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QUALITY SYSTEMS: SUPPORT OR HINDRANCE FOR LEARNING

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INTRODUCTION

Quality and quality systems have received increased attention in all industrial activities over the last ten years. The driving force for this attention can be found in the need for defining quality of certain products in objective terms and to ensure that a defined quality level can be reached on a continuing basis. Quality is in this context understood to be a set of attributes that characterise products, services and work processes on some more or less objective scales. The quality of a product could for example be defined in terms of dimensions of performance, features, conformance, reliability, durability, serviceability, perceived quality, and aesthetics. Quality of work processes is somewhat more abstract, but could for instance be characterised through people employed, resources and time spent, and methods and tools used in the work. It should be noted that quality always is placed in relation to a specific purpose, or in other words quality measures the fitness of a product, service or work process for its purpose.

Nuclear power plants use quality systems as an important part of the activities by which safety is managed. Quality is also an important concept in defining goals and assessing their achievement. Quality systems are required by nuclear regulatory bodies and the International Atomic Energy Agency (IAEA) has issued recommendations for how quality systems should be built and maintained (IAEA, 1996). Anecdotal evidence from

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the quality systems at nuclear power plants point to various problems in their implementation. A small study was therefore initiated within the Nordic Nuclear Safety Research (NKS, http://www.nks.org) to collect views on quality and quality systems. A total of 74 persons at the nuclear power plants in Finland and Sweden and at one research reactor in Norway were interviewed in the study.

The study brought many concrete suggestions for how quality systems should be built, adapted and integrated in the activities at the nuclear power plants. The demands set on hazardous industrial activities necessitate the implementation and use of a formal quality system, but there are many pitfalls, implementation and use of a formal quality system, but there are many pitfalls, which should be avoided when such systems are built and used. The position of a formal quality system as a vehicle for organisational learning and knowledge management is discussed based on the results from the study. It is concluded that quality systems, which are built on participation and understanding, have a large potential of becoming efficient tools for organisational learning.

QUALITY IN THE NUCLEAR POWER INDUSTRY

The nuclear industry has become one of the most controversial industries in the world. The accidents at TMI and Chernobyl brought the hazards of nuclear power plants to the attention of the general public and they also made it clear for the industry that safety and high quality of all plants worldwide is a necessary precondition for continued operation. The nuclear industry has been a forerunner in the development of safety management activities as discussed in more detail below. The quality systems have an important role in these activities.

Requirements for nuclear power plant operation

The operation of nuclear power plants have characteristics similar to other industries that have a high accident potential such as air transportation and the chemical industry, but it is also different in some respects. Perhaps the most important technical difference is that nuclear power plants require a continued oversight even when they are shut down. The societal concern of risks connected to nuclear power, are much larger than risk estimates given by experts. The nuclear industry is global in the sense that bad performance in one plant has an impact everywhere due to decrease confidence and trust. All this implies that the burden of proof that continued operation is safe is far greater for nuclear power plants than for conventional installations.

The safety of the nuclear power plants builds on a number of safety principles of which the *defence in depth* is the most important. This principle implies that several independent barriers and safety systems are implemented to prevent the plants from entering a course of events, which may have disastrous consequences. In-depth safety analyses are used to ensure that all applicable safety criteria are fulfilled also during accident conditions. The *safety analysis report* is a comprehensive set of documents, which provides the basis for a plant owner to apply for a license to operate the plant and it also functions as a documented reference for safety management activities. The licensing conditions given by a nuclear regulator contain many provisions which should be attended continuously together with the requirement that formal reports should be issued whenever there have been deviations from the licensing conditions.

All these requirements taken together introduce the need for a formal system to regulate work activities at the nuclear power plants. The need for this system to be both comprehensive and well documented is further increased with the projected life-time of the plants, which even can be above sixty years, in combination with the large variety of skills which is needed for plant operation. In summary one could say that a formal system also brings the benefit of systematic and regular actions to correct for possible slow deterioration's, thus ensuring a covering collection of world-wide feedback of experience and standardised methods to ensure that experience is made easy to access.

An industry in change

The nuclear industry has gone through a considerable change since most of the present nuclear power plants were taken into operation. In the 1970ies the nuclear industry had a considerable political support in most countries. At that time it had no difficulties in attracting the brightest students from the best universities. This situation has changed radically today. Some countries have decided to phase out their nuclear capacity, although it may seem difficult to decrease the present share of nuclear power in the electricity supply (European Commission, 2000).

The deregulation of the electricity supply, which has taken place in many countries, has put a pressure on many nuclear operators to decrease their costs. The deregulation has also lead to a restructuring of the ownership of the electric utilities, which has been reflected in mergers and acquisitions. To adapt to the new situation several nuclear power plants in the world have initiated organisational changes, which among others include downsizing and outsourcing.

Some nuclear regulators have reacted to the changes in the industry with an expressed fear that important safety related knowledge could be in the danger of being eroded. Some regulators therefore require licensees to prepare a safety case before entering major organisational changes. An important part of such a safety case is an extensive survey of necessary skills and knowledge for running the nuclear power plant safely. Such surveys are further motivated by the fact that many nuclear plants worldwide are facing a generation change in their personnel.

Quality systems at nuclear power plants

A scientific approach to quality and quality control goes back to the early decades of the last century, when the building industry used collective experience to achieve high quality through repeatability in work processes (Slaton 2001). After the Second World War quality was introduced into Japanese management thinking by pioneers such as Deming. Later this development led to concepts such as Kaizen and Total Quality Management (TQM), which were used extensively in the Japanese car industry. The quality thinking was adopted gradually in the rest of the world through quality associations and the use of quality circles. Quality is now a well-established concept through the ISO 9000 series of standards and many companies now a well-established concept through the ISO 9000 series of standards and many companies today have certified their quality systems. Writing on quality can be grouped into three types, the prescriptive teaching of quality experts, quality certification and quality awards, and academic research (Ahire and Ravichandran 2001).

