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ADVANCED METHODS OF PROCESS/QUALITY CONTROL IN
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FOREWORD

Nuclear fuel plays an essential role in ensuring the competitiveness of nuclear energy and its acceptance by the public. The economic and market situation is not favorable at present for nuclear fuel designers and suppliers. The reduction in fuel prices (mainly to compete with fossil fuels) and in the number of fuel assemblies to be delivered to customers (mainly due to burnup increase) has been offset by the rising number of safety and other requirements, e.g. the choice of fuel and structural materials and the qualification of equipment. In this respect, higher burnup and thermal rates, longer fuel cycles and the use of MOX fuels are the real means to improve the economics of the nuclear fuel cycle as a whole. Therefore, utilities and fuel vendors have recently initiated new R&D programmes aimed at improving fuel quality, design and materials to produce robust and reliable fuel for safe and reliable reactor operation more demanding conditions.

In this connection, improvement of fuel quality occupies an important place and this requires continuous effort on the part of fuel researchers, designers and producers. In the early years of commercial fuel fabrication, emphasis was given to advancements in quality control/quality assurance related mainly to the product itself. Now, the emphasis is transferred to improvements in process control and to implementation of overall total quality management (TQM) programmes. In the area of fuel quality control, statistical methods are now widely implemented, replacing 100% inspection.

The IAEA, recognizing the importance of obtaining and maintaining high standards in fuel fabrication, has paid particular attention to this subject. The Technical Reports Series on Quality Assurance and Control in the Manufacture of Metal Clad· UO_2 Reactor Fuels Technical Reports Series No. 173 and No. 221 on "Guidebook on Quality Control of Water Reactor Fuel" and IAEA-TECDOC-584 "Guidebook on Quality Control of Mixed Oxides and Gadolinium Bearing Fuels for Light Water Reactors" were published in 1976, 1983 and 1991 respectively. Conferences on Practical Experience in the Application of Quality Control in Water Reactor Fabrication and on Characterization and Quality Control of Nuclear Fuels were held jointly with the Kernforschungszentrum Karlsruhe in 1984 and 1990. Some aspects of quality assurance/quality control (QA/QC) in fuel fabrication were reviewed at the IAEA fuel related symposia in Prague and Stockholm (1978 and 1986) and at several technical committee meetings.

In response to the rapid progress in development and implementation of advanced methods of process/quality control in nuclear fuel manufacture and on the recommendation of the International Working Group on Water Reactor Fuel Performance and Technology, the IAEA conducted a technical committee meeting. Upon invitation of the Government of Germany and Siemens AG, KWU/Advanced Nuclear Fuel GmbH, the meeting was held in Lingen, Germany from 18 to 22 October 1999. In total, 19 papers from 10 countries were grouped into four sessions which covered new developments for control of process and product quality, their implementation and results obtained including new approaches to employee motivation.

EDITORIAL NOTE

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SUMMARY

1. INTRODUCTION

Reliability of nuclear fuel has been improving steadily over recent years. For LWRs, the main type in service worldwide, fuel failure rates have been around 10^{-5}, which is about ten per year per million fuel rods in service. The mitigation and control of fuel defects are driven by economic and safety considerations. The goal of " zero fuel failures", which means in practice a reduction of the fuel failure rate to 10^{-6}, has been the target of utilities and fuel vendors over the near term. Major causes of fuel failures to date have been mainly related to initial design, debris fretting and, sometimes, to fabrication problems. New fuel rod and assembly designs are being developed and implemented in response. For example, at light water reactors, metallic debris in the primary coolant system of the plant is known to cause a significant fraction, about 40%, of the fuel failures. As a result, utilities have developed programmes to identify and eliminate the sources of debris, and fuel vendors are offering "debris resistant" fuel designs.

In their turn, fuel vendors implement, apart of the above-mentioned design-related process optimization, technical qualification and quality assurance systems to fulfil the requirements according to fuel specifications in the framework of the quality management system.

Recognizing the importance of this subject, the rapid progress in the area reached during the last several years, the leading position of the IAEA in the collection, evaluation and dissemination of the information on nuclear fuel QA/QC and on request of IAEA Member States, the International Working Group on Water Reactor Fuel Performance and Technology recommended at its 14th Plenary Meeting in 1997 to hold the Technical Committee Meeting on Advanced Methods of Process/Quality Control in Nuclear Reactor Fuel Manufacture. Upon invitation of the Government of Germany and Advanced Nuclear Fuel GmbH, the meeting was held in Lingen, Germany, 18–22 October 1999. In total 19 papers from 10 different countries were presented. Forty participants from 14 countries participated in the meeting.

The presentations covered a broad scope of activities in process/quality control in various companies and countries from specific measuring techniques through quality assurance or quality control strategies to overall total quality management (TQM). This means a company wide effort to integrate all forces and operations necessary to fulfill the business objective. This effort is customer oriented and has to continuously adjust all quality related actions to the growing quality awareness of the customer. In the understanding of the TQM concept, in a company with complex production flow, a vendor-customer relation between the different departments has to be developed and established. The main objective of the TQM is prevention of quality deficiencies, its typical timing- during planning, fabrication and lifetime of a product and main characteristics of quality strategy is active integrative emphasis on system's thinking. All company's employees, in particular management, are involved in the realization of TQM.

It became obvious that the different suppliers of commercial nuclear fuel are applying similar programs for further improvement of their products and processes. The progress that has been achieved up to now varies depending on the startup of those programs.

There was a common understanding that a systematic and consistent improvement of processes and quality will not only improve quality and reliability of the fuel but also reduce manufacturing costs. It was also mentioned that product and process design has a significant effect on product and process quality and costs. Efficient programs, therefore, include design and engineering activities and are

based on a total quality management approach as given for example by the model of the European Foundation on Quality Management (EFQM).

All activities on product and process improvement should also include a clear focus on the employees. Communication, motivation, training and education of the people and a clear commitment of the management are as important as the technical aspects. To get a broad acceptance of those programs the application in the workshops has to be simple and easy to understand. This seems to be one of the key success factors during the implementation and application of TQM programs.

As far as TQM activities are additive to standard procedures of quality control there will be no objection from the customers or the authorities. If we want to achieve a second step of cost reduction by eliminating or reducing classical product examinations it has to be discussed very thoroughly and agreed upon with customers and licensing authorities. As most of the fuel suppliers are serving international markets a common understanding has to be created assisted by IAEA.

The meeting showed that we can learn from each other by exchanging our experiences with application of TQM programs without disclosing intellectual property of the different companies. This will contribute not only to maintain and even to improve the high safety standards that have been achieved in nuclear power generation but also to assure its commercial competitiveness in the world's deregulated power markets.

2. SESSION I: NEW DEVELOPMENTS FOR PROCESS CONTROL AND PRODUCT QUALITY
   (Chairman — Mr. A. Hüttmann, HEW AG, Germany)

The first session presented the views of power plant operators and fuel vendors.

The first paper reviews the boundary conditions for QA in the fuel area pointing out some specifics in the German licensing. With very tight QA guidelines fixed in part by operating licenses, there is only limited flexibility. The incentive to rethink QA strategies for the utilities is a potential for cost reduction without compromising safety or current quality standards. One possible way to regain flexibility and focus the QA activities on important factors might be the introduction of new methods. Statistical process control was named as one mean for the design of robust fabrication processes, which could be a benefit for all parties involved in the QA field.

