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; to promote the coordination of work that serve maintaining competence in the nuclear safety matters, including the establishment of joint undertakings.

The committee shall focus primarily on existing power reactors and other nuclear installations; it shall also consider the safety implications of scientific and technical developments of new reactor designs.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA) responsible for the program of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health (CRPPH), NEA's Radioactive Waste Management Committee (RWMC) and NEA's Nuclear Science Committee (NSC) on matters of common interest.

FOREWORD

The Committee on the Safety of Nuclear Installations (CSNI) Working Group on Integrity and Ageing of Components and Structures (IAGE) has as a general mandate to advance the current understanding of those aspects relevant to ensuring the integrity of structures, systems and components, to provide for guidance in choosing the optimal ways of dealing with challenges to the integrity of operating as well as new nuclear power plants, and to make use of an integrated approach to design, safety and plant life management.

The Working Group has three subgroups dealing with (a) integrity and ageing of metal structures and components, (b) integrity and ageing of concrete structures, and (c) seismic behaviour of components and structures.

The IAGE sub-group on concrete structures developed a medium to long term programme of work in the area of structural integrity and ageing of concrete structures.

The programme includes a series of workshops that address specific issues associated with ageing of concrete structures such as Loss of pre-stress force in tendons of post-tensioned concrete structures, In-service inspection techniques for reinforced concrete structures, Response of degraded structures, Instrumentation and monitoring and Repair methods including criteria for conditions assessment.

This report compiles and summarises conclusions derived from each of the workshops and include recommendations on collection and recording of data and information obtained during nuclear power plant decommissioning.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

FOREWORD	7
ACKNOWLEDGMENTS	9
TABLE OF CONTENTS	11
EXECUTIVE SUMMARY	13
I. AGEING AND STRUCTURAL INTEGRITY OF NPP CONTAINMENTS	15
I.1 Background and scope.....	15
I.2 Loss of pre-stress force in tendons of post-tensioned concrete structures.....	16
I.3 In-service inspection techniques for reinforced concrete structures having thick sections and areas not directly accessible for inspection	18
I.4 Response of degraded structures (including finite-element analysis techniques)	19
I.5 Instrumentation and monitoring	19
I.6 Repair methods; criteria for condition assessment	20
II. RECOMMENDATIONS ON UTILISATION AND COLLECTION OF DATA AND INFORMATION OBTAINED DURING DECOMMISSIONING.....	23
II.1 Background	23
II.2 Scope and objectives	23
II.3 Visual inspection	23
II.4 Concrete characterisation programme.....	24
II.5 Predictive models and safety evaluation analyses	24
II.6 Recommendations	25

EXECUTIVE SUMMARY

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD-NEA co-ordinates the NEA activities concerning the technical aspects of design, construction and operation of nuclear installations in so far as they affect the safety of such installations.

In 1994, the CSNI approved a proposal to set up a Task Group under its Principal Working Group 3 (re-named as the Working Group on Integrity of Components and Structures (IAGE)) to study the need for a programme of international activities in the area of concrete structural integrity and ageing and how such a programme could be organised.

The task group reviewed national and international activities in the area of ageing of nuclear power plant concrete structures and the relevant activities of other organisations. The results of this review were provided in a report:

OECD Nuclear Energy Agency, NEA/CSNI/R(95)19, "Report of the task group reviewing national and international activities in the area of ageing of NPP concrete structures" (<http://www.nea.fr/html/nsd/docs/2002/csni-r2002-14.pdf>).

That report recommended that a CSNI programme of workshops be developed to address specific technical issues, which had been prioritised by the OECD-NEA task group into three levels.

This document contains a summarisation of conclusions drawn from these workshops as well as expert-generated recommendations on collection and recording information during NPP decommissioning to provide an improved understanding of the long-term behaviour of concrete structures.

The programme of workshops run under the auspices of CSNI has directly addressed the concerns of designers, operators and regulatory bodies with regard to the performance of concrete structures on nuclear facilities. The series of workshops has allowed the exchange of information and good practice between individual plants, national and international programmes and informed decision making in other international bodies such as IAEA and the EC.

I. AGEING AND STRUCTURAL INTEGRITY OF NPP CONTAINMENTS

I.1 Background and scope

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD-NEA co-ordinates the NEA activities concerning the technical aspects of design, construction, and operation of nuclear installations in so far as they affect the safety of such installations. Ensuring the performance and function of nuclear power plant safety-related concrete structures is important to continuing the reliable and safe production of electricity.