The nuclear industry joined the development of formal quality systems in the late 1960ies and early 1970ies. Initially the driving force was connected to the requirements for pressure vessels, but it was soon realised that the systems had a larger area of application. The concern for nuclear safety and the need for establishing systematic methods, by which a high repeatability in operations could be achieved, also contributed to this development. A working basis of quality assurance (QA) was first established in the nuclear field through early American legislation. Today national regulatory bodies require quality systems to be implemented at nuclear power plants, largely in line with recommendations given by the IAEA for how quality systems should be built and maintained.

The basic thinking in and philosophy of the quality systems in the conventional and nuclear industry is very much the same, but the historical development, paired with the special requirements for nuclear installations, has caused a difference in the details. A comparison of differences between the IAEA recommendations and the ISO 9000

standard can for example be found in IAEA (2000). In spite of national and international requirements and standardisation efforts, there are still variations in details of how different nuclear power plants have built their quality systems.

The perhaps most important trend in the quality systems at the nuclear power plants today is that they are integrated into the larger context of management systems. This development also includes the introduction and use of environmental monitoring systems. This development could be seen as a move towards a wider application of the TOM thinking in the nuclear industry. This is perhaps also to be expected, as TQM has been characterised to be among the most prominent operations improvement approaches of the twentieth century (Ahire and Raviehandran, 2001). In moving along this path it would however be important to understand why some companies have succeeded where others have failed in applying quality systems.

VIEWS ON QUALITY AND QUALITY SYSTEMS

In this section we report on a study concerning views on quality and quality systems. The data were collected through interviews with a total of 74 persons at the nuclear power plants in Barsebäck, Forsmark, Loviisa, Olkiluoto, Oskarshamn and Ringhals, and at the research reactor in Halden. The study was motivated by the importance quality systems have in a safe operation of nuclear installations. Anecdotal evidence of problems in the implementation of quality systems was also available as a motivator for the study.

The study

The study was initiated as a part of the SOS-1 project "Risk Assessment and Strategies for Safety" within the Nordic Nuclear Safety Research (NKS). The study was a follow up of a similar study investigating views on safety culture (Hammar et al, 2000). That study showed that aspects of safety culture are manifested in the quality systems and that safety culture on lower levels in the organisation is often associated with the quality system.

The aim of the study was to collect views and opinions concerning suitability and efficiency of the quality systems. As the systems at the various plants differed in certain respects, an opportunity was also seen in gaining understanding of the effects these differences. Another matter of interest was whether the rather elaborate quality systems gain adequate commitment on the part of all concerned. There have been some fears that

such commitment might be lacking at the practical working level in the organisations, although high commitment to quality in a practical sense always has been present.

The persons interviewed were selected by a contact person at the sites to represent both developers and users of the quality system. The dates for the interviews were proposed by the contact persons in order to make a suitably diverse group of people available for the interviews. A categorisation of the persons interviewed showed that 49 represented users of the systems and 25 developers of them. Of the interviewed, 36 had a managerial position and 38 could be considered as having the position of an expert within their organisations.

Before the interviews took place participating organisations were asked to send descriptions of their quality systems to the interviewers. The interviews were carried out in the period 30.8-13.12.2000 and each interview took about one hour. In the interviews ten broad areas connected to quality were discussed (table 9.1). The selection of these areas was based on earlier experience and discussions with people from the nuclear field. They also provide a kind of logical sequence from the more general to the more specific, rounding off the interview with a discussion of the future. All interviews were taped and transcribed. The full report of the study has been issued by NKS (Hammar *et al,* 2001). Preliminary results from the study were presented and discussed at a seminar, which was held at the Ringhals nuclear power plant (Hammar and Wahlström, 2001). These discussions provided additional insights for the analysis of the results.

1. The quality concept
2. Quality systems
3. Topical quality related issues
4. Means to reach quality ends
5. Rules and procedures
6. Competency and training
7. Safety inspections and reviews
8. Process oriented activity control
9. Fostering quality thinking and commitment
10. Strategies and development needs for the future

Table 9.1: Areas discussed in the interviews,

Reflections from the interviews

The quality concept. As was to be expected there was complete agreement that quality is essential in ensuring safety at the nuclear installations as well as for meeting other operational goals. Some people pointed at the need of accounting properly for all types of goals to be met in assessing quality of operation. Some expressed doubts, however, as to whether elaborate quality assurance concepts add significantly to people's generally rather obvious dedication to quality.

It appeared that quality was well understood in line with currently established definitions, i.e. in relation to requirements and expectations set for products and services. Many advanced the supplier's point of view relating quality largely to customer satisfaction in the broadest sense. Some took the view of the nuclear operator in emphasising the need *of* also gaining general approval of the enterprise by the society, together with confidence and goodwill. In this perspective the quality concept can be extended to apply, in general, to all activities involved in the operation of the nuclear power plants.

Some difference in the interpretation of quality could be seen depending on the role and function of the persons. People in managerial positions, for example, more often pointed to the need to define *sufficient* quality as compared with extravagant and unnecessarily expensive quality.

Quality systems are sometimes associated with bureaucracy and some people reported that they try to avoid the word quality. The bad ring *of* the word quality seems to be connected to the way early quality systems were introduced. Thus, a preference for speaking of, e.g., *operational control* instead of *quality of operation* can now be found.

Quality systems. The quality systems at the participating organisations were typically described in a top-down fashion starting with a quality policy, which is broken down into managerial directives and requirements to be applied at different organisational levels. The directives and requirements link further to detailed instructions and working procedures to be used in operation, maintenance, and technical support activities, etc.

The interviewed were generally quite satisfied with their own quality system, but they also indicated various needs for improvement. Examples were given of measures to verify that requirements made at certain organisational level indeed constitute a comprehensive response to directives and requirements by defining *quality demands* to be met by *quality responses*. *A* weakness commonly pointed at was that specific information could not always be found easily and quickly. Another weakness in the quality systems was that the links between the managerial requirements and the underlying instructions were not always seen clearly.