The second presentation was split in two parts. The first part describes the QA monitoring process implemented at JSC "TVEL" in Russian Federation. The QA monitoring approach has 3 levels, in which the customers (domestic and foreign power plants) are involved as well as the QA department at JSC "TVEL" and the institutes dealing with design and design methods. Detailed plans for QA auditing are developed according to QA manuals. Whereas the requirements for domestic customers are based on the fuel contract and different Russian guidelines, the QA requirements implemented for foreign plants are following international standards like ISO 9000ff.

The second part reports on the QA guidelines and their implementation at MSZ plant. Details of planning activities when setting up the new quality management system as well as the schedule of implementation are discussed. Just recently MSZ plant was certified to ISO 9000ff by the German technical expert TÜV. Besides a better position in the international market, there was also an immediate effect on employee motivation. The review during the certification process increased people's awareness of quality issues improving the plant performance.

The next paper describes the classical approach of quality control in combination with modern quality management methods accepted by Framatome-FBFC (France). The statistical process control (SPC),

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which detects process changes and keeps the process under control, leads to optimal distribution of quality characteristics. It does not protect against non-systematic or local disturbances at low frequency. Only systematic 100% inspection is capable of detecting local quality deviations. Both approaches, including 100% inspection (the traditional way of quality control) and the statistical process control, are complementary for an efficient quality management. With the combination the feedback between manufacturing and quality control will improve the fabrication process. The integration level of the process control methods with the systematic inspection on products was described and illustrated by examples from laser welding of fuel rods for fuel manufacturing.

The Japan Nuclear Cycle Development Institute (JNC) at the Tokai Mura plant has developed MOX fuel for advanced thermal reactors. The classic concept and associated procedures of quality control related to fuel fabrication at JNC is described. The homogeneity of distribution of plutonium and uranium are key properties from a viewpoint of local power distribution and dissolution in reprocessing. Based on the experience the present quality control and assurance system, JNC is satisfied to fabricate the MOX fuel correct and reasonable in fuel safety aspects. This however considers, that the current procedure for quality control may have a conservative margin for fuel safety and seems to loose rationality from an economic point of view. Therefore it will be requested that more rational production and inspection methods should be developed and established in the future.

ENUSA (Spain) started the project "Quality at the Source (QATS)" on pellet fabrication. Product characteristics and fabrication process parameters have been classified. The design was elaborated especially to identify the CTQ (critical to quality) items. By means of the QATS system design under the 6 Sigma methodology, all customer requirements are included in the product specifications and drawings. According to the degree of expected improvements in the product ENUSA presented the evaluated dimensional and functional characteristics for the pellet fabrication. Therefore a quality index for each characteristic was introduced. With this effort the pellet manufacturing will be on a higher quality standard, it improves the necessary tools to avoid manufacturing defects and assures the productivity continuously.

3. SESSION II: DATA MANAGEMENT AS A BASIS FOR EFFICIENT PROCESS AND
    QUALITY CONTROL AND MODELLING (Chairman — Mr. J. Vandezande,
    Belgonucleaire, Belgium)

Three papers deal with the use of digital image processing systems as part of a data management system and the modelling of different stages of the MOX fuel fabrication process.

Mathematical algorithms are able to compensate for non-perfect conditions (by e.g. digital image processing) or to simulate (by modeling) these situations. In the first case, compensation is needed because we do not manage to create the environment, which we would like. In the second case, modeling is required when we want to evoke situations, which are not practicable because of safety, technical restrictions, and processes.

Besides creating conditions, which cannot be executed in reality, mathematical processes can now be taught (or trained) in a fast and easy way. From models one can learn (i.e. not only to understand certain processes better but also to predict what will happen if a part of the process is changed in order to develop better operations and to improve the existing ones) and feedback the system. All of this with a high degree of automation, which stands for similarity. Mathematical processes are definitely both time and cost saving, because human effort is diminished and defects (by modeling) can be avoided before the production starts.

Although PC-implemented algorithms have a lot of advantages we must not forget a couple of things. First of all, everything stands or falls with the input to the system. For digital image processing, the algorithm expects images, which are more or less similar. Our first concern must be to acquire images that have the best quality possible before we try to improve the image with software. If we use modeling for simulation, we have to be careful with the parameters that we give as input. Software,

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being tested thoroughly, can still contain bugs, and neither hardware is free of failure Precautions must be taken, so that no erroneous data is acquired Mathematical processes, which make some assumptions in order to facilitate the calculations, have to be checked extensively to verify that they are not distorting reality instead of improving/simulating it

A trend for present day algorithms is the open structure This gives not only the possibility to add improvements without too much effort but also to expand the algorithm without starting again from the beginning

Finally, the variety of platforms, at the present time, calls for software which can handle all of this

Two other papers in this session have been dealt with fabrication process and process quality control for MTR-type fuel elements (Egypt) and UO_2 powder and pellets (Ukraine) While for Ukraine it is typical laboratory-scale activity, for Egypt fabrication of LEU (19 75 wt% U-235) fuel elements is well established process with capacity of 40 elements/year

Since continuous improvement of burning characteristics and reliability of fuel elements is pursued, quality control has to evolve simultaneously, by preference in a economical way Although advanced computerized machines improve production, more process monitoring is still desirable in some cases

A classical way to perform this, is to examine all the different characteristics with a whole set of methods, which are applied separately Often, this is very time consuming and is accompanied with a high production cost

In modern practice, more and more installations are used to permit the simultaneous use of several methods This gives raise to a higher efficiency not only because two (or more) objects can be analyzed simultaneously, but also because the most effective configuration the installation can be used Finally, methods are implemented which can analyze a longer scope of elements to reduce the number analyses

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The third session was devoted to discussion on the implementation of advanced methods in process and quality control in nuclear fuel production The first paper describes the actual realization of the main idea of quality management philosophy-to investigate the relationships between process parameters and product characteristics and to create the control program on the basis of these experiments

This program developed and introduced at Siemens (Germany) allows determining the trends in quality parameters which have tendency to change within the margins of specification limits Such approach permits concentrating attention on critical technologic points and sufficiently reduce the production cost

In the report this quality management method was illustrated by its implementation into pelletizing and welding processes with the help of control charts, X-Y-plots and others

At present, the inspection methods used in nuclear fuel production become international This means that all nuclear producing plants have very similar sets of testing methods and devices But still there exists some deviation in inspection methods at different nuclear plants, which reflects some variations in technology The paper on QC methods and means during pellets and fuel rods manufacturing at JSC "MSZ" (Russian Federation) presents the main inspection methods and system of their metrological qualification It is clear that nuclear industry needs new ideas in the fields of non-destructive testing and routine analytical procedures to increase the accuracy and reliability of inspection procedures

Vibropack oxide fuel pin fabrication stands aside from the main direction of development of nuclear power production. But nevertheless this technology has certain advantages. The next paper presents the latest results in the development of vibropack pin production at the Research Institute of Atomic Reactors (Russian Federation).

