Unclassified **NEA/CNRA/R(2011)6**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

14-Mar-2011

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

NEA/CNRA/R(2011)6
Unclassified

Cancels & replaces the same document of 11 March 2011

Operating Experience Report:
Recent Failures of Large Oil-Filled Transformers

Working Group on Operating Experience (WGOE)

JT03298131

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

English text only

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 29 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

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.

COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

The Committee on Nuclear Regulatory Activities (CNRA) shall be responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. The Committee shall constitute a forum for the effective exchange of safety-relevant information and experience among regulatory organisations. To the extent appropriate, the Committee shall review developments which could affect regulatory requirements with the objective of providing members with an understanding of the motivation for new regulatory requirements under consideration and an opportunity to offer suggestions that might improve them and assist in the development of a common understanding among member countries. In particular it shall review current management strategies and safety management practices and operating experiences at nuclear facilities with a view to disseminating lessons learnt. In accordance with the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016, the Committee shall promote co-operation among member countries to use the feedback from experience to develop measures to ensure high standards of safety, to further enhance efficiency and effectiveness in the regulatory process and to maintain adequate infrastructure and competence in the nuclear safety field.

The Committee shall promote transparency of nuclear safety work and open public communication. The Committee shall maintain an oversight of all NEA work that may impinge on the development of effective and efficient regulation.

The Committee shall focus primarily on the regulatory aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it may also consider the regulatory implications of new designs of power reactors and other types of nuclear installations. Furthermore it shall examine any other matters referred to it by the Steering Committee. The Committee shall collaborate with, and assist, as appropriate, other international organisations for co-operation among regulators and consider, upon request, issues raised by these organisations. The Committee shall organise its own activities. It may sponsor specialist meetings and working groups to further its objectives.

In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on the Safety of Nuclear Installations in order to work with that Committee on matters of common interest, avoiding unnecessary duplications. The Committee shall also co-operate with the Committee on Radiation Protection and Public Health and the Radioactive Waste Management Committee on matters of common interest.

FOREWORD

The NEA Committee on Nuclear Regulatory Activities (CNRA) believes that sharing operating experience from the national operating experience feedback programmes are a major element in the industry's and regulatory body's efforts to ensure the continued safe operation of nuclear facilities. Considering the importance of these issues, the Committee on the Safety of Nuclear Installations (CSNI) established a working group, PWG #1 (Principle Working Group Number 1) to assess operating experience in the late 1970's, which was later renamed the Working Group on Operating Experience (WGOE). In 1978, the CSNI approved the establishment of a system to collect international operating experience data. The accident at Three Mile Island shortly after added impetus to this and led to the start of the Incident Reporting System (IRS).

In 1983, the IRS database was moved to the International Agency for Atomic Energy (IAEA) to be operated as a joint database by IAEA and NEA for the benefit of all of the member countries of both organisations. In 2006, the WGOE was moved to be under the umbrella of the Committee on Nuclear Regulatory Activities (CNRA) in NEA. In 2009, the scope of the Incident Reporting System was expanded and re-named the International Reporting System for Operating Experience (although, the acronym remains the same).

The purpose of WGOE is to facilitate the exchange of information, experience, and lessons learnt related to operating experience between member countries. The working group continues its mission to identify trending and issues that should be addressed in specialty areas of CNRA and CSNI working groups.

TABLE OF CONTENTS

1. BACKGROUND

A main activity of the WGOE is to review events and trends from operating experience that have safety issues with generic importance and need to be addressed from a regulatory viewpoint. From this activity performed by WGOE, recommendations are provided to the CNRA on regulatory issues and the Committee on the Safety of Nuclear Installations (CSNI) on technical and scientific issues.

At the May 2009 meeting of the WGOE, transformer failures were discussed as an issue of generic importance. The US NRC had identified that transformer failures had an increasing trend. Transformers are non-safety related equipment. As such, the maintenance practices are generally outside of the regulatory purview. The US NRC developed a short questionnaire to discuss the regulatory treatment of transformers and the operating experience in the member countries. At the conclusion of the discussion, the members decided that sufficient information and interest was available to support a task on large oil-filled transformers.

In December 2009, the WGOE was granted CNRA approval for a task on transformer failures. The United States and Canada volunteered to support the task. A more detailed questionnaire was developed for the member countries to contribute their operating experience on transformer failures.

2. FAILURES OF LARGE, OIL-FILLED TRANSFORMERS AND RISK SIGNIFICANCE

2.1 Large Oil-Filled Transformers

Large oil-filled transformers provide the primary connections between the nuclear power plant and the electric grid, with the main generator transformer providing output to the grid and unit and station auxiliary transformers providing offsite power to the plant. Rated at tens or hundreds of thousands of megavolt-ampere (MVA), these high energy systems are often maintained by outside contractors, and involve multiple supporting components, including cooling systems, surge arrestors, bushings/insulators, and control systems, all of which must be properly maintained in order to provide for the safe operation of the transformer.