Protecting the environment from the release of radioactive material under normal operational and accident conditions is a fundamental safety function in a nuclear plant. On most modern plants a containment structure is used to provide the final barrier to the environment. These structures are large and complex and are normally formed from concrete. Containments are usually pre-stressed to keep the structure in compression under normal and design accident loads and may have bonded (grouted) or unbonded (ungouted) tendons with or without a steel liner. Some containments consist of a single shell whereas in others, particularly unlined containments, there may be an outer shell which provides additional impact and weather protection with the ability to evacuate the interspace between the shells to prevent external leakage. In some reactor designs, reinforced concrete is used for the containment structure. In such cases the structure is heavily reinforced with steel to prevent and control cracking. Containment structures are generally the most important structures on NPPs but there are other concrete structures, generally dependent on particular reactor designs, which also fulfil important safety functions. In the case of UK Advanced Gas-cooled Reactors and some designs of high temperature reactor, the reactor pressure vessel is formed from pre-stressed concrete with a steel liner.

In order to guarantee structural integrity, the management of ageing is important for all concrete structures that are required to fulfil a nuclear safety function. Consequently, various national and international programmes have investigated ageing effects and potential failure mechanisms in order to understand the mechanisms involved more fully.

In 1994, the CSNI approved a proposal to set up a Task Group under its Principal Working Group 3 (recently re-named as the Working Group on Integrity of Components and Structures (IAGE)) to study the need for a programme of international activities in the area of concrete structural integrity and ageing and how such a programme could be organised.

The Task Group reviewed national and international activities in the area of ageing of nuclear power plant concrete structures and the relevant activities of other organisations. The results of this review were provided in a report: "Report of the Task Group Reviewing International Activities in the Area of Ageing of Nuclear Power Plant Concrete Structures," NEA/CSNI/R(95)19 (<http://www.nea.fr/html/nsd/docs/2002/csni-r2002-14.pdf>).

The Task Group found that a number of national and international programs were addressing ageing issues associated with these structures; however, these studies are generally application specific, or in the case of international programs, tend to be more general in that they are preparing state-of-the-art reports and not addressing specific issues in depth. As a result of this, the Task Group recommended a medium-to-long term CSNI program of work that included holding a series of workshops that address specific issues associated with ageing. These workshops were prioritised by the Task Group as follows:

- First Priority
 - Loss of pre-stress force in tendons of post-tensioned concrete structures.
 - In-service inspection techniques for reinforced concrete structures having thick sections and areas not directly accessible for inspection (a round robin testing activity could result from this workshop).
- Second Priority
 - Viability of development of a performance-based database.
 - Response of degraded structures (including finite-element analysis techniques, possibly leading to an International Standard Problem).
- Third Priority
 - Instrumentation and monitoring.
 - Repair methods.
 - Criteria for condition assessment.

As a result of this recommendation, the CSNI convened a series of workshops and published related reports as shown in the Table below. Most of these reports summarise the findings derived from the workshops. In addition, the IAGE has developed a recommendation on collection and recording of data and information obtained during nuclear power plant decommissioning to provide an improved understanding of the long-term behaviour of concrete structures. Conclusions derived from each of the workshops and information related to utilisation of decommissioned facilities are provided below:

WORKSHOP TOPIC	LOCATION AND DATE	OECD REPORTS
Pre-stress Loss	Poitiers, FR, August 1997	NEA/CSNI/R(97)9
NDE in Concrete	Risley, UK, November 1997	NEA/CSNI/R(97)28
FE Analysis of Degraded Concrete Structures	Upton, NY, October 1998	NEA/CSNI/R(99)1
Instrumentation	Brussels, BE, March 2000	NEA/CSNI/R(2000)15
Monitoring and Repair	Berlin, DE, April 2002	NEA/CSNI/R(2002)7

I.2 Loss of pre-stress force in tendons of post-tensioned concrete structures

Maintenance of pre-stress above the minimum design level is necessary for the structural integrity of pre-stressed concrete structures, such as nuclear containments, under accident conditions. Pre-stress reduces with time and it is important to ensure that the condition of the pre-stressing system is maintained in an appropriate manner for the life of the nuclear facility. A number of different factors can influence pre-stress losses, some of which are generic and others specific to particular designs. The workshop on pre-stress loss considered experience and practice internationally and drew the following conclusions;

1. Present experience suggests that current methods for prediction of the loss of tendon pre-stress are generally satisfactory.
2. The nuclear industry has adopted regulatory and codified methods for predicting the loss of pre-stress in nuclear power plant (NPP) pre-stressed concrete containments from international and national standards that are not necessarily specific to nuclear design. The application of the different methods to a specific case is likely to lead to significant differences in the predicted losses.