The last paper of this session presents the Ukrainian State Program of creating national nuclear industry from U_3O_8 to fuel assemblies. The important step of this program is to build national zirconium cladding production on the basis of Ukrainian mines and existing scientific and industrial capabilities.

5. SESSION IV: STATUS AND RESULTS OF INTRODUCTION OF NEW PROCESS/QUALITY CONTROL METHODS IN FUEL FABRICATION PLANTS (Chairman — Mr. P. Reimann, Siemens AG KWU, Germany)

This session describes the status of the implementation of the process and quality control methods. It has become obvious that the advanced methods in this field must focus more on items like motivation of the employees or visualization and data presentation techniques.

The paper on the application of self-assessment in the nuclear fuel supply activities of Siemens AG explains that the self-assessment process, which is based on the model of the European Foundation for Quality Management (EFQM), provides quantitative measures to evaluate all processes in a company. This also includes administrative or management processes. Criteria like leadership, management of resources or people management are included and quantitatively measured with e.g. the customer satisfaction, business results or employee satisfaction. The results of the self-assessment approach were presented for a five year period showing a positive trend.

The next paper describes an experience of the implementation of the quality management system at Joint Stock Company MSZ" (Russian Federation). It is pointed out that the quality management (QM) at MSZ has a long history, starting in the mid-1950's. Later, in the 1970's, a formal quality control system was installed, being replaced by a quality management system shortly after. Today MSZ works in compliance with the international QM system defined in the ISO 9000ff standard. To include aspects of an more competitive environment into the quality system MSZ applied the model of the Russian Quality Award, which they won in 1997. The model on which this award is based on is very similar to the European Quality Award (EQA). It is intended at MSZ to also apply for the EQA and certify the company in accordance with the environmental protection standard ISO 14001. All these activities are a visible indicator for the philosophy of "never ending improvement".

The paper on introduction of new process and quality control methods in fuel fabrication at Siemens/ANF (Germany) indicates that quality improvements require a continuous effort. Additionally, all lifetime phases of a product, from product definition, research until manufacturing and operation, must be considered for an economical implementation of improvements. The paper presents examples for different phases in quality planning, which are attributed as "the driving force for continuous improvement". The phases are prefabrication studies, fabrication and inspections planning, inspections and visualization of all this information. The visualization plays a very important role in transforming data into information to finally derive measures. The techniques shown are Pareto Analysis, Box-Plots, trend analysis, 3D-graphics, quality control charts and others.

An obviously important aspect in a highly competitive environment is presented in the paper on reduction of cost of poor quality (COPQ) in nuclear fuel manufacturing in ABB Atom AB, Sweden. The paper explains the measures taken to reduce "non-value creating cost" on different examples. It is pointed out, that such a system needs the support of upper management and a measuring system to quantify the results. At ABB Atom the COPQ information are entered in the different departments into a very simple database. This local information is then linked and made available to all employees via the Intranet. The measures taken to reduce COPQ are very much depending on the specific goal. Automation is used in manufacturing to minimize the possibility of errors. Also an automated machine

or even automated line must have proved its capability in order to operate reliably. Other methods used are: Process reengineering for optimization of the project execution process, upgrading of test equipment to derive more and more precise product performance information and finally a system of survey the suppliers performance. It is emphasized that the employee support to all of these is essential. ABB Atom held a 3-step training for all employees to increase motivation. This training did not only include a self knowledge part and a classical course phase, but ended with actual improvement projects the participants worked on.

The last paper of the meeting on improvements by employee motivation in the manufacture of nuclear fuel assemblies for LWRs focuses on the progress possible by employee motivation. System introduced at ANF/Siemens (Germany) consists of 3 different parts. The "3-i" program is an awarding system for improvement ideas of the employees. It was pointed out, that it is most important in such a system to award the ideas very fast. For this reason the supervisors are allowed to award ideas up to a certain amount immediately. The second part are the "Work Groups". The work group consists of 3-10 people who work together in a manufacturing area. The group is self-responsible and organizes its work, working time and, if possible, also the maintenance themselves. The advantage of process ownership and responsibility also is, that the employees train the other members of the group to come to the best practice. Finally, the continuous improvement process (CIP) is explained. Ideas from the CIP groups are immediately analyzed and if possible directly implemented. Here again response time is a key to success. The CIP groups report to management about their results and problems. It was pointed out that management has the responsibility to start these kinds of initiatives and must constantly promote them in order to have ongoing success.

NEW DEVELOPMENTS FOR CONTROL OF
PROCESS AND PRODUCT QUALITY

(Session I)

CHANGES IN QUALITY MANAGEMENT FOR
LIGHT WATER REACTOR FUEL MANUFACTURING —
A UTILITY'S VIEW OF DRIVING FORCES AND STATUS

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Abstract

Quality management in LWR fuel manufacturing for the use in German reactors is based on international guidelines and national/local authority requirements defined in operational licenses. The quality management is twofold and comprises a quality assurance system and the check of manufacturing documents including witnessing of fabrication processes and inspections. Utility and authority appointed technical expert witness manufacturing and take part in inspections performed by the manufacturer where the scope is strictly defined and does not provide possibilities of flexible responses to manufacturing occurrences. For future developments in quality management HEW supports strengthening the ideas of quality planning. Analysis of all factors influencing fuel reliability shall be performed prior to manufacturing. This will increase the efforts in reviewing of drawings and specifications. Included here shall be a review of processes that will be used in manufacturing. The qualification and robustness of processes shall be demonstrated with special qualification programs and analysis of manufacturing statistics. Instead of product/project related inspections the use of all manufacturing data will provide a complete picture of the manufacturing quality. By applying statistical methods it will be possible to identify trends in manufacturing before deviations occur. So the basic driving force to implement statistical process control for the utilities is the wish to get comprehensive information of delivered quality, whereas for manufacturers it might be to increase production yields and thus to lower costs. The introduction and full use of statistical process control requires open information about manufacturing processes and inspection results by the manufacturers. This might include data judged to be economically sensitive. It also requires changes in attitude at the utilities and appointed experts. HEW has started to review and change internal guidelines to allow implementation of modern quality management instruments.

1. QUALITY MANAGEMENT FOR LWR FUEL – THE REGULATORY BACKGROUND

Already since the beginning of commercial use of nuclear energy, there was a vast agreement among authorities and utilities, that quality assurance measures have to be taken in design, manufacturing and operation of nuclear power plants and their components. The achieved successes in development of new LWR fuel designs and advanced core operating strategies are unimaginable without the accompanying quality assurance. The basic requirements for quality assurance here are common for all the nuclear industry: Make sure, that all design requirements are fulfilled by manufacturing and the final product.

Most international industry standards, e.g. 10 CFR 50 App B "Quality Assurance criteria for Nuclear Power Plants", concentrate on the quality assurance system. It is obviously impossible to introduce a standard quality assurance system for different companies as every company has different external and internal constraints that have to be taken into account. However, the DIN/ISO 9000 ff series provides some guidelines for the structure of a quality assurance system.

The quality management schemes applied in the German nuclear industry are regulated by national and local authority requirements. The national guidelines are summarized in the rule KTA 1401 "General Requirements on Quality Assurance". Instead of focussing on the quality assurance system, this rule describes overall requirements concerning quality assurance measures to be implemented in design and manufacturing of nuclear power plants and their components. Also the implementation in the power plant and operational procedure requirements are regulated here.