Good quality systems are associated with structure and understandability. A quality system has to be a living system, which means that it is updated regularly to reflect changes in organisation and practices. *A* quality system has also to be enforced through managerial example and actions. A good quality system is used in practice, as reflected by records of updates made in various parts from time to time.

A rather common view was expressed that the working staff generally is less familiar with the higher levels of quality system than with the lower level procedures and instructions and may therefore not see the quality system in its full context.

Topical quality related issues. Asked about what kind of quality issues currently is topical all indicated satisfaction that the operation at their plant is well under control and in compliance with the requirements for quality and safety. There are many activities continuously ongoing at the nuclear installations, which are related to quality and quality systems. Firstly according to the requirements of the quality systems themselves audits are conducted on a regular basis and remedial actions are taken in response to observations and deviations. Secondly various minor changes in the organisations bring in the need to update the quality systems and many such were under way at the installations visited. There are also quality issues raised in ongoing development programs which are concerned with documentation of rules and procedures, information technology, competence management, safety assessment practices, etc. Finally some of the visited organisations were involved in rather large modifications of their quality systems.

There was significant development activities under way in the organisations visited. These included quality audits, broadening the scope of individual audits to cover entire processes, working for a larger commitment of the top management, and involving the organisation as a whole in quality activities. They also included a transfer of emphasis to inspecting relevant activities instead of just collecting information in interviews and meetings. Finally there is an increased focus on the identification of root causes of observed deficiencies to identify efficient remedies.

Some of the nuclear power plants have on voluntary basis selected to comply with the standard ISO 14000 to minimise environmental impacts and to have this activity certified. Also plants which had not yet taken this route were preparing to take such steps in a near future. As a follow up of these activities many saw a benefit of a further integration of safety, quality and environmental issues into one management system.

Means to reach quality ends. Asked to indicate various means to reach quality ends, which require particular consideration to achieve continued improvements, it was largely pointed to documented procedures, instructions and handbooks. The utilisation of information technology was also seen as a way for improving access to the quality system.

Involvement and commitment on part of senior management in quality activities was generally thought to require further promotion. A high degree of involvement and participation from the whole organisation in all developments of the quality system was considered important in achieving commitment and efficient implementation of the quality system. Training in the quality system and more generally providing the reasons behind the system together with its bearing principles were seen as important.

The auditing process was emphasised by many as carrying further potentials for improvement in addition to being fundamental to quality. The audits are also considered valuable in spreading sound quality thinking and providing the reasons behind the system together with its bearing principles. The audits were also seen as a vehicle for insight and learning both in being audited and participating in the audit team. In some of the organisations the higher management took regular part in the audits and this had proven to be very useful.

Organisational structure was also pointed out as needing attention, e.g. in regard of managing various work processes involving several units in the line organisation. Another organisational issue pointed at, was the extent to which co-operative relations in the organisation should emulate those between sellers and buyers in order to emphasise mutual responsibilities. Recent experience has indicated that some caution should be observed in this respect.

Rules, procedures and instructions. Many of the interviewed were concerned about that their systems of procedures, instructions and handbooks had been allowed to grow too large. Reasons were given that deficiencies were previously often rectified by issuing supplementary instructions rather than by adjusting existing instructions. Unawareness of already existing, applicable documentation, due to lacking transparency of the documentation system also contributed and possibly also some craze for writing instructions. At many of the visited organisations work is now under way to reduce the number of instructions and at the same time improve the structure of the documentation system.

The point was often made that different types of instructions are needed of which some are intended to be followed step by step, where others are more for guidance and memory support. There were some remarks that detailed step by step instructions, while necessary in certain applications such as in the main control room, may not contribute to professional pride and commitment if used unnecessarily.

In a general comparison the operating instructions seem to be of high quality, while the maintenance instructions have somewhat uneven quality and the administrative instructions have the largest need to be improved.

It is evident that the instructions and procedures need to be updated regularly and that this work may become voluminous. To succeed this work has to be systematic and carried out to account comprehensively for all collected insight and experience. Most of the organisations have acquired computerised documentation systems to support the updating process. Many also indicated a belief that modem information technology has a potential to solve some of the problems as seen in present paper based systems.

Competency and training: All organisations visited conduct some kind of systematic competency inventory on a regular basis. In Sweden new regulatory ruling requires a systematic approach in performing such inventories. An extensive documentation concerning competency of operational staff and other staff involved in decisions or actions directly affecting the safe operation of the nuclear reactors was under way.

All organisations visited have individualised training systems in place, although some people gave examples of practical difficulties with the systems. Many asked for more training in quality and safety issues.

Despite the energy policy in Sweden, which implies a definite although yet not fixed time limit for operating the nuclear plants, there seems presently not to be too difficult to maintain the required level of competency. Many of the interviewed however, articulated fear that this might change on a medium term. In Finland some mentioned the possibility of a new nuclear power plant as one opportunity to attract new people to the field. On a longer term it is clear, however, that there will be considerable difficulties in maintaining competency in specialised nuclear professions.

Safety inspections and reviews: Safety authorities require plant owners to perform a large variety of safety inspections and reviews. These include reviews of safety related plant modifications, changes in operational procedures, event reports, etc. and also verification of operational readiness before start-up.

A safety inspection and review is conducted in the first place within the department responsible for the point at issue, while observing that staff which as been directly involved in work to be assessed will not take part in the assessment. As a rule, the inspection and review will be assessed independently by another party.

In Sweden the regulatory body requires that the plant owner makes independent safety assessments on its own to verify the quality of safety inspections and reviews made by the responsible department and to also make in-depth checks as deemed necessary. Such independent assessments are then organised through the plant quality department, which reports directly to the plant general management. In Finland the final safety review is made by the safety authority.