2.2 Risk Significance

With the exception of some auxiliary transformers which function as part of the onsite electrical distribution systems, large, oil-filled transformers are generally considered to be non-safety related equipment. Their primary function is continued power production, and they are not relied upon for the safe shutdown of the reactor. As such, failures of large transformers generally are not, in and of themselves, required to be reported, nor are they covered by specific regulatory requirements.

Though they are not considered nuclear safety equipment, the failure of a large transformer at power usually results in a reactor trip. The complications associated with a transformer failure, including fire, electrical distribution disruption, emergency declarations, and hazards to personnel, create distractions for operators and can complicate efforts to maintain the reactor in a safe, shutdown condition.

2.3 Broader Implications for Safety-Related Maintenance Programmes

Industry operating experience identified a constant trend in transformer failures over a ten year period despite a concerted effort to identify and correct the leading causes of the failures. While some failures can be traced to weaknesses in the manufacturing process or design vulnerabilities in essential support systems, the root cause for many failures are weaknesses in the maintenance and monitoring programmes.

To the extent that transformers are covered by nuclear safety regulations at all, it is through regulations in some countries that require plant maintenance programmes in general to meet acceptable standards. Successful maintenance programmes will not only determine that testing results are within specification, but will trend results to note if there is a deteriorating condition, or if there has been a step change that could indicate imminent failure. Analysis of the transformer oil, particularly analysis of the gas content, which increases due to breakdown of the oil caused by hot spots and faults in the transformer, can provide an indication of the overall health of the transformer.

3. QUESTIONNAIRE ISSUED TO MEMBER STATES

3.1 Questions for the Regulatory Body

- Are there regulatory requirements for the maintenance of large transformers? If so, what are they?
- Are there regulatory requirements for reporting transformer failures? If so, what are they?
- What parameters does your regulatory body monitor, trend, and analyse for large transformers to detect degraded conditions?

3.2 Questions for the Operating Organisation

- What parameters do operators monitor, trend, and analyse for large transformers to detect degraded conditions?
  - Are single-point failure vulnerabilities, potential sources of spurious transformer trips that can cause an improper actuation of a single relay or component considered?
- Does the operator have a predictive and preventive maintenance programme for large transformers? Describe the framework of the programme.
  - Does it include, transformer years of service, risk importance, duty cycle, transient cycles, and environmental conditions?
  - Does the operator have a contingency plan for transformer inspections if a significant degraded condition exists?
  - Does the operator conduct detailed maintenance rounds on major station transformers and spare transformers? Do seasonal and operating conditions affect the depth of the maintenance rounds?
- Does the operator have sufficiently detailed operating and abnormal procedures related to transformer activities?
- Does the operator have clear job responsibilities for transformer operation, maintenance, and performance monitoring?
- Who verifies transformer maintenance activities by contractors or offsite organisations?
- Training and knowledge:
  - Is appropriate training included with infrequent transformer activities?
  - Are onsite personnel knowledgeable and proficient at maintaining the large transformer?
  - Does the operator provide training for the station fire brigade, non-licensed operators, and the control room operators on transformer fire response? This training may consider the possible isolation of the unit from the grid, as well as isolation of the site from the grid.

4. ANALYSIS AND CONCLUSIONS

4.1 Country Inputs

This report documents inputs received from twelve countries regarding maintenance and regulations associated with oil filled transformers. These responses came from:

- Belgium
- Canada
- Czech Republic
- Finland
- Germany
- Japan
- Netherlands
- Slovakia
- Republic of Korea (South Korea)
- Spain
- Switzerland
- United States

Though generally classified as power generation systems rather than nuclear safety systems, transformer failures have the ability to affect safety related systems, as well as to pose a hazard to site personnel. Ageing systems may be more susceptible to failure, making lessons learnt from previous event and best practices a valuable operating experience tool.

4.2 Recent Events

The United States issued Information Notice 2009-10 (IRS 8024) addressing concerns about maintenance issues for main transformers after observing a significant increase in the number of failures despite industry guidance providing recommendations. Germany posted IRS 8049 describing complications following a transformer fire that revealed weaknesses in the ventilation system design as smoke from the fire was drawn into the main control room. IRS 7928 from the United Kingdom describes an event which challenged operators with a reactor trip, fire, and scattered debris after a high voltage bushing on the main transformer exploded. Seismic effects following an earthquake in Japan caused a fire due to grounds on one of the main transformers as described in IRS 7922. The event was complicated as the water supply for firefighting efforts was also disabled by the earthquake. IRS 8008 from Russia on the other hand, describes an event where alarms received in the control room alerted operators to the deteriorating condition of the transformer insulation, allowing them to trip the transformers before a catastrophic failure occurred. IRS 8011 from Argentina and IRS 7947 from Lithuania describe situations where inadequate maintenance procedures and design features resulted in actuation of transformer trip features, requiring reactor scrams.