For any German nuclear facility the requirements above are applicable. The actual quality management measures to be taken are, however, defined by the operating license and (possible) additional instructions from the local nuclear regulatory authority. Thus the quality assurance measures might differ for any individual power plant in Germany.

The regulatory requirements ask for checking of the quality assurance system and its effectiveness by auditing as well as for checking of manufacturing documents, processes and performance of product inspections by the plant operator. Licensing authority supervises the quality management procedures implemented by the operator. The technical review and check of manufacturing is performed by independent experts hired by the authorities.

2. ACTUAL REVIEW PROCESS FOR FUEL FOR HEW'S PLANTS

Based on operational licenses and guidelines the quality assurance performed for fuel assemblies can be divided in several steps. The fuel supplier, plant operator and independent technical experts appointed by licensing authority are involved. This paper will be focussed on steps related to manufacturing.

The responsibility for product quality is primarily with the supplier who has complete control over manufacturing. The quality assurance steps taken by the plant operator and independent expert are very much comparable. They can be divided as follows:

a)   Manufacturing documents review.

This review step shall assure, that all design boundaries are kept. Any constraints from licensing need to be fulfilled. The review includes detailed checking of drawings and specifications for all components and piece parts including material conditions of a fuel assembly. The operational experience and manufacturing experience are considered in this review process. Finally it is stated, that all fuel assemblies manufactured according to these documents will be suitable for insertion into the core.

b)   Fabrication process qualifications review.

Only suitable processes shall be used for manufacturing. The qualification of important processes has to be demonstrated and is reviewed. Which process needs qualification is described in the manufacturing documents mentioned above. The aim of the qualification process is to proof, that the manufacturing will yield products according to specification if manufacturing parameters are kept within qualified and tested limits. The parameter sheets derived from the qualification provide the boundary used for actual production. Also here, the final statement is, that manufacturing applying these qualified processes including the relevant manufacturing parameters will yield fuel assemblies whose quality allows insertion into the reactor.

c)   Witnessing of actual fabrication and product inspection.

Manufacturing visits used to be the major step in quality assurance in the past. Frequent visits and the discussions during fabrication and inspection can provide an immediate response to any occurrences.

With the manufacturing visits both, the plant operator and the technical expert will get the necessary understanding of the manufacturing process and can by comparison with former manufacturing campaigns conclude on the relative product quality.

d)   Check of documentation.

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The final documentation needs to be reviewed because here all specified inspections are certified by the manufacturer. The results are checked. The utility and the technical expert get hereby the confirmation, that the product meets the design specification or that any deviations that have occurred are acceptable from a product performance point of view. Traceability to raw material is checked to assure all parameters influencing performance of the product can be retrieved later in case of any performance problems.

The manufacturing documents also describe in detail all inspections to be performed by the manufacturer. The witnessing of fabrication and inspection by the utility and the independent expert is thus a visit to watch the fuel suppliers doing their work correctly.

The internal guidelines developed for the quality assurance process are based on the operational license and authority requirements. Whereas the review of manufacturing documents and qualifications is described pretty coarse, the manufacturing visits and participation in inspections are defined in much detail. E.g. for KKK the scope and frequency for visits is pre-determined on the fuel assembly component level.

With all these detailed instructions it is easy to demonstrate conformance with the internal guidelines by simple check lists. However, the current approach asks for visits even in those cases, where no deviations have happened over several projects, but it will not require special attention to those areas, which have proven to be problematic in the past or today. Thus there is no system immanent flexibility to customize the quality assurance approach to a changing environment.

3. SOME IDEAS FOR A FUTURE QUALITY ASSURANCE APPROACH

Although there is agreement on the necessity of quality assurance measures performed by the utility and independent experts, the market situation requires a reasonable and effective approach. Also in the field of quality management – like in other technical areas – new methods have been developed in recent years. Slowly they are now introduced also into the nuclear business. The driving force for all developments were economic aspects. The recent developments may be summarized by the following principles:

* Design robust processes and products

* Analyze influences on product quality and control them during production

* Increase efforts in production planning and process qualification to increase process yields

These principles are governed by the idea of „doing it right the first time". This „first pass acceptance" policy will reduce production costs and lead to substantial economic advantages. But how could this influence the quality assurance measures taken by the utility and independent experts?

Obviously it is in the interest of the utility to cut costs anticipated with quality assurance programs – without compromising product quality. By simply changing the focus in the review process and during manufacturing the new quality management philosophy can be implemented.

The review of the manufacturing documents has to be strengthened. The incentive here is to evaluate, that the drawings and specifications will limit manufacturing variability inside the boundary given by the design and the licensing constraints. It will, however, not be sufficient to review these manufacturing documents. Fabrication processes have to be evaluated in parallel. The introduction of statistical methods like the Failure Mode and Effect Analysis (FMEA) will help to design stable and reliable fabrication processes.

A systematic analysis with the help of statistical methods allows to discuss process control measures during the product and manufacturing process design. The effectiveness of the process control can itself be also checked by applying statistical methods.

The technical expert and the utility will by the review of the process analysis and design data gain a real good understanding of the fabrication and inspection flow. Based on the deep knowledge about the process flow in manufacturing, the follow-up visits can be focussed on items of real importance. Thus the frequency of visits – and therefore the encountered costs – can be reduced when manufacturing process qualification and stability is proven.

4. STATISTICAL PROCESS CONTROL AND IMPLICATIONS ON MANUFACTURING REVIEWS

Good and accurate planning provides the basis for high quality production, however, to give a statement about actual delivered quality, manufacturing and inspection data is needed. The two ways to gather the necessary data are

- Sample data from product inspections for the specific project and demonstrate, that drawing and specification requirements are met.

- Make use of statistical process control and sample data over the entire production. Demonstrate that processes are stable and that products meet specified criteria.

The review of the entire production will provide a comprehensive overview on production and its control. Any trend recognized can be strengthened for increasing quality or adjusted, when it leans towards lower production yields. The statistical methods will provide guidelines on how to control the process, about sampling frequencies as well as give indications when changes in the process were initiated. The latter might allow identification of process disturbances and their root cause. So preventive actions can be taken for the future. The statistical methods also allow for evaluation of the product quality produced over a certain time frame.

For the manufacturer the incentive to use the statistical process control clearly is the potential to cut costs by increased production yields achieved with well controlled production. Once established the effort for process control sampling will be less than for the traditional quality assurance inspections. The focus is laid on those process steps, that need improvement, whereas the checking frequency for the stable processes is relaxed.

The utilities will certainly support any development that is leading to lower costs for the supplier because in a competitive market, the utility as the customer will profit in the end. But there is also a more immediate incentive for the utilities: narrowing the manufacturing follow-up visits closer on those issues directly affecting quality will allow to reduce the utility's and the independent expert's efforts while maintaining the quality standards.

5. FIRST STEPS TOWARDS IMPLEMENTATION STATISTICAL METHODS FOR HEW'S PLANTS

As mentioned above, the quality assurance measures taken by the utility are based on national and local authority requirements. Thus any change needs licensing authorities' concurrence.