All interviewed expressed confidence in the inspections and reviews made at their plants, that the quality of particular assessments made as well as that all matters possibly involving risks are sufficiently well accounted for. The interviewed were convinced that independent inspections and reviews add to the quality of the activities as a whole. Some pointed out that there is a need for structuring inspections and reviews properly to utilise resources more efficiently. There were also remarks that it is necessary to ensure that the thoroughness of the initial safety assessment does not weaken because of undue reliance on assessments known to follow.

In Sweden the new regulation issued in 1998 has contributed significantly to clarifying regulatory requirements on safety assessments to be made by the plant owners. Several of the interviewed reported that the new regulation had been a valuable aid in structuring the safety assessment work.

Process oriented activity control: Industrial management can be regarded as a matter of controlling and coordinating work processes, like production, maintenance, procurement, development etc. Because there are many interacting work processes to be managed, process oriented activity control has been developed as a method to put a focus on the flow of work activities over organisational borders. *A* process view helps in detecting and correcting bottlenecks in handing over results from one work activity to another. The process view is sometimes seen as horizontal and complementary to the vertical view as provided by the line organisation. According to process oriented thinking it is a common practice to divide between core and supporting processes. Process orientation in the control of work activities has been introduced in many organisations, perhaps more outside than within the nuclear power industry. The process view is also supported by the ISO 9000 series of standards. A more detailed account of this methodology has been given by Rummler and Brache (1990).

Some of the visited organisations have introduced or are about to introduce process thinking in their quality systems, while others continue to use more traditional approaches in structuring their activities. There was a group of the interviewed that were

not entirely familiar with the concept of process oriented activity control, but when the concept was explained, they had an intuitive feeling of its benefit. Most of the persons interviewed saw process orientation as a concept helping to structure activities in which many organisational units are involved. Requirements in regard of processes, when incorporated in the quality systems were seen to include requirements for each process to be clearly described and to assign responsibility for it to a *process owner*.

In spite of the benefits of process oriented activity control, there are still things to be resolved in trying to find a proper balance between the traditional line-organisation and a process oriented way to organise. Should both views be pursued in parallel or should one be selected before the other? Regulation implies the existence of a clear line of command and reporting which has to be merged with another structure, oriented along the processes. There were remarks to the effect that process orientation should not be understood to mean predisposition towards complete reorganisations along certain processes, but rather the attentiveness of the concept when possibilities for improvements are sought.

Process oriented activity control has been considered in some way or another in all the organisations visited. There were also references to cases where the process concept has played an important role in the development. For instance, there have been recent reorganisations at two of the visited plants to form a common maintenance department to units serve all production units at the site. In connection with these reorganisations thorough process analyses of the maintenance activities were performed.

Fostering quality thinking and commitment: In fostering quality thinking, many emphasised the need for applying a motivational approach instead of just considering the formal aspects of the quality system. That also implies that quality audits are seen as opportunities for improvements instead of a search for deficiencies. When this is achieved quality audits are capable of contributing to good quality thinking. Two of the organisations visited noted that they had positive experience of analysing deviations more thoroughly as symptoms of more general deficiencies. An active participation on part of the management as well as of peers from other departments or organisations in the audits are also due to increase their significance.

Commitment to quality requires, as several pointed out, knowledge and understanding of how it is connected to organisational goals. Commitment to quality can, for this reason, not be expected unless the quality system is well understood, e.g. in regard of definitions of authority, obligations and responsibilities. Fostering quality thinking is also connected

to participation and efficient communication within the whole organisation. Many thought that promoting the process approach in work activities contributes to sound quality thinking and that it helps to give people a broad insight of their own roles in a larger context.

In the discussions several persons referred to the importance to understand organisational goals and how they are broken down to set the goals for organisational units. Some of the organisations visited have defined their major success factors and broken down them to provide a top down definition of a goal structure through organisational levels and even down to single individuals. This break down provides also a possibility to follow-up how these goals are achieved.

Several of the interviewed thought it would be important to create an understanding of the quality system and the ideas behind it, basically to tell what is right and why, and thereby to facilitate doing things in a right way. Information about the quality system should be given repeatedly and discussed actively, not only in training and education programs but also in management meetings as well as informal meetings arranged specifically for that purpose. Meeting days wholly assigned to related matters, like safety culture, were mentioned as highly valuable.

Favourable promotion on broad basis of quality thinking, specifically in regard or safety, was reported at two plants as a result of a long lasting campaign called STARK[2]. The campaign continues to be visibly pursued, by means of posters and gatherings receiving considerable support from all management.

Asked to judge on the general commitment to quality on part of their co-workers, all expressed full satisfaction. The high degree of commitment to safety was generally attributed to good traditions and culture developed in the nuclear field and not that much to the existence and content of the formal quality systems.

Strategies and development needs for the future: The largest future challenge is to maintain public trust and confidence in the safety of the plants while at the same time keeping them economically competitive. All this should take place in an environment where the safety requirements most likely would be increasing. Only then it would be possible to keep the installations in operation for their remaining lifetime. Many referred in this connection to the deregulated electricity market and present difficulties in maintaining

[2] Stanna, tänk, agera, reflektera, kommunicera (stop, think, act, reflect, communicate). Stark is the Swedish word for strong.

economic competitiveness with prospects of lower electricity prices. Many of the interviewed referred to safety as an absolute requirement, which is not possible to compromise in any situation. Others noted that a sustained safety could be reached only through the application of the principle of continuous improvements. Ensuring safety at constant high level requires, in practice, that there are continuing efforts expressly aimed at achieving further improvement of the safety. Several of the interviewed persons noted that if one would be satisfied with the present level, there is a risk for developing complacency.

Many of the interviewed in Sweden referred to the uncertainty for the future in regard of the political decision to close down the nuclear plants in a foreseeable future, well before the end of their economic life expectancy. The present strategy is to continue investment programs in safety and operational quality as if such a political decision would not come. This is applicable also for the reactor tentatively scheduled for closure in 2003.