4.3 Summary of Countries' Responses

Several general conclusions can be drawn from the various responses received. Transformers are not regarded as nuclear safety equipment in any country, and as such no country that responded (with the exception of Republic of Korea, which includes transformers in its regulations for periodic inspection by regulatory body inspectors) had regulations specifically addressing transformer maintenance. Likewise, no country had a specific reporting requirement regarding transformer failures. Recognizing that transformer failures can lead to reactor trips, most countries do have regulations addressing maintenance programmes in general, and inspections to verify the effectiveness of these maintenance programmes. In addition, reportability requirements addressing the consequences of most transformer failures (reactor trip, extensive fire), effectively capture the vast majority of the catastrophic failures.

Licensee maintenance and monitoring programmes are generally structured around available industry recommendations and operating experience. Key operating parameters including oil temperature and level, along with currents, voltages and capacity factor are available in the control room, or at least will cause alarms in the control room in the event of an abnormal condition. Visual inspections are generally carried out on a shiftly or daily basis, and preventive maintenance is scheduled regularly, usually with major overhauls and assessments made every several years to verify that no significant degradation has occurred. Many licensees have adopted continuous online gas analyzers to trend the gas content in the transformer oil for indication of insulation or dielectric breakdown. Those that do not have the online analyzers installed perform oil analysis at least annually. The industry recommendation is that new main transformers have online gas analyzers included, and that operating transformers be retrofitted if there are indications of possible deterioration.

As transformers are not considered nuclear safety equipment, many of them do not have redundancies built in and are thus vulnerable to single point failures. Industry guidance recommends analyzing areas susceptible to single point failure to determine the risk to the transformer and the feasibility of adding redundancy. Some operators have redundant main transformer trip relays to minimize spurious trips, but in most countries they have determined that the trip risk from other large transformers is sufficiently low that redundant features are not necessary or cost-effective.

All licensees have detailed procedures addressing the plant response to a reactor trip caused by a transformer failure, and most plants have abnormal operating procedures addressing other concerns that may arise as a result of the failure. Many plants have followed industry recommendations to develop procedures to address parameters that fall outside the normal range, or which indicate a deteriorating trend. These procedures may require increased monitoring and maintenance, or set limits for taking additional actions, including taking the transformer offline to avoid a catastrophic failure.

Nuclear plants in most countries do not maintain sufficient personnel onsite with the experience and training necessary to perform maintenance on transformers, and so this maintenance is usually contracted out. Plant personnel maintain oversight of contractor activities, and require adequate knowledge of the system to ensure that work is performed to site standards and meets regulatory requirements. Industry operating experience has highlighted the use of outside contractors as a possible source of concern for transformer maintenance, especially if the procedures, training, and acceptance standards are not sufficient. Updated industry guidance suggests that the licensee be involved at every stage of contracted maintenance (including from the time of original manufacture) with testing and inspections to ensure the required level of quality is maintained.

Another common theme among all of the responses was in the area of fire fighting. Though in many countries training for licensed and non-licensed operators was for a general approach to fires and their potential effects on the plant, licensees in all countries provided the fire brigade with training specifically for transformer fires. Multiple countries cited operating experience from previous fires, in particular the transformer fire at Krümmel Nuclear Plant in 2007, as providing valuable lessons learnt for complications that can arise from this type of fire.

4.4 Commendable Practices

The primary concern for a plant operator upon loss of a main transformer, once immediate actions to place the plant in a safe condition are complete, is the availability of a replacement. The long lead time necessary for the manufacture of a new main transformer means that if there is no functional spare transformer available, the plant will remain shut down for an extended period of time. As this is not a nuclear regulatory concern, industry groups have generally taken the lead in addressing transformer failures, preventive measures to be taken, and recommendations for minimizing the potential for catastrophic failure.

Aside from the initiating event (loss of power, reactor scram etc.) which is likely to result from the failure of a large transformer, nuclear regulators have seen other causes for concern from a spate of recent failures. Catastrophic failures of the main transformer challenge operators with distractions from fire, affected equipment, and the coordination of emergency operations while they place the plant in a safe, shutdown condition. Fires and explosions pose a hazard to personnel and equipment, and contribute to the difficulty of restoring normal conditions.