The plant internal guidelines are now reviewed and will be changed. In all cases, the focus of quality assurance measures is to strengthen planning and design. The actual manufacturing visits shall be limited to changed processes and components of major importance including those components with deviations.

HEW has approached the authority and its experts and discussed changes in the manufacturing accompanying quality assurance process. New guidelines were presented. Everybody was willing to

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listen and to add the new concepts. The consequential drop of aspects of the traditional concept was, however, not fully appreciated.

In parallel HEW has discussed the potential of the new approach with the fuel suppliers, who are by far more open minded. Although manufacturing statistics, production quality data, process yields etc. are sensitive economic data which need to be disclosed to utilities and the technical expert to make full use of the statistical approach, the suppliers are ready to implement statistical process control in those manufacturing steps, where real mass production takes place.

Focussing quality assurance measures on those components or fabrication steps which are of major importance or had deviations in the past should be considered to improve the effectiveness of the quality assurance approach.

QUALITY ASSURANCE MONITORING DURING NUCLEAR FUEL PRODUCTION IN JSC "TVEL"

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Abstract

The paper describes Quality Assurance (QA) monitoring during fabrication of nuclear fuel in Russian Federation. Joint Stock Company "TVEL", natural state monopoly of the type of holding that fabricates and supplies nuclear fuel for the NPPs of Russia, CIS and Europe, incorporates the major enterprises of the nuclear fuel cycle including JSC "Mashinostroitelny zavod", Electrostal (fabrication of fuel pellets, rods and assemblies for different types of reactors), JSC "Novosibirsky zavod khimconcentratov", Novosibirsk (fabrication of fuel rods and assemblies for WWER-440 and WWER-1000), JSC "Tchepetsky mechanitchesky zavod", Tchepetsk (fabrication of Zr tubing). Monitoring of QA is an important element of Quality Management System (QMS) developed and implemented at the above-mentioned enterprises of the JSC "TVEL" and it is performed on three levels including external and internal audits and author's supervision. Paper also describes short- and long-term policies of the JSC "TVEL" in nuclear fuel quality field.

1. Introduction

The Open Joint Stock Company "TVEL" is one of the major enterprises in the nuclear complex of the Ministry of the Russian Federation on Atomic Power, natural state monopoly of the type of holding that fabricates and supply nuclear fuel for the NPPs of Russia, CIS and Europe. The company was set up on 12.09.96 on the basis of the decree of the President of the Russian Federation dated 08.02.96 № 166 "On the optimization of the management of the nuclear fuel enterprises" and Decree of the Government of the Russian Federation dated 11.06.96 № 677.

In accordance with the law "On using the atomic power", JSC "TVEL" is an operator and it performs the state regulation of the activity of the nuclear fuel cycle enterprises.

The company incorporates the major enterprises of the nuclear fuel cycle: JSC "Mashinostroitelny zavod", Electrostal (fabrication of fuel pellets, rods and assemblies for different types of reactors), JSC "Novosibirsky zavod khimconcentratov", Novosibirsk (fabrication of fuel rods and assemblies for WWER-440 and WWER-1000), JSC "Tchepetsky mechanitchesky zavod", Tchepetsk (fabrication of Zr tubing). Taking into account the modern requirements of the market and using the experience of leading Western companies engaged in the supply of nuclear fuel, JSC "TVEL" provides a complete package of services for the customer in the development, fabrication, licensing, delivery and accompanying of nuclear fuel, including the provision of operation guaranties for the reactor cores at NPPs.

To settle this task, JSC "TVEL" got unified with the leading scientific and design centres of Russia into the Association "TVEL – Nauka". JSC "TVEL" finances the scientific and design developments within the complex program "Fuel rods and assemblies of nuclear reactors at NPPs".

The quality assurance (QA) is the most important strategic task of the company. The monitoring of the quality assurance during the nuclear fuel fabrication is an importance element of the quality management in JSC "TVEL". The monitoring diagram is given in Fig. 1.

2.   Monitoring purpose and designation

QA monitoring during the nuclear fuel fabrication is used for the estimation of the effectiveness, correctness and development level of the quality systems of the industrial enterprises, design bureaus and scientific - research institutes, cooperating with JSC "TVEL".

On the basis of the information obtained on the results of the monitoring the heads of JSC "TVEL" get the possibility to:

(1) determine the correspondence of the quality assurance of the nuclear fuel fabrication and scientific-research products to the requirements of the contracts and agreements;

(2) plan and carry out the actions aimed at the correction and development of the quality systems of the enterprises;

(3) plan and carry out the actions and related to the development of the production and scientific-research basis;

(4) plan and achieve the strategic targets in the field of the product quality assurance.

3.   Monitoring structure and basis for its performance

Three levels of the monitoring of the quality assurance may be indicated:

(1) data of the Customers' audits and supervising bodies acting in the interest of the Customers;

(2) data of the audits of JSC "TVEL" of the systems and quality assurance programs of the industrial enterprises, design bureaus and scientific - research institutes;

(3) data of the author supervision of , design bureaus and scientific - research institutes of the fabrication of products at the enterprises of JSC "TVEL".

3.1.   Level 1

In accordance with the terms and conditions of the contracts between JSC "TVEL" and foreign customers, the latter have the right to perform external audits of the quality systems of the enterprises fabricating nuclear fuel as well as the quality system of design bureaus and scientific - research institutes, if the contract contains the provision of certain scientific and technical services to the customer.

For foreign customers the basic requirements during an audit are:

(1) Contract terms and conditions;
(2) Requirements of the regulating bodies of the customer's country;
(3) Standards ISO series 9001/9002/9003;
(4) Standards NUSS, IAEA.

For the Russian NPPs the basic requirements are:

(1) Contract terms and conditions;
(2) PNAE G-01-28-91 "Rules and norms of the atomic power. Requirements on the quality assurance programs for NPP".

In accordance with the contract terms, JSC "TVEL" transfers to the foreign customers the Quality Manuals, Quality Assurance Programs (QAP) and Programs of Quality Control (PCQ) of the enterprises, the products of which is supplied by JSC "TVEL".

The Control - Acceptance Inspection (KPI) performs the inspection and supervision of the nuclear fuel fabrication, supplied to Russian and a number of foreign NPPs. On the basis of the agreement (Letter № 32-09/3352 dated 15.10.98), KPI sends periodical reports to JSC "TVEL" on the results of the inspection and supervision.

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3.2. Level 2

The external audit of JSC "TVEL" is carried out by the specialists of the QA department, involving the specialists of the enterprises incorporated in JSC "TVEL". When planning the audit, the following data are used:

(1) Customers' audits;

(2) reports on the inspection and supervision of the bodies presenting the interests of the customers;

(3) reports on the author supervision of design bureaus and scientific - research institutes at the enterprises of JSC "TVEL";

(4) previous reports on the audit of JSC "TVEL";

(5) those of the customers on the nuclear fuel quality as delivered and operated.

3.3. Level 3

Design bureaus and scientific - research institutes perform the design of the nuclear fuel and its components as well as the author supervision of the products fabricated under these projects. To perform the author supervision, the factories – manufacturers sign contracts with the respective design bureau or scientific - research institute for the performance of the author supervision.