Another challenge mentioned by many relates to the retirement of many of the present specialists in vital areas, within a decade. In Sweden plant owners are presently jointly surveying the situation for the nuclear plants in regard of the future availability of competency and other resources. A similar study was recently reported by a government working group in Finland (Ministry of Trade and Industry, 2000).

Observations from the study

The study confirmed that quality and quality systems have an important place in ensuring a safe operation of nuclear installations. There seems also to be a very good awareness and understanding of the demands, which are set on various activities to be acceptable. This awareness and understanding can be divided to address three different aspects of the systems, i.e. the existence of various threats, the actions, which can be implemented to meet them and the quality at which these actions are implemented.

Organising for quality: There are regulatory requirements on quality systems that they should be documented, reviewed and updated. These requirements have taken slightly different forms in Finland, Norway and Sweden. The organisations visited have selected different ways of structuring their quality systems. In spite of the differences the views on quality and how it can be ensured were rather similar. A view that quality assurance is a responsibility only of the QA-department seems not to be valid. Instead there is a large agreement on that quality is a concern for everybody in the organisation. There is also a

broad understanding of the need for formality in the quality systems. Still it seems that the quality systems in some of the organisations were better accepted than in other.

Today the quality systems are expanded and merged with other systems to become integrated management systems providing a planned and documented account of all activities. In the management systems there is usually an easily traceable path from broad mission statements to the detailed instructions for tasks to be carried out. These systems then integrate all aspects of the enterprise such as business objectives, strategies and policies, rules, requirements, organisation and procedures. This goes along with a view that quality is built on awareness about goals, requirements and acceptable practices among all those taking part in the common mission of the organisation. This similarity between for instance quality, environmental monitoring and management in general has also been illustrated by Curcovic *et al (2000).*

The challenge in developing a good quality management system seems to be in finding a suitable structure, which makes it easy to navigate between principles, requirements and solutions. Another challenge is to break down general goals and requirements to give practical guidance for all work activities. A successful combination of all these requirements in the management system with a due account of both the line organisation and process-oriented activities will require some innovative thinking.

Goal definition and follow up. The formulation, prioritisation and follow up of goals are important parts of activities aiming at quality. Definition of goals and follow up how they are achieved, typically go through cycles of strategic and yearly planning. Today there is a tendency to break down company goals in several hierarchical steps even down to the level of individual persons. This is often done rather formally in the framework of the so-called balanced scorecards, which were introduced by Kaplan and Norton (1996). According to the concept the overriding goals or success factors for an organisation are defined in a systematic way and to further broken down into sub-goals. One example of the high level indicators on the balanced score card used in one of the organisations was *production, safety, economy* and *public confidence.*

The balanced scorecard concept was seen to enhance a participation in goal formulation throughout the whole organisation. Following up to what extent goals have been achieved take a reversed process starting from individual performance appraisals and ending with an assessment of the indicators on the balanced scorecard. Many of the interviewed saw the balanced score card as a functional approach, in emphasising a

selection of fundamental areas in which goals have to be reached for ensuring survival of the organisation.

Some of the interviewed pointed to the need for arriving at a proper balance between the sometimes conflicting goals as set on the nuclear installations. Safety culture has for some time been seen as a goal in itself and has been strongly promoted by international organisations and national safety authorities. The strength of safety culture is however difficult to assess and quantify.

Some remarks on the often discussed conflict between safety and economy in nuclear operation were made and it was argued that such conflicts disappears in a longer time frame, because economy can only be ensured if safety is demonstrated consistently. There were, however, also remarks that the increasing economic pressure due to the deregulation of the electricity markets may accentuate the conflict. This may indeed be a danger if it is not forcefully resisted, because even safety improvements tend now to be postponed if not considered to be absolutely necessary.

Inspections, audits and reviews for quality: Inspections, audits and reviews are important activities with which a continued quality in the work is maintained. All components and equipment that are procured are inspected to ensure that they fulfil their requirements. Inspections are made when components and equipment are installed at the plants to ensure that everything has been correctly done. For more complicated inspections an inspection plan is usually prepared in beforehand.

Regular audits of all activities or parts of the organisation are made according to stipulations in the quality systems. In an audit, a small team goes through the activity or the work of an organisational unit in a large degree of detail. Audits usually aim at detecting discrepancies between defined and actual ways of carrying out work. One common observation from audits is that the same observations tend to repeat. This point to underlying causes that have not been brought into the open. Several persons thought that observations from the audits should go through the same formal analysis as incidents.

The regulatory bodies are carrying out regular inspections, audits and reviews. Plant modifications with a safety impact are usually inspected by regulatory representatives. Quality and safety audits are done every year on slightly varying activities. A larger safety review consisting of several different areas is typically required with a ten-year interval

and this includes both self-assessments by the nuclear utility and reviews by the regulatory body as described by IAEA (1994).

Audits are sometimes seen as to be more concentrating of doing things right than doing the right things. Activities should therefore also be reviewed in a more comprehensive way. Various review methods have been developed, and are in regular use by the nuclear power plants. International Atomic Energy Agency (IAEA) and World Association of Nuclear Operators (WANO) are offering peer reviews where a group of outside experts during a period of two to three weeks make a comprehensive review of many different safety related activities.

Use of information technology: It is evident that modern information technology offers several opportunities in making the quality systems easier to use and update. The accessibility of the quality system can be improved using computerised information systems with hyperlinks between different parts of the system. The transfer of procedures and documentation to a suitable computerised platform has a large potential as compared with traditional paper based systems.

All organisations visited were using e-mail and some kind of Intranet and people expressed a large satisfaction with these systems. Some pointed to the possibility of information overload when it has become too easy to send everything to everybody. There is on-going activities at all organisations visited which aim at providing information about their quality system through their Intranets. In an assessment of a future development it is possible that an increased use of information system may introduce a gradual shift to a situation where people are not passively fed with information, but are supposed to actively search for what they need.