Predictive and preventive maintenance is key to maintaining equipment, and to detecting any degrading conditions before they pose problems for operation. All plants have maintenance procedures detailing work to be performed or parameters to be observed at regular intervals. A programme that takes into account the condition of the transformer during these maintenance intervals in order to inform future maintenance requirements can help to extend the operating life of the transformer and aid in detection of impending problems in time to prevent a catastrophic failure. Japan has developed a transformer life management evaluation programme which incorporates time-based management and condition-based management, along with life cycle management assessments at twelve and twenty-four years, to determine future transformer maintenance and replacement requirements (see appendix).

Poor oversight of contracted maintenance personnel and a lack of understanding by plant personnel of main transformers have been highlighted by industry groups as a possible contributor to transformer failures. Most nuclear plants do not retain the expertise onsite for anything more than routine sampling and maintenance. Operators need to ensure that contractors, required for more extensive maintenance and testing, understand the quality control and procedural practices required for nuclear plant operations. Republic of Korea and the United States noted that licensees who run multiple reactor sites may maintain a central group responsible for transformer maintenance, facilitating the sharing of operating experience between multiple sites and helping to ensure an understanding of plant practices. The Republic of Korea also reported a strong degree of on-site staff training and involvement in transformer maintenance, which appears to be a good practice in light of the noted industry guidance.

Industry operating experience has identified continuous online gas analysis as the best method for identifying an impending failure of a large oil-filled transformer. Advantages of online analysis include measurements of gas content in the oil that are less susceptible to sampling errors, and which allow for timely recognition of deteriorating conditions. However it is recognized that the cost-benefit analysis of back-fitting transformers already in place may not justify the expense. Benefits may be gained from identifying degrading trends in key parameters that may indicate degraded insulation conditions. This degrading trend could justify the installation of continuous monitoring equipment in order to identify when the transformer should be taken out of service for repair or replacement before a catastrophic failure occurs. At the Peach Bottom plant in the U.S., regular oil samples noted higher than normal gas levels, prompting the licensee to install an on-line gas analyzer.

When the on-line analyzer detected gas levels above a pre-set limit, the plant shut down and replaced the transformer before it actually failed. In any case, any new large, oil-filled transformers that are installed should be equipped with continuous gas analysis capability.

Although all nuclear plants have staff trained in fire response identified on every shift, most plants do not maintain dedicated firefighting staff capable of combating a large fire. Most fire response crews consist of licensee personnel who have received training on basic firefighting techniques. Procedural response for large fires usually involves coordination with offsite firefighting organisations. As transformer fires present additional hazards, some plants have instituted specific training for dealing with the challenges presented by a large transformer fire. In Japan, lessons learnt from a transformer fire at Kashiwazaki-Kariwa 3 resulting from the earthquake in 2007 (IRS 7922) were applied to fire response training programmes around the country. In Spain, the Garoña Nuclear Power Plant incorporates specific transformer fire scenarios into fire response training. Canada and the Netherlands used operating experience from the Kruemmel fire in 2007 (IRS 8049) to inform their response to transformer fires. Republic of Korea ensures regular participation of offsite fire stations in plant fire drills to enhance communication and cooperation.

5. RESPONSE OF OECD-NEA COUNTRIES TO TRANSFORMER FAILURE QUESTIONS

The following section provides the summary response of each OECD-NEA country that replied to the questions posed by the U.S. NRC about main transformer failures.

5.1 Belgium

There are no regulatory requirements which govern the maintenance of transformers and no reporting requirements that apply directly to transformer failure. The regulator does not monitor any parameters to detect degraded conditions in transformers. This is the responsibility of the licensee.

Licensees have implemented preventative and predictive maintenance programmes based upon manufacturer maintenance guidelines, internal and external operating experience. Online monitoring of transformer key fault gasses provides an early warning of fault conditions that could lead to transformer failure. Oil temperature and level are monitored by the licensee. Additionally, thermography, dissolved gas analysis, air cooling system checks and inspections for oil leaks are performed. Maintenance and testing frequency is influenced by the results of previous testing, as well as by environmental and operational considerations.

Transformer maintenance is typically conducted by site maintenance personnel who have received appropriate training on transformers. Onsite staff verify transformer maintenance performed by contractors. An offsite maintenance competence center, with extensive training provided by the equipment manufacturer, is available to share operating experience about the transformer fleet.

Operators perform daily maintenance rounds and weekly inspections of critical parameters. The spare transformers have their own maintenance rounds. Adequate procedures are in place if an abnormal condition is detected. In the event of fire, the control room operators will follow the instructions provided by the fire brigade officer. Fire brigade officers have been trained on the electrical dangers on site.