3. Theoretical and experimental research have established the importance of understanding how chemical, hygral, mechanical, and thermal factors influence the short-term and long-term behaviour of pre-stressed concrete. In particular, they have differentiated between creep, drying shrinkage, and relaxation of pre-stressing steel, and identified the interdependency of these phenomena. However, research has, as yet, failed to formulate a universal and reliable model for predicting both short and long-term loss of pre-stress in actual pre-stressed concrete structures. Current and proposed activities aimed at improving the prediction of loss of pre-stress include: the creep behaviour of concrete in a biaxial or multiaxial stress field; standardisation of creep experiments to provide reliable data; experiments on the effects of temperature on pre-stressing steels and the development of approximate formulae; and both empirical and semi-empirical models to improve the prediction of shrinkage and creep in concrete, and relaxation of steel.
4. Improved and simplified simulations of creep and shrinkage phenomena that can account for the environment and loading history of pre-stressed concrete containments and pressure vessels will assist: the development of design regulations/standards; the choice of concrete mix; the development of relevant monitoring programmes; and ageing management, including plant life extension.
5. Pre-stressed concrete containments and pressure vessels use both grouted (bonded) tendons and ungrouted (unbonded) tendons. The relative merits of both systems were considered.
 - Grouted Tendons. The cementitious grout surrounds the tendon with an alkaline environment that will inhibit corrosion of the steel, and prevent the ingress and circulation of corrosive fluids. In case of break of a tendon, due to the bond with the grout, part of the pre-stress remains transmitted to the concrete. Therefore grouted tendons are less vulnerable than ungrouted tendons to local damage. They reduce the risk of the containment being by-passed via tendon ducts, which is particularly important where the containment is unlined. However, grouted tendons cannot be visually inspected, mechanically tested, or re-tensioned.
 - UngROUTED Tendons. Pre-stressing force is transmitted to the concrete, primarily at the location of the anchorages. Corrosion is prevented by organic petroleum-based greases or corrosion-inhibiting compounds that are either applied to the surface of the tendon prior to installation or injected into the tendon duct following completion of the stressing sequence. Some countries use a combination of both coating and injection. Tendons can be removed for visual inspection/replacement, mechanically tested in-situ, and retensioned to maintain pre-stress. UngROUTED tendons are more vulnerable than grouted tendons to local failure and corrosive fluids can circulate along the ducts. Ducts may provide a route for containment by-pass in unlined containments, although the practice of keeping ducts filled with corrosion protection medium reduces the likelihood of by-pass.
6. Comprehensive and regular monitoring of the behaviour of containments and pressure vessels at operational plants will assist in understanding the cause of loss of pre-stress. Many containments around the world include instruments to measure: anchorage loads; concrete strain; structural geometry; concrete temperature; and surface cracking. Data collected from more than 150 structures aged between 3 and 40 years indicate that, for the majority, loss of pre-stress has been less than predicted; however, for some containments, losses have exceeded predictions. Measured losses vary from containment design to containment design but significant differences have also been observed between containments in the same design series. The variation in measured losses has been attributed to a number of factors including: concrete composition; aggregate type; presence of a liner; high relaxation of steel tendons; concrete temperatures; loading history; and the environment. Regulatory and codified prediction techniques do not necessarily account for such factors.

7. Many plants include direct measurement of tendon loads at the anchorage. Problems have been reported relative to the reliability and accuracy of tendon load measurement. The use of tendon load to interpret loss of pre-stress requires careful consideration of the method used to measure the load and the design of the pre-stressing system.
8. Nuclear containments and pressure vessels are designed with large margins on structural integrity. Therefore, a higher than expected loss of pre-stress does not necessarily jeopardise the integrity of the structure. However, under accident conditions the margin on pre-compression of the concrete is reduced and therefore there is an increased risk of cracking. This may result in a corresponding increase in the leak rate of unlined containments. Periodic testing of the containment is used to evaluate its leaktightness.
9. Organic-based greases or corrosion inhibitors have been used as the corrosion protection media for containments and pressure vessels having ungrouted tendons. For systems where the tendon duct is filled with protection media, greases have been developed that optimise: viscosity, resistance to penetrating concrete; water displacement; alkalinity and electrical conductivity. For systems using coated tendons, with time the grease loses its lighter oil component but the residue is still capable of providing corrosion protection to the tendons.