Some of the interviewed indicated needs for improved handling a variety of administrative information, such as meeting protocols, decisions on actions to be taken, deviations identified in audits, etc. If that information can be accessed a compiled easily it would be easier to manage the follow-up activities to ensure that important issues are dealt with according to plans.

One drawback with modem information technology is that the systems tend to become obsolete very quickly. This introduces a burden in the training of people. The systems are also expensive and there are several examples of overruns both in costs and time when new information systems have been installed.

Exchange of experience: The study demonstrates large similarities both in solutions and in ongoing activities at all the visited organisations. Still there are relatively few direct contacts between the organisations. One could for example have expected joint seminars for exchanging information on ongoing activities and exchange of auditors for the quality audits. Active contacts were more directed towards technical details for example within working groups aiming at establishing common interpretations of certain standards.

The contacts between the nuclear power plants for an exchange of information seem to have been decreasing over the last ten years. One likely reason is linked to the increased competition brought by the deregulation of the electricity market. The deregulation has also had an effect of forcing nuclear power plants to reduce their costs, which may have had an influence on activities that are considered less important.

In the organisations visited there is no confidential reporting system like those in use for instance at many airlines. According to regulatory requirements all incidents above a certain level of severity are reported to the regulatory body. These incidents are analysed using formal methods for identifying root causes. There are arguments that confidential reporting could stimulate a more covering reporting, but the present practices seem to be able to capture the most important lessons due to two reasons. Firstly the reporting atmosphere is open to encourage people to report mistakes they have made. Secondly most incidents, which contain a safety challenge, tend to be complicated and involve several actors making it less likely that they will not be reported. Such incidents also make a formal analysis necessary for all the lessons to be learned. Some of the plants visited have a system for reporting minor problems, but they are more to be seen as a way to stimulate suggestions for improvements from the shop floor.

Anchoring the quality system in the organisation: The persons who were responsible for quality activities mentioned as their largest challenge to get the quality system anchored in the organisation. Many of these persons saw their job as service activity in the organisation to promote quality thinking and good practices in all activities. It is evident that a system, which only is seen as a binder collecting dust on a shelf, cannot have its desired influence on the quality of work. There seems to have been earlier excesses in the quality assurance activities which have given the word quality a bad ring, but these problems have evidently been cleared away today.

Most people viewed the attitudes of the senior management as crucial in getting an organisational commitment to quality. Some of the persons interviewed who had a managerial position even expressed some astonishment with the small interest for quality

activities that some senior mangers showed. A visible participation in quality activities could be seen in a larger attention to issues concerned with quality in that organisation.

A broad participation in the development of the quality system was seen to carry a potential of larger commitment to the system. Someone has to take the lead when a new system is developed and introduced, but it is important that everyone has a saying and that the system is systematically anchored. A novel view on quality system used in some of the organisations is that management formulates requirements for the organisational units and they in turn describe their responses to these quality requirements.

Regulatory oversight: In the study no explicit question was asked on regulatory oversight. In spite of that, many of the interviewed made several references to regulatory activities. Differences in national regulation as well as the difference between commercial and research reactors were clearly reflected in the interviews. The structure and organisation of the regulatory activities in Finland and Sweden concerning the commercial nuclear power plants is also somewhat different as described by Wahlström et al (1996).

Regulatory activities have a large influence on quality-related activities at the nuclear installations. This is certainly also the intent, but there was a clear view expressed that the authorities should avoid having a too large influence on the alternatives selected for structuring work processes. This view is well in line with the bearing principle that the plant owners should have an undivided responsibility for safety. This implies that it is important to maintain a distance in the regulatory involvement. Additionally it is important that the regulatory attention is balanced in that respect that issues are given the weight they deserve by their safety importance. The study also supports the result of other studies (Sinkkonen, 1998) and Wahlström and Sairanen 2001), that requirements which are considered legitimate get a larger acceptance at the nuclear power plants.

In spite of the need for a certain distance between the regulator and the operator of a nuclear installation it is necessary to maintain open and trustful dialogue in all interactions. Such a dialogue seems to be facilitated by a mutual understanding of roles and practices. An important part in the processes for creating a pertinent regulatory oversight is also connected to activities of the regulatory body for developing its own competency and practices as reported by Reiman and Norros (2001).

IMPLICATIONS ON LEARNING AND KNOWLEDGE SHARING

Nuclear installations use formal quality systems to ensure accuracy and repeatability in all important activities. At best this quality system institutionalises organisational learning in a formal system into which the principle of continuous improvements has been built. At worst the formal quality system could be a bureaucratic burden which stifles individual initiative and thereby becomes a hindrance for learning. If the formal quality system is constructed and implemented with due consideration of the people who are going to use them there should not be any obstacles for the systems to be efficient vehicles for organisational learning and knowledge sharing.

Reasoning about quality and safety

The concept of quality is important for all work processes. The word quality embodies a set of attributes or properties to some object i.e. a product, service or work process, which can be measured on a scale to identify a region of acceptability. This region of acceptability is connected to a customer defined in a broad sense. Sometimes quality is seen in relation to expressed, tacit and even unconscious needs of this customer. Quality of a product can often be expressed in quite concrete terms, but quality of work processes tend to be more abstract. A large part of the quality requirements set on a certain product, service or work process are seldom fully expressed, which means that transactions between two or more people often need a clarification of tacit assumptions in the characterisation of quality. This actually implies that quality in a more formal sense cannot be defined without several consecutive loops of externalisation, combination, internalisation and socialisation as described by Nonaka and Takeuchi (1995).

Causation is another concept, which is important in a consideration of quality. One has to be able to reason about causes of good or bad quality. Such causes can be imbedded in work processes and the materials used, they could depend on knowledge and skills of the people doing the work, and could also depend on processes of chance beyond the control of anybody. The quality systems build on the assumption that quality can be controlled by influencing the work processes. An unsuitable work process together with negligent inspection may result in inferior quality with further consequences on safety and/or economy. The quality systems therefore include review activities aiming at identify reasons for inferior quality and possibilities to introduce remedies.