5.2 Canada

Though there are no regulatory requirements specifically governing Large Oil-Filled (LOF) Transformers, there are regulations which apply to maintenance programmes in general. These require the licensee to consider vendor recommendations, industry codes and standards, design and operating conditions, operating experience, and aging management requirements in their maintenance programmes. More generally, licensees are required to ensure that maintenance on equipment is performed regularly, and to industry standards.

Systems important to the nuclear power plant are required to function reliably. Though transformers are not considered safety significant, and so in and of itself a failure is not reportable to the regulator, their failure is usually accompanied by a nuclear plant transient, which is reportable. This potential for impact on the reactor raises the level of regulatory interest in LOF transformers, despite their non-safety status.

As with other nuclear and non-nuclear plant parameters, the function of the regulator and the inspection staff is not to monitor specific indications or detect degraded conditions, but rather to verify that the licensee monitoring programme is sufficient, and that licensee response to abnormal indications is in accordance with designated procedures.

Licensee maintenance and monitoring programmes track oil properties, particularly gas concentrations in the oil indicative of insulation breakdown and arcing events, as well as oil and winding temperatures, oil level, pump pressure, insulation deterioration, and possible leaks. Monitoring frequencies are based on established industry recommendations, ranging from continuous monitoring of vital temperatures and pressures (and in some case continuous gas analysis) to infrared thermography checks, Doble testing, and complete overhauls every few years. Maintenance frequency is determined by a combination of industry guidance, risk importance, operating experience, duty cycles and environmental factors.

In general, plant personnel are sufficiently familiar with transformer operation to recognize abnormal circumstances, but maintenance is performed by contractors under oversight of specified licensee engineers. Training is provided to operators to diagnose abnormal conditions and take appropriate actions to stabilize the plant if necessary. Specific training for combating transformer fires is provided to the fire brigade, while control room operators and non-licensed operators receive general training for plant fires and fire safe shutdown procedures.

5.3 Czech Republic

As transformers are not classified as safety related equipment, they are not specifically covered by regulatory requirements. Likewise, reportability requirements do not address transformer failures, however the transients resulting from transformer failures are covered by the standard events reporting scheme. Additionally, as the regulator receives all licensee event reports, including reports of transformer failures, specific reportability requirements regarding large transformer failures are not necessary. Resident inspectors perform an inspection sample of general transformer parameters to verify that they are within specification, however the sample size is small, and monitoring of parameters is primarily the responsibility of the licensee.

Licensees monitoring consists of continuous gas in oil analysis to keep track of the status of the insulation and dielectric properties. Equipment required for continuing operation, including pumps, fans, and dryers are also monitored. The preventive maintenance schedule accounts for the age of the components, risk importance, duty cycle, and environmental conditions, with augmented inspection requirements in the event of abnormal results or trends.

Operators receive periodic training on actions to be taken in accordance with abnormal operating procedures in the event of a transformer malfunction. Operators are trained to recognize abnormal indications, however actual maintenance of the transformers, both preventive and reactive, is performed by outside contractors. Contractors are expected to ensure the quality of their own work, which is also overseen by station system engineers. Licensee quality assurance inspectors also review contractor work on a sample basis to ensure it meets station standards. Station personnel, including the fire brigade, are trained to respond to fires, and abnormal conditions resulting from a transformer fire are covered in operating procedures.

5.4 Finland

As large transformers are classified as non-nuclear, in the lowest safety class, there are no specific regulatory requirements regarding transformer maintenance programmes, nor are there specific reportability requirements for transformer failures. The regulator oversees licensee implementation of all maintenance programmes, including those for large transformers, particularly during annual maintenance outages. The licensee is responsible for regular monitoring of transformer parameters and conditions, and the regulator performs a regular assessment of the licensee programmes. Reports including transformer failures are made to the regulator in the event that the failure results in a plant transient or disturbance.

Operators are provided with control room readouts of key transformer parameters and results of online hydrogen gas-in-oil analysis. Thermal and optical sensors and oil level alarms are also provided. In an effort to eliminate single point of failure trips, redundant main transformer protective relays are provided. The preventive maintenance programme schedules inspections, surveillances, and component replacements at intervals ranging from monthly to decennial based on operating experience, inspection results, and component conditions. The transformer lifetime management programme accounts for years of service, risk importance, duty cycles, and transients to provide feedback to the preventive maintenance programme for maintenance scheduling. In the event of a degraded condition, the maintenance and surveillance schedule is advanced to ensure timely assessment of transformer operability.

Operators are trained on procedures for monitoring and operating the plant in the event of an abnormal condition with the transformer, including grid disturbances and transformer fires. While onsite personnel are sufficiently knowledgeable to recognize abnormal conditions and evaluate operability, maintenance is generally contracted to outside organisations. Contract maintenance is overseen by the plant electrical maintenance manager, and contracted maintenance procedures are expected to meet the basic expectations of licensee maintenance procedures. Licensed and non-licensed operators, as well as the fire brigade, receive training on transformer fire response, including the wide-ranging and potentially unpredictable plant responses that could result.