The basic requirements for the author supervision are:

(1) Contract terms and conditions;

(2) PNAE G-01-28-91;

(3) RD 95-540 (Guiding document. Instruction. Order of development and fabrication of nuclear reactor cores and their components";

(4) OST 95 581 (Branch standard. Order of the transfer of technical documentation to the fabrication. Author supervision).

One of the main requirements of OST 95 581 is the estimation of the stability of the stability of technological processes used for the fabrication of the concrete product.

4. Using the monitoring results

The customers, their representatives, design bureaus and scientific - research institutes, on the basis of the results of their checks, send reports to JSC "TVEL", as it is seen from Fig. 1. The customers also send to JSC "TVEL" their comments and claims on the product quality. On the results of the external audits, the QA department presents its own report to the management. So the recording system related to the monitoring of the quality assurance is formed.

The monitoring results are used for:

- the estimation of the current state and of the quality assurance in the fabrication and designing of the nuclear fuel;

- correction of the quality systems of the factories – manufacturers and design bodies to reach better level and interaction of the quality assurance system;

- strategic planning of the activity in the field of the quality assurance in JSC "TVEL" and its enterprises;

- planning and fulfillment of the technical actions activity in the field of the quality assurance;

- planning of external audits of JSC "TVEL".

Policy of JSC "MSZ" on the quality field is the good example in the quality assurance.

The policy of JSC "MSZ" in the quality field was finally formulated during the setting up of the QMS on the basis of IS ISO 9000. It became the basis for the QMS creation.

Presently, the long-term purpose of the policy of JSC "MSZ" in the quality field is the fabrication and release of the competitive products meeting all the requirements of the customers at the domestic and foreign markets. The enterprise shall supply to the customer the products of given quality, within set periods, in pre-determined amounts and for acceptable price.

Quality assurance monitoring
in the manufacturing of nuclear fuel
in JSC "TVEL"

Basis
letter 32-09/
3352 from
15.10.98

JSC "TVEL"

KPI

Report

Nonconformin's

Customers

Standart for foreign
NPP:
(1) ISO 9001/9002/9003
(2) IAEA 50-C-QA

Basis for Russian
NPP:
(1) contact
(2) PNAE G-01-028

Plan for audit
SQ (QAP)

Audit Report

Manual
for quality
assurance,]
QAP, PCQ

Manual
for quality
assurance,]
QAP, PCQ

Suppliers (wares)
JSC MSZ, JSC NZHC,
JSC CHMZ, JSC UMZ

Contract
of author supervision

Report

Suppliers (service)
VNIINM, NIKIET,
GIDROPRESS, OCBM

Basis
(1) contact
(2) PNAE G-01-028
(3) OST 95 540-88
(4) OST 95 581-78

JSC "TVEL"
Suppliers (service)
Suppliers (wares)
KPI
Customers

FIG. 1. Diagram of QA monitoring in the manufacturing of nuclear fuel in JSC "TVEL"

The task set is settled by means of the valid QMS and includes the following:

- study of the customers' requirements;
- analysis of the trends in the science and industry development in the field of the fabrication of the nuclear fuel for NPPs;
- study of the world market;

- close interaction with the product designers;
- improvement of fuel assemblies design;
- implementation of modern technological processes and equipment;
- optimization of inspection and testing;
- analysis of the product operation.

The enterprise spends dozens of million dollars annually to modernize and improve the process, inspection and test equipment, implementation of new technologies, analysis and inspection methods, staff training. The QA and its improvement is within the range of the main tasks faced by each employee in accordance with his responsibility, competence and authority.

The analysis of the QMS operation demonstrated that, to make QMS function effectively, it is needed to develop medium and short term targets on the basis of the long term targets of the policy in the quality field. These targets shall have concrete, measurable results. To reach this the procedure of the policy formation, including the development of the strategic (long term), medium term (for 3-5 years) and short term (for 1 year) targets, was developed. This procedure involves all the managers of JSC "MSZ" and functional departments into the policy development.

The targets for 1999 – 2001 are developed on the basis of this procedure.

5.   QMS documentation

The QMS documentation has 3-level structure. At the first level there is the general system document "Quality Manual", a part of which is the "Policy of JSC "MSZ" in the quality field". Besides, the "Quality Manual" contains:

- matrix of the responsibilities of the managers and departments and their main functions in QMS;
- description of the QMS structure;
- description of the main QMS procedures;
- list of main normative QMS documents.
-

The next documentation level is a set of methodological instructions, that control each system element. And, at last, the lowest level: inspection, technological instructions, factory standards and other normative documentation.

To carry out the special requirements of the customers or supervisory bodies quality assurance programs are being developed.

6.   QMS arrangement

Almost all the structural departments and high level managers of JSC "MSZ" are involved in the quality management system. (see Fig. 1).

6.1.   Coordination board

The coordination board is the body under the general director existing for the settlement of strategic issues related to QMS. It incorporates all the directors and the chief specialists of the enterprise.

6.2.   Constant quality commission

The constant quality commission is the body under the technical director existing for the settlement of the issues related to the product quality management at the level of JSC "MSZ".

6.3. Authorized management representative

The authorized management representative settles the tasks related to the quick provision of the QMS functioning. These are the responsibilities of the deputy general director in quality.

6.4. Coordinators in the department quality system

They settle the tasks related to quick provision of QMS functioning at the level of departments.

6.5. Departments directly under the deputy general director in quality

Quality Department – functioning and development of QMS, analysis of the product manufacturing and fabrication results.

Design-technological standardization department – management of the normative documentation at the enterprise, norm control, product certification.

Technical control department – incoming inspection, inspection during fabrication and acceptance inspection.

Central Factory Lab – analytical inspection and tests.

One of the main results of this work was fact that QS of our enterprise was certified by TUV and reception of the Governmental Award of the Russian Federation in quality.

7. Obtaining the certificate of TUV CERT for QS

The TUV certificate has the authority in Europe and worldwide. The obtaining of this certificate characterizes a company as a serious partner, gives the possibility to hold negotiations on signing different contracts as the availability of this certificate is desirable for many companies and often – a must.

In March, 1996, JSC "MSZ" got the TUV CERT certificate for the fabrication of fuel assemblies. 2 supervisory audits passed successfully; during the last one – extending, in April, 1998 - certification of magnet production was performed. The peculiarity of our magnets is their quality: high magnetic parameters and variety and complexity of geometry. The TUV CERT certificate for the magnet production without any doubt shall assist in moving our magnets to the European market. In June, 1999, we performed certification under model ISO 9001. At the same time the air conditioners and other consumer goods production is certified.

8. Reception of the Governmental Award of the Russian Federation in quality

The reception of the governmental Award of the Russian Federation in quality during the first competition for this award is the proof of the effective functioning of QMS and a good advertising factor. The participation in the competition allowed us to learn the methods of self-assessment and find out the weak points of the valid QMS.