The concern for safety was the driving force behind the application of quality systems in the nuclear industry. It is easy to understand that inferior quality can cause safety problems, but it is also important to see the quality systems as providers of efficiency.

The relationship between safety and quality should be mapped and considered to define the specific quality requirements by which safety and economic performance can be reached. The projected lifetime of a nuclear power plant also puts a demand on a comprehensive documentation of quality requirements and the work processes by which this quality can be reached. In this light the formal quality systems that are used at nuclear installations can actually be seen as a construct driven by safety requirements.

A functional view on quality systems

Quality systems can be seen as a mean to reach certain ends. The quality systems therefore have a well-defined function. On a basic level one could say that they contain descriptions of the agreed quality that has to be reached, methods for reaching this quality and the processes by which the quality system is maintained. From a purely functional point of view it does not matter if the quality system is tacit and embedded in the work practices or if it is explicitly described in a set of documents. From a practical point however, there is a need to have it formalised in one way or another to make it accessible and reviewable.

When a quality system is created there are several dimensions of freedom. Should for instance the system cover only the quality of products that are manufactured or should it also regulate work processes of the organisation? If a formal management system is used it is natural to include the quality considerations in this system. A second question is if the same quality system should apply to all parts of an organisation or is it acceptable that different organisational units have their own quality systems? Even if several different systems are used it seems however practical to tie them together in some high-level management documents. If different quality systems are used in the same organisations it is also practical to require a reasonable similarity between the systems.

Given the freedom in building a new quality system, one could ask what the characteristics of a good quality system would be. The process of building up a quality system gives many insights for the people involved in that work, but these insights have to be transferred to the whole organisation. One important characteristic is that the quality system must be easy to understand and apply. Understanding can be facilitated if the quality system is well structured and based on an explicitly expressed philosophy. A quality system can be brought in with force and excessive training, but a system that people can accept and apply by heart is always more efficient. Finally a quality system should have the full support of the management and it should be updated at regular intervals.

Perhaps the most important function of a formal quality system is to set an explicit requirement on systematic audits and reviews at regular intervals. In this function the quality system acts in a similar way as outside triggers in initiating a search for ways to improve. The trigger built into the quality systems is also enforced by the regulatory agency, which for example will ask questions about audits and their results. The quality system can in this way be viewed as a tool for continuous performance measurements and internal benchmarking.

The quality system as vehicle for learning

The quality system typically encompasses practices for activity planning, documentation and performance evaluation. Quality system can therefore provide a vehicle for learning if this purpose is considered and adapted to. This possibility has to be put in relation with the fear that a formal system may stifle innovation. From the point of organisational learning the question of whether or not to have a formal quality system, is reduced to a question of a preference between formal and ad hoc procedures for management. It is clear that a formal system never can make ad hoc procedures unnecessary, because no system can be designed to foresee all future needs. On the other hand a reliance on only ad hoc practices becomes inefficient if there are no systematic procedures to capture experience and make it operational. The need for formal quality systems therefore depends on the degree of uncertainty in the organisational environment.

Formal quality systems assume audits at regular intervals and they therefore facilitate systematic handling of operational experience. Audits and systematic analysis of events generate recommendations for improvements. These recommendations are transformed to specific actions to be undertaken and the actions are followed up. A formal quality system enforces reconsideration of old strategies and practices at regular intervals and it could therefore be seen as one example of the learning agent, which is discussed in the Chapter 2.

Audits and the analysis of events are typically done in small groups, which combine different specialisation and skills. This practice has the benefit of supporting the emergence of a shared language and understanding between different professions within the organisation. The quality auditors can also act as agents for the transfer of good practices, where both the audited part of the organisation and the auditors are exposed to different sets of assumptions and practices. Similarly participants in peer reviews have many opportunities to transfer good practices between different nuclear installations. To be efficient in this respect it may be necessary to give the auditors and reviewers training in this aspect.

The quality systems, and more generally, the practices, which are used in the nuclear industry for utilising operational experience, have large potentials to support organisational learning provided that the obstacles can be overcome. Perhaps most important is the attitudes people have towards the quality systems. If they are viewed as bureaucratic, difficult and not worth the effort, it is not likely that they can support learning. A second obstacle is connected to the problem of finding suitable concepts and models with which the bulk of operational experience can be coded to make sense and be accessible in a formal system. A third challenge is connected to the difficulty of translating experience coming from one nuclear power plant to concrete actions in a completely different setting.

Finding a balance between various extremes

The management at a nuclear power plant and in organisations in general has to find solutions, which satisfy goals and requirements. Sometimes this implies finding a balance between two extremes that appear conflicting. In a discussion of quality, such a balance has for instance to be found between quality and price or perhaps more correctly between defined quality requirements and the price that has to be paid to get it. This balance involves many considerations, because it may for example be advantageous to standardise to a higher quality, which then can mean that unnecessary high quality is used at some places. Relationships between quality and cost can be quite complex and express dynamics over time as Oliva and Sterman (2001) point out.

The quality systems give guidance for various work processes and they will therefore at least implicitly define how much effort that is spent reaching the required quality in the work process itself as compared with efforts spent afterwards on inspecting and correcting the work. The crucial factor here is the variability in the output as introduced by the work process, where a low variability can eliminate the need for extensive checks. According to commonly accepted views it is not possible to achieve quality just by inspections and reviews. This also means that quality deficiencies have to be caught as early as possible in the work processes.

Building up and maintaining a quality system involves finding balances between several extremes. The perhaps most important is a selection of the degree of formality to be used in the quality system. In a very formal system there are clear rules for how to act in various situations, but such a system may become very difficult to work with. A quality system should also be reasonably documented, but too many documents in the system may render specific documents difficult to find and access. The extent of a similarity in structure and content of the quality systems used in different parts of an organisation is

also an important balance. A similarity can enhance communication and understanding, but it may be unpractical taking into account the specific needs in different parts of the organisation. All these questions may stir up emotions when two organisations are brought together in a merger and there are two quality systems that are built on different principles.