5.5 Germany

Transformer events are not reportable unless they affect the emergency power distribution system or other safety related systems.

Online gas monitoring is used to detect the breakdown of oil used to cool the transformer, which can be indicative of potential problems, but even with continuous monitoring, this breakdown may not be discovered until it is too late. Utilities collect and analyse samples regularly to determine the condition of the oil, as well as its water and gas content. Protective relays which can sense step changes in pressure or temperature and trip the transformer offline are used to protect equipment and personnel in the event that testing fails to detect a problem before a failure occurs.

5.6 Japan

Transformers are not nuclear safety equipment, and so are not covered by regulations. The regulator does not monitor any transformer parameters, and failures are not reportable except as they may be incidentally related to a reactor trip.

Licensees act upon a life management programme based on time-based maintenance every six years and full assessments every twelve years. At twenty-four years, a prediction of remaining life is made and the maintenance schedule adjusted accordingly. Implementation of condition based maintenance is based on regular monitoring and trending of important parameters, including gas concentration and temperatures. (See Appendix: Japanese Typical Recommended Transformer Maintenance Program)

Transformer maintenance is carried out by contractors, overseen by the utilities, but is not included in regular or abnormal procedures. Abnormal procedures contain response requirements for transients resulting from transformer incidents, but do not address transformer maintenance. Training on infrequent activities relating to transformers is not included in the regular training cycle, however operators and contract employees are considered to be sufficiently experienced to handle situations as they arise. Fire fighting response to transformer fires is emphasized in training programmes, incorporating lessons-learnt following an earlier transformer fire.

5.7 Netherlands

Main transformers are not classified as nuclear safety equipment; therefore they are not covered by regulations and are not monitored by the regulatory body. Though there are no reporting requirements specifically addressing transformer failures, there are requirements for grid disturbances, reactor transients, and fire damage, any of which might result from a transformer failure.

Licensee maintenance programmes involve annual oil sampling, analysis, and trending, testing of protective relays, and regular inspection and replacement of important components. Maintenance is generally performed by contractors, however plant personnel receive specific training on transformer operation and maintenance to ensure proper supervision of contracted activities. Abnormal operating procedures focus on response to reactor plant transients and grid disturbances that may affect (or be affected by) transformer anomalies. Specific training on response to transformer fires has been implemented as a response to the Kruemmel transformer fire in 2007.

5.8 Slovakia

Regulations do not specifically target the reporting of transformer failures. However, failures that affect systems covered by the regulations would be reported. Transformer maintenance is covered by regulations under requirements for basic maintenance and operations for specified items.

Twice a shift, operators perform rounds to verify the proper operation of transformer functions and check that levels, temperatures, and voltage readings are within specified ranges. Twice a year, the operator performs an oil sample analysis to check color, gas and water content, and the extent of oil degradation. A full preventive maintenance workup is performed during each planned outage, or about every two years. These maintenance activities are performed by offsite personnel under agreements with the grid operator, but are verified by the plant operator as meeting the requirements of the nuclear regulator.

Abnormal operating procedures describe operational limits for the transformers and corrective actions to be taken in case of abnormal indications, including shifting the plant to operate in island mode. This allows plant systems to be fed from standby lines or EDGs. Training is provided to operators on the use of normal and abnormal operating procedures, and on a regular basis to all plant personnel, including the fire brigade, for emergency preparedness and scenarios involving transformer failures.

5.9 Republic of Korea (South Korea)

Oil filled transformers are identified in regulations as equipment subject to periodic inspection by regulatory inspectors. Inspectors confirm insulation resistance checks and protective device tests, and examine the condition of tap changers along with the exterior of the transformer. If abnormal degradation is identified during the inspection, recommendations or findings may be issued by the regulatory body. There are no regulatory requirements directly related to reporting of transformer failures. However, if an event is caused as a result of transformer failure, the licensee reports that event to the regulator.

Both predictive and preventative maintenance is performed on large oil filled transformers. Preventative maintenance has included replacement of all transformers more than 23 years old, and replacement of protective relays on a 5-year cycle. The moisture levels and gas concentration in the insulating oil are analysed every two hours to detect degraded conditions. Thermography and partial discharge tests occur each spring. Operators monitor the temperature of the transformer during walkdowns 1-3 times a shift. A periodic inspection is performed by maintenance personnel once a month and transformer engineers walk down the equipment to determine system integrity on a quarterly basis. Automatic responses, emergency actions and corrective measures required due to transformer failure have been clearly described in system operating, alarm response, and abnormal operating procedures.