I.3 In-service inspection techniques for reinforced concrete structures having thick sections and areas not directly accessible for inspection

Concrete structures on NPPs are generally heavy industrial structures which often have a significant nuclear safety function. It is important that the condition and future lifetime of such structures may be assessed to ensure nuclear safety. The workshop on In-Service Inspection Techniques for Reinforced Concrete Structures having Thick Sections and Areas Not Directly Accessible for Inspection considered experience and practice internationally and drew the following conclusions:

1. NDE techniques have the potential to satisfy at least some of the needs of the nuclear industry. NDE techniques have been used successfully on a variety of reinforced and post-tensioned concrete structures, notably highway and reservoir structures. However, there is limited experience of their use to evaluate typical nuclear safety-related structures having thick sections, steel liners, or where access is limited to one side only.
2. There is a general lack of confidence in the NDE techniques because there is very little independent advice on their applicability, capability, accuracy, and reliability. The information obtained by techniques such as RADAR, ultrasonics, stress wave, and radiography appear to be more qualitative rather than quantitative, and there is concern that NDE procedures lack the necessary qualification to permit their use on safety critical structures. There is no authoritative international guidance or standard for NDE of concrete structures.
3. NDE of concrete structures is often based on equipment developed for other materials and technologies (e.g., examination of steel and evaluation of ground conditions). Other industries are developing equipment specifically for civil engineering applications and a number of relevant national and European programmes exist. The nuclear industry maintains its awareness of developments and should seek to influence the development of equipment.
4. Quantification of the capabilities of NDE techniques is seen as a priority area for development. The provision of authoritative documentation in the form of reports and standards is desirable; however, the industry lacks an international standard for quantifying the NDE of nuclear safety-related

concrete structures. Qualification is important to the successful deployment of NDE techniques and will need to be considered when addressing this issue.

5. The high cost of developing software and equipment, with no guarantee of success, means that the nuclear industry is unlikely to consider this to be a priority area for funding. However, it is important for the industry to establish national networks with groups that are funding development. There is support for the principle of establishing a group of international experts to monitor national developments.

I.4 Response of degraded structures (including finite-element analysis techniques)

Structural ageing effects may lead to degradation of the structural condition and performance of concrete structures on nuclear facilities. It is important that the effects of such degradation are included in the modelling of concrete structures for the nuclear industry in order to accurately confirm their performance. The workshop on Response of Degraded Structures considered experience and practice internationally and drew the following conclusions:

1. Finite-element (FE) methods are widely used to meet regulatory requirements for assurance of structural safety.
2. For most analyses of concrete structures, simplified methods or linear-elastic analyses are adequate, but for realistic response predictions non-linear analyses are often needed, especially for high temperature applications or predictions of local failures.
3. The application of non-linear FE analysis to degraded concrete structures is considered to be a relatively new research subject. There is limited information available on non-linear behaviour of concrete. A valid non-linear analysis depends on a constitutive model that can adequately represent the behaviour of concrete beyond its linear range, and appropriate materials data.
4. Other industries are currently pursuing FE analysis of degraded structures.
5. Some scatter and uncertainty in the results have been identified.
6. Three-dimensional FE calculations for reinforced concrete requires a good understanding of the behaviour of concrete structures, and experience to judge validity of the results.
7. Degraded structures have special features of material behaviour and structural modelling that need to be considered.
8. With few exceptions, analysis of initially degraded concrete containment structures has not been adequately investigated.
9. There are very limited experimental data on degraded concrete structures that would permit validation of the non-linear FE analytical method. Test results for shear transfer in cracked reinforced concrete panels would be useful to develop/refine models for degraded structures.

I.5 Instrumentation and monitoring

Instrumentation and monitoring fulfils an important role in the on-going assessment and lifetime prediction of concrete structures on nuclear facilities. At depth in large, thick concrete structures and in areas where personnel access for other forms of monitoring and inspection are not possible, instrumentation provides a useful, and in many case only, method by which changes in the structural condition or performance may be

measured. The workshop on Instrumentation and Monitoring considered experience and practice internationally and drew the following conclusions:

1. There is now a perceived need to address the ageing of concrete structures. To this end, the use and acceptance of instrumentation techniques has increased with time and more reliance is being placed on such techniques.
2. It is extremely difficult to replace instrumentation that was installed at the time of construction. Cabling can also cause problems, but is easier to replace unless imbedded.
3. Instrumentation provides an indication that something may be happening. Interpretation and diagnosis require detailed studies and assessment and eventually additional inspection.
4. Numerical modelling assists in interpretation of results obtained from instrumentation. Revised numerical models based on data from instrumentation are useful in predicting future performance. Data from instrumentation during destructive tests of models and monitoring of decommissioned plants can provide useful information for validation of finite-element codes.
5. The usefulness of installed instrumentation is dependent on the accuracy and reliability of the sensors used. Instrumentation has been improved by developments with regard to computer management systems and databases.
6. The understanding and use of instrumentation, numerical modelling techniques, and promising NDE methods are complementary tools for the assessment of ageing of concrete structures.
7. New plants should include instrumentation with defined objectives for the purpose of monitoring structural performance and aging from the time of construction through decommissioning.

I.6 Repair methods; criteria for condition assessment

In order to maintain concrete structures on nuclear facilities in a condition that will ensure that they will continue to perform the duty required of them with regard to maintaining nuclear safety it is often necessary to consider carrying out repairs based on assessments of their condition. This is particularly important as structures become older and ageing degradation is more evident. The workshop on Repair Methods and Criteria for condition Assessment considered experience and practice internationally and drew the following conclusions:

1. Repairs to concrete NPP structures and their durability will continue to be an issue until final decommissioning.
2. Experience gained during repair projects, and extensive field studies of repaired structures, show that the effectiveness of the concrete repair is dependent on:
 - correct diagnosis of the cause of the damage;
 - selection of a repair strategy that addresses this cause;
 - choice of appropriate repair materials and methods;
 - careful management of the process; and
 - post repair maintenance strategy supported by comprehensive records.

Computerised databases can assist with: recording the detection and diagnosis of damage; recording the location of, and specification for repairs; and management of the subsequent repair.

3. The combination of concrete with composite materials is useful in a repair situation. These materials now have a track record in structural repairs through their application to a decommissioned pre-stressed concrete containment (PCC). Extensive testing has proved their potential as an alternative to steel as a liner for PCCs, and they are currently being considered for enhancing the leak tightness of unlined containments.
4. Surface overcoating materials can protect exposed concrete surfaces from deterioration due to environmental factors (e.g., carbonation and chlorides). Careful design will ensure that the coating system can accommodate structural movement, maximise durability, and satisfy aesthetic considerations.
5. Experience of repairs, supported by field studies of repaired structures, confirm that a principal cause of damage to reinforced concrete structures is corrosion of the reinforcement. Impressed current cathodic protection (CP) has been shown to be effective in improving the durability of a repaired structure exposed to a very severe marine environment. Laboratory examination of samples of concrete removed from a structure protected by CP has shown that long-term application of impressed current CP was not detrimental to the original concrete and did not affect the steel to concrete bond.
6. There was recognition that the nuclear industry might benefit from improved guidance on assessment of defects and the effectiveness of subsequent repairs. However, absolute criteria are difficult to define and may not be universally applicable.
7. Laboratory trials of impact echo and the synthetic aperture focusing NDE techniques have shown that they have potential to detect subsurface features in concrete elements, but significant further development is required for field implementation.
8. Laboratory tests are providing important data on the leakage of air and air/steam through cracked concrete. These tests will help provide information related to the assessment of pressure-retaining concrete structures for NPPs and provide a useful source of validation for numerical models and simulation.
9. Results from structural monitoring of NPP concrete structures confirm that the practicality of installing instrumentation is of equal importance to its ability to measure the damage parameter under investigation. Acoustic monitoring has demonstrated the potential to detect and locate cracking and may warrant further consideration as a tool for assisting in the testing of containment structures.
10. There is little data available on the effect of irradiation on concrete. Samples of concrete removed from a biological shield structure have provided some information.
11. A pre-prepared structural condition assessment procedure listing nuclear safety related structures may be useful in assessing post-fire damage on NPPs. Materials used in the repair of fire damage must be capable of meeting the fire performance criteria required by the original structure.

II. RECOMMENDATIONS ON UTILISATION AND COLLECTION OF DATA AND INFORMATION OBTAINED DURING DECOMMISSIONING

II.1 Background

The evaluation of concrete structure performance after many decades of service is of interest for safety evaluation of nuclear installations. Many NPPs are approaching the end of their design life and programmes to extend their operating licenses have been undertaken in many countries to assure adequate safety levels for the extended operational period. Some of these programs also address the whole decommissioning phase that can last, depending on the strategy of decommissioning, from a few years up to several decades.