Quality systems can be seen as a response to the need for conservatism and stability of the nuclear industry. All solutions adopted for various purposes should in principle be proven to avoid the danger of later problems with immature solutions. This will to some extent slow the process of learning, but it will on the other hand prevent the organisation from jumping on all new management whims. Quality systems can support evolutionary developments, but will most likely tend to stifle development in cases where more revolutionary changes are needed.

Implications for organisation and management

The quality systems tend today to be integrated into the management systems. This is practical because quality is actually one of a variety of concerns, which can be handled with similar methods. There are a variety of standards and guidelines, which give excellent advice on how to set up and maintain the systems. The difficulty however, is that the guiding documents tend to be thick and somewhat difficult to access. An illustration of the underlying principles may help in this regard. A second observation is that the standards and guides do-not usually give much guidance in how to make the systems user friendly and accepted.

The increasing complexity of industrial systems has brought an insight that a confidence in quality can be obtained only by a simultaneous consideration of both the product itself and the work processes that have generated this product. To verify that a product fulfils a certain quality level it would therefore be necessary to get an access to a large amount of information from the initial phases of design and use of the product. Unfortunately there are many products on the market, for which this kind of information can be very difficult to get.

When a formal quality system is developed it is necessary to have a person or a group of persons to whom the task of creating and documenting it is given. To ensure a successful result it is however necessary to have enough consultations with the persons who are going to use it. Some of the organisations participating in the study even expressed the

view that the persons supposed to use instructions should be formally involved in creating them.

The quality system can be seen as a normative framework, which defines a formal organisation as opposed to actual or informal ways of organising work activities. There is anecdotal evidence that the formal and informal organisations may start to diverge and there may be various reasons for this. One possible reason is that the basic assumptions and philosophy of the quality system is not adapted for its intended purpose in the organisation. Another possible reason is that the quality system has not been anchored in actual practices on the shop floor. A third reason may be the absence of sound human factors principles in the creation of the quality system.

A vision for the future

Quality system will also in the future be one important part of the safety management activities at nuclear installations. Experience from the use of the quality systems has been accumulated in the systems themselves and also in various standards and guidelines for their design and operation. This development over the years as promoted by several organisations can be seen as a kind of organisational learning on a global level. In spite of the improvements made so far, there seems however still to be room for further improvements. This is perhaps a reflection of the general strategy of continuous improvement. Without this strive in the organisation there is the danger of complacency.

Presently there are considerable differences in the structure and details of the management and quality systems used at the nuclear installations. There are also differences between the management and quality systems used in the nuclear industry and in other safety-related industries. The application of the TQM concept in a wide sense has a potential to narrow these differences to make the views on the quality systems to converge. On a medium term it may be expected that the quality systems will become more similar. Such a development will however rely on a collection and analysis of experience from various quality systems to evaluate the characteristics, which make them fit for their purpose.

Quality systems are more geared to learning from failure than success, but due to the way audits and reviews are organised they have the potential also to transfer good practices. In the future this part may need strengthening. Another reason to stress also learning from success is that disappearing failures it would remove events at which learning takes place. To counteract this other learning mechanism may be necessary. One possibility

may be to have some kind of institutionalised imagination to envisage how causal factors behind an incident somewhere else could be transfer to a completely different environment as March *et al* (1991) are discussing. This would need formal analysis and suitable methods and theories to make a believable shift of an event from one cultural setting to another.

CONCLUSIONS

Man is adapted to learn by trial and error. There are many systems in use today where this approach to learning cannot be tolerated. Experience from high reliability organisations has brought many insights by which activities can be made very safe (Rochlin, 1999). Experience however also point to mechanisms, which may introduce hidden deficiencies in the safety management activities as illustrated by Baumont *et al* (2000). The challenge is to detect and correct such deficiencies before an incident has made them obvious. The quality systems have an important function in this endeavour.

Nuclear installations are in many respects similar to other installations where a high safety is required, but there are also important differences. The quality systems that are used in the nuclear industry provide a reflection of these requirements. The nuclear industry is presently in the middle of a change process, which will be reflected also in the quality systems in use. Changes bring opportunities for learning and renewal, but they also carry an increased vulnerability that something important is forgotten. Opponents to nuclear power have claimed that it is impossible for any organisation to live up to a demand of zero errors and that accidents therefore are inevitable. The experience collected so far from the use of quality systems and from safety management more generally, has demonstrated that there are no obstacles in ensuring a continued safety of the nuclear power plants in the world.

The study gave many useful insights in the position the quality systems have as a part of the safety activities at nuclear installations. Given the historical background of the organisations it is often easy to understand solutions selected and positions held. Sometimes however, this historical ballast gives a feeling that it would be easier to start with a clean table, but the need to consider accumulated knowledge seldom makes this possible. The interviews brought many concrete suggestions for how quality systems could be improved and integrated in the safety activities at the nuclear power plants. There is clearly a need for a broad participation in the creating and maintaining of the quality systems. It is also important that the principles of the systems are understood and

accepted. If that is not achieved they have no function and cannot consequently fulfil their purpose of controlling work activities. Properly used the quality systems have a potential of becoming good tools for organisational learning.

Finally there seems to be a need for a coordinated effort in approaching some of the important issues connected to quality systems used in the nuclear industry of today. These include, but are not restricted to; the structure of the quality system, its implementation and the ways to get it anchored into the organisation. The quality system should provide support for their users in making sense of the requirements that are placed on various activities and of the methods selected to meet those requirements. Quality systems are often viewed as rather technical, but they certainly have to do with people and how they communicate. Many managers at the nuclear power plants agree on that there is a need for development activities, but it seems difficult to find a natural body, which could approach this challenge with the correct blend of both theoretical and practical skills.

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