INTEGRATION OF PROCESS-ORIENTED CONTROL WITH SYSTEMATIC INSPECTION IN FRAMATOME — FBFC FUEL MANUFACTURING

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XA0055749

Abstract

The classical approach to quality control is essentially based on final inspection of the product conducted through a qualified process. The main drawback of this approach lies in the separation and , therefore, in the low feedback between manufacturing and quality control, leading to a very static quality system. As a remedy, the modern approach to quality management focuses on the need for continuous improvement through process-oriented quality control. In the classical approach, high reliability of nuclear fuel and high quality level of the main characteristics are assumed to be attained, at the manufacturing step, through 100% inspection of the product, generally with automated inspection equipment. Such a 100% final inspection is not appropriate to obtain a homogeneous product with minimum variability, and cannot be a substitute for the SPC tools (Statistical Process Control) which are rightly designed with this aim. On the other hand, SPC methods, which detect process changes and are used to keep the process "under control", leading to the optimal distribution of the quality characteristics, do not protect against non systematic or local disturbances, at low frequency. Only systematic control is capable of detecting local quality troubles. In fact, both approaches, SPC and systematic inspection, are complementary , because they are remedies for distinct causes of process and product changes. The term "statistical" in the expression "SPC" refers less to the sampling techniques than to the control of global distribution parameters of product or process variables (generally location and dispersion parameters). The successive integration levels of process control methods with systematic inspection are described and illustrated by examples from FRAMATOME-FBFC fuel manufacturing, from the simple control chart for checking the performance stability of automated inspection equipment to the global process control system including systematic inspection. This kind of process control method, with follow-up of process and product variables, combines the high reliability level obtained by systematic inspection with the continuous improvement approach authorised by process oriented control.

1. INTRODUCTION

In the common practice and the recent developments in the field of process and quality control in fuel manufacture, it is now customary to distinguish the modern quality management from the traditional one. In the traditional approach of quality control, the typical quality organisation may be summarized by the following extreme scheme :

- a qualified process, with qualified process parameters;
- the systematic inspection of the quality characteristics of the product, generally in a final inspection;
- a quality assurance system which guarantees that :
    - the process is working under qualified conditions,
    - the accepted product is in conformance with quality requirements, generally expressed in form of inspection requirements.

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This approach may be qualified as "product-oriented" :

- the main corrective actions are focused on product,

- the process itself is treated like a product : when qualified, the process is "acceptable" and authorised to work .

The main drawback of this approach lies in the separation, and therefore in the low feedback, between manufacturing and quality control, leading to a very static quality system.
As a remedy, the modern approach to quality control focuses on the need for continuous improvement through a process-oriented quality control :

- the main corrective actions are focused on process : the qualified process is subject to trends or changes which have to be corrected before they have an impact on product conformity;
- product quality is the result of process performance :
    - the matching of process performance with product quality requirements is quantified (capability analysis),
    - if lack of matching, action for process improvement;
- product inspection remains a temporary remedy for quality trouble.

2. 100% OR SYSTEMATIC INSPECTION

In the traditional approach, high reliability of nuclear fuel and high quality level of the main characteristics are assumed to be attained, at the manufacturing step, through 100% inspection. In the technical file, 100% inspection requirements bear generally :

- upon the main quality characteristics of the product,
- upon the visual inspection of the product,
- sometimes upon process variables (welding intensity recording for example).

The realisation of 100% inspection may be classified according to the following criteria :
- automated / manual,
- final / in process,
- quantitative/ qualitative variables.

Whatever the kind of inspection may be, 100% inspection seems to be a typical tool of the traditional, product-oriented quality control.

We want to deal with the problem of the relationship between 100% inspection and process oriented quality control:

- is 100% inspection of the product necessary at the output of a process under control?
- how to introduce the modern quality control approach into the practice of 100% inspection?

3. INCOMING AND OUTGOING QUALITY

100% inspection is never 100% efficient. Any 100% inspection method has limited performance quantified by the efficiency. In the discrete model, the efficiency e is quantified by the probability of detection of one defect.
If p_i is the defect rate before inspection, the observed or apparent defect rate, through 100% inspection, is equal to $e\,p_i$, and the outgoing defect rate, after inspection, is equal to $(1-e)\,p_i$, where (Fig. 1):

$$p_i = p_a + p_o$$
$$p_a = p_i\ e$$
$$p_o = p_i\,(\,1\text{-}\,e\,)\,e = p_a\,(\,1\text{-}e\,)\,/\,e$$

100% INSPECTION
INCOMING AND OUTGOING QUALITY
(discrete model)

Incoming p_i

Apparent pa

Inspection

Efficiency e

p_o **Outgoing**

$$p_i = e\ p_i + (1\text{-}e)\ p_i = p_a + p_o$$

FBFC
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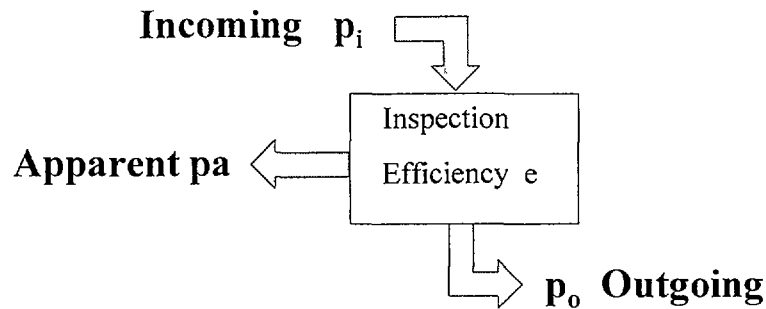
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FIG.1   100% inspection - incoming and outgoing quality (discrete model)

100% INSPECTION
INCOMING AND OUTGOING QUALITY
(continuous model)

Char value or defect size

EFFICIENCY

Outgoing
Incoming
Apparent
Acc Limit
Spec. limit
Efficiency

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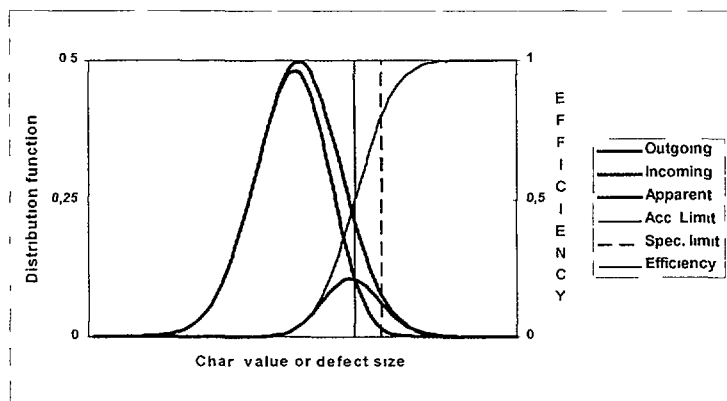
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FIG 2. 100% inspection - incoming and outgoing quality (continuous model)

In the continuous model, the efficiency is a function of the defect size **e(d)** , and the incoming, apparent and outgoing defect rates are obtained by integration on the defect size distribution (Fig. 2).

The different ways to control or improve the outgoing defect rate ($p_0 = p_i(1\text{-}e) = p_a(1\text{-}e)/e$) are:

- direct estimation of outgoing defect rate,
- control or improvement of efficiency ,
- control and improvement of incoming defect rate.