Detailed inspections of the inside of the transformer are periodically performed by vendors. Maintenance work conducted by contractors is performed according to approved procedures and is supervised by the site maintenance and engineering divisions. Site staff is knowledgeable and proficient at maintaining large transformers. Training is performed on an annual basis and includes theory, maintenance and operating experience. Workshops are held to highlight relevant events and share experience in the operation and maintenance of these transformers. Both the onsite fire brigade and the offsite fire station have been trained for onsite fire accidents, including transformer fires.

5.10 Spain

Transformer maintenance is not specifically mentioned in regulations, and events are not reportable except as they result in reactor transients. Licensees perform regular monitoring of components important to normal transformer operation. Some licensees have installed continuous gas analyzers to provide timely notice of impending failure; other licensees perform in-depth physical and chemical analysis of oil samples on a semi-annual basis. The preventive maintenance schedule was established based on industry and vendor guidelines, and though the basic maintenance schedule is not adjusted based on duty cycle, environmental conditions or transients, additional maintenance will be performed in response to observation of deteriorating trends.

Basic maintenance is performed by licensee personnel, however most maintenance is performed by contractors under the supervision of licensee personnel. Procedures detail the appropriate responses for alarming conditions and potential transients. The fire brigade receives specific training regarding transformer fires, while licensed and non-licensed operators receive training on general fire-fighting scenarios. While not specifically focused on transformer fires, this training has included drills involving transformer fires.

5.11 Switzerland

Regulatory requirements addressing quality assurance and maintenance programmes are applicable to the associated programmes for large transformers. These regulations also require reporting of any failures that lead to an unplanned power reduction or cause damage to safety-classified components. Events caused by lightning strikes are also reportable to the regulatory body. In addition, monthly and quarterly reports on maintenance and testing, including that performed on large transformers, are required, as are safety assessments performed every ten years, which include an evaluation of the condition of equipment. Monitoring of transformer parameters is the responsibility of the plant, though the effectiveness of maintenance and monitoring programmes is subject to inspection by the regulator.

Transformer operating conditions and readings are monitored as part of routine shift rounds. The short-term and long-term maintenance schedules are influenced by any normal alarms received, results of regular monitoring, and any conditions noted during regular maintenance. All main transformers have been replaced since original installation as part of power upgrades that made more efficient use of the heat available from the reactor plant rather than because of degraded conditions noted on the transformers themselves. Maintenance is usually performed either by plant personnel or by qualified employees of the parent corporation, with oversight from plant personnel.

5.12 United States

Though there is no regulation specifically addressing main transformers, there are regulations requiring the licensee to monitor the performance and condition of equipment to ensure it is capable of fulfilling its intended functions. Quality assurance requirements also may apply to various aspects of transformer maintenance. Transformer failures are not reportable in and of themselves, however any transformer event that results in a reactor trip or a fire requiring an emergency declaration is required to be reported. Monitoring of transformer operation and performance is the responsibility of the licensee. The regulator evaluates the effectiveness of the licensee maintenance programme.

Licensees monitor important parameters on a continuous basis. The latest industry recommendations include installation of continuous dissolved gas analyzers, however not all licensees have completed this upgrade. Preventive maintenance schedules use industry and vendor recommendations, operating experience, trend results, and component age to determine inspection and maintenance frequencies. Indications of degradation generally result in increased monitoring and evaluation. Industry guidance recommends abnormal operating procedures addressing any alarming or abnormal condition.

Licensees are expected to have the knowledge and experience available for most routine transformer maintenance. Any work that is performed by contractors or off-site organisations should be performed under the oversight of licensee personnel familiar with the equipment and the work to be performed. Contractors are expected to have procedures and qualifications which meet the requirements of site procedures and qualifications. Industry guidance also recommends that licensees verify contractor work at multiple stages of a project, including manufacture, to ensure the quality of the work.

Training on transformer fires is expected to be provided to the fire brigade and to licensed and non-licensed operators. Fire fighting procedures should include consideration not just of the fire, but of potential hazards involved in a transformer fire, and of operations independent of the grid.