The massive size of NPP reinforced concrete structures and the limited accessibility of some areas constitute a great challenge for in-situ inspection and monitoring in operating NPPs. The usefulness of and interest in investigation of concrete structures of nuclear plants during decommissioning is therefore apparent. The possibility of carrying out extensive campaigns with some of the access restrictions reduced and the chance of executing different types of destructive and semi-destructive testing is appealing.

II.2 Scope and objectives

A complete programme of concrete structure characterisation can be deemed worthwhile for those decommissioning strategies, such as SAFESTORE, that imply the need for continuing maintenance and operation for a long period. Evaluation of the status of concrete structures and prediction of the remaining service life are therefore important issues in decommissioning management.

Even when the duration of the decommissioning period is much shorter, as it is for the DECON strategy, the possibility offered by a facility no longer in operation can be exploited by the plant owner to develop plans to gather relevant data that would not be possible in an operating plant.

It is presumable that the environmental and operating conditions experienced by plant structures are sufficiently similar that data from the decommissioned unit can help to assess the relations between ageing mechanisms and concrete degradation. This could permit the development of improved methods for facility inspection and maintenance as well as the set-up of damage predictive damage models for a more realistic evaluation of the remaining life of concrete structures of units still in operation.

The collected data and the tested methodologies will moreover provide interesting information to be used in the design of spent fuel storage facilities and radioactive waste repositories, where concrete efficiency for period of times on the order of more than one hundred years is requested.

II.3 Visual inspection

A detailed plant survey can be considered as a preliminary step, whatever is the decommissioning strategy adopted, for the data collection and recording from a decommissioned facility. Visual examinations helps in identifying ageing related problem areas by detecting the visible effects of ageing stressors - such as cracking, spalling, moisture, efflorescence, etc. - on the surface of the structural elements.

The objective of the activity is to identify concrete structures where ageing damages can be expected - thus focusing further investigation on these parts further investigation activities to provide a preliminary assessment of their state of preservation. Knowledge of results from past surveillance, inspections and investigations (periodic mapping, measurement) are important with respect to evaluation of the progressive nature of damage and consequently the original causes.

This activity can be easily performed in a cost-efficient way but it provides only a picture of the surveyed surface symptoms of ageing mechanisms acting on the structures. Its contribution to the improvement of ageing issue in an operating plant is therefore limited.

II.4 Concrete characterisation programme

Decommissioned facilities allow extensive and different types of investigations (non-destructive and semi-destructive techniques) with some of the access restrictions reduced. A wide experimental program is generally justified for decommissioning periods greater than 30 years.

Experimental activities can be developed to identify the most important chemical and physical degradation mechanisms and their effects and to determine the mechanical properties of the material. In most of the safety-related structures of in-service nuclear facilities, destructive techniques (like coring of concrete to provide samples for testing) are not always applicable. Non destructive techniques (NDT) generally furnish qualitative results; however, some limitations to their use come from limited accessibility, large section thickness and heavy reinforcement of structural elements to be investigated.

The relevant aspect of data collection from decommissioned plants, as compared to normal in-service plants, is therefore the opportunity to integrate non-destructive measurements with destructive tests, including accelerated ageing tests, allowing:

- a better assessment of the state of preservation of concrete structures and steel reinforcement,
- the investigation of NDT capabilities in detecting material properties degradation, including development and validation of new innovative techniques, and
- an estimate of the durability of concrete and of the safety margins of the structures for times equal or greater than the design life.

II.5 Predictive models and safety evaluation analyses

The interpretation of experimental data - historical data, in-situ and laboratory test measures and accelerated tests results – is essential to develop predictive models that are able to describe the degradation of reinforced concrete structure in relation with chemical and physical processes. At the base of model development are:

- identification of the parameters that govern the predictive models response, and
- validation of the predictive model on the basis of the effects of degradation processes measured on the structures.

Even though numerical activities are characterised by a high level of uncertainty about environmental and structural loads as well as engineering materials properties and strength degradation mechanisms, they constitute the best tool engineers have to extrapolate structural safety margins.

II.6 Recommendations

- The opportunity to obtain samples and data from decommissioned concrete structures in nuclear power plants should be taken whenever possible.
- A comprehensive survey should be carried out during decommissioning including the use of NDE or destructive sampling. Where possible, decommissioned structures should be used for the evaluation of NDE techniques (existing as well as new approaches).
- The particular aim of any investigation during the decommissioning of a plant should be to identify in-service degradation and ageing effects.