APPENDIX: JAPANESE TYPICAL RECOMMENDED TRANSFORMER MAINTENANCE PROGRAM

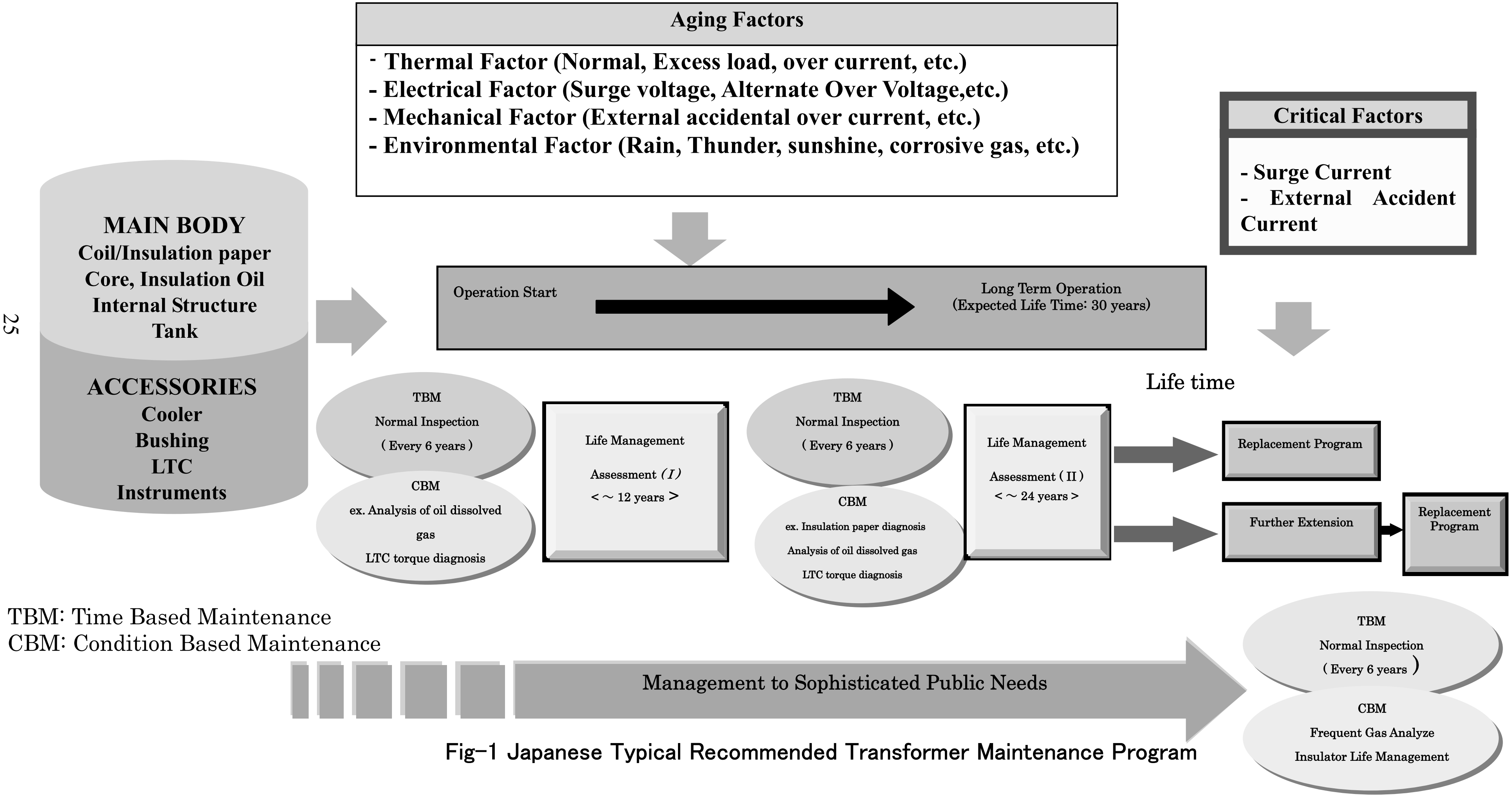

Fig-1 Japanese Typical Recommended Transformer Maintenance Program

Life Management Evaluation

Life Management Evaluation (I)
- Analysis results of dissolved gas in oil
- Degradation of the gasket
- Corrosion of the cooler (Heat exchanger)
- Degradation of oil feed pump and fan bearings
- Performance of the insulation oil
- Degradation of instrumentations

Life Management Evaluation (II)
- Residual life evaluation of insulation papers
- Purchasing of the spare parts quitted to produce (LTC)
- Compliance to the latest codes and standards (Sea breeze, structural integrity of the tanks)

In case of Service Life Extension;
Preparing Life Extension Program
e.g. to decrease oil temperature

<Referenced standard and guidance>

*The Japan Electrical Manufacturers' Association:
"Proposed replacement time of oil cooled transformer accessories (spare parts)"
(JEM-TR197)

*Electrical Joint Research Report
"Maintenance Management of Oil cooled Transformers"

■ Management to Sophisticated Public Needs

Energy Saving
- Hi-Efficiency Cooler
- Efficient Cooler Operation (Sequencer)

Low Noise Product
- Noise Shielding
- Low Noise Cooler Fan

Increase Reliability
- Pressure Release