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4. ESTIMATION OF OUTGOING DEFECT RATE BY SAMPLING PLAN

This method is suitable if the efficiency is unknown and variable, and for qualitative characteristics, for example for visual inspection with operator-dependent efficiency (Fig. 3).
In FBFC , the Quality Department performs a systematic surveillance of the outgoing quality level by
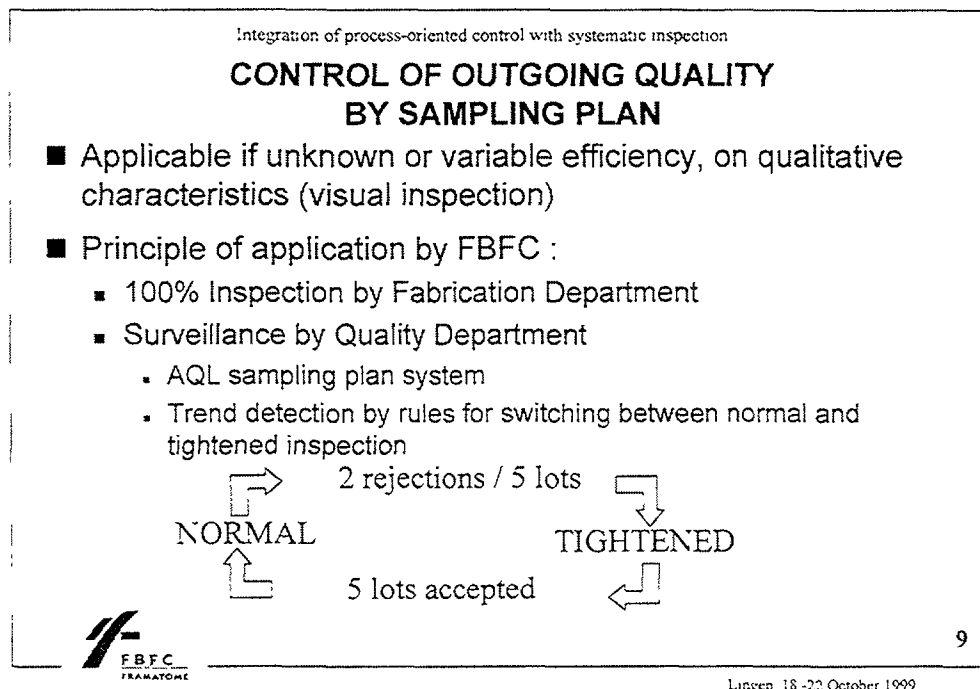
FIG. 3. Control of outgoing quality by sampling plan
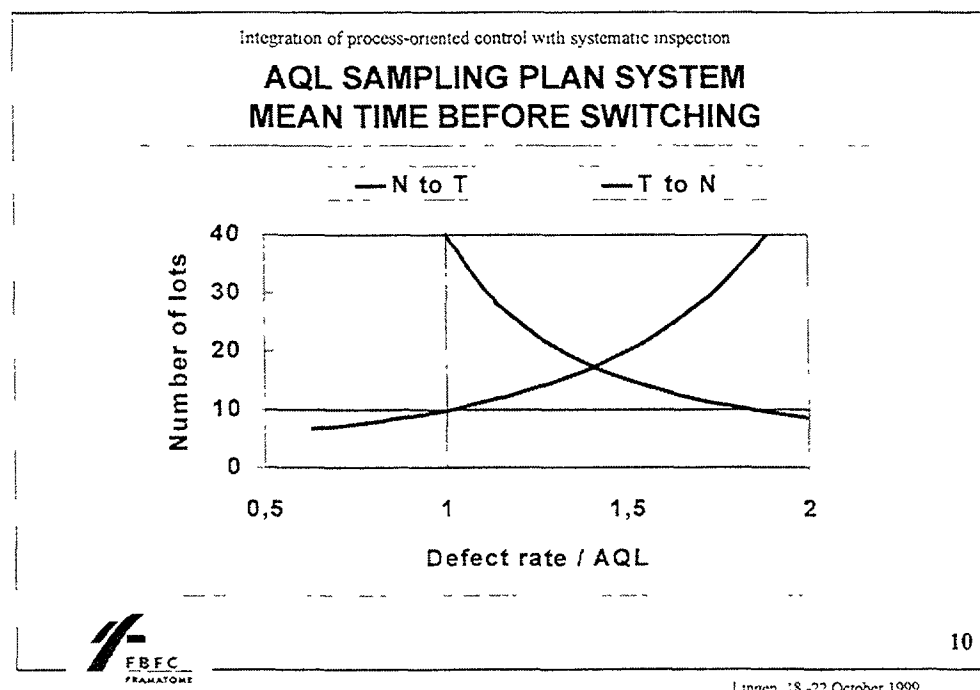
FIG. 4. AQL sampling plan system - mean time before switching

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sampling plans based on AQL (Acceptable Quality Level), after visual inspection by the Fabrication Department. The most important criterion in selection of sampling plans is the contribution of the sampling plan system to quality improvement.

In the AQL sampling plan system, the pressure for quality improvement results from the rules for switching between normal and tightened inspection. With these rules, the sampling plan system works as a control loop (Fig. 4):
- in case of change (increasing) of the mean defect rate, the increasing rejection frequency induces the switching from normal to tightened inspection,
- going back to normal inspection is only possible after quality improvement.
The complete and right application of these rules is the pre-condition for efficient working of sampling plans.

5. CONTROL AND IMPROVEMENT OF INSPECTION EFFICIENCY

This method is suitable for automated inspection devices, where the efficiency is calculable and adjustable from the calibration curve and the rejection limit (slide 11).
The intrinsic performance of the inspection device is determined from the calibration curve, giving the relationship between signal and measured characteristic or defect size, and may be generally summarized by the ratio a/σ between the slope of the (linearized) calibration curve and the residual signal dispersion. For constant inspection performance, the efficiency is then a function of the rejection limit applied to the signal during inspection. There are three kinds of action on efficiency:

-check on stability during inspection,
-efficiency adjustment to incoming quality,
-intrinsic inspection performance improvement.

Therefore, there are different ways to control or improve the inspection efficiency :

-Check on the performance stability of an automated inspection device:
- control chart for the response-signal of standards;
- in case of NDT :
- on artificial defects used for the determination of the calibration curve,
- on a selection of real defects.
Examples: UT inspection of cladding-tubes, automated X-ray weld inspection of fuel rods ;

- Outgoing quality regulation:
- adjustment of efficiency to the detected defect rate (p_a) through the rejection limit, see Fig. 5.
Example : rod-scanner;
- Improvement of intrinsic performance (Fig. 6) :
- optimisation of signal processing by experimental design.
Example : rod scanner.

6. CONTROL AND IMPROVEMENT OF INCOMING QUALITY

According to the modern approach of quality control, the best way to improve outgoing quality is to reduce the defect rate before inspection, at the fabrication step by correction of the process itself (Fig. 7). For qualitative characteristics or for low defect frequencies, the application of the SPC method is difficult and the best way to improve quality is to collect and analyse inspection results in the long run, thus permitting the detection of process changes and the need for preventive actions. For quantitative characteristics, the SPC methods are designed with this aim.

7. SPC AND 100% INSPECTION

The central concept of statistical process control is that process variations are traceable to two kinds of causes:
- random causes, due to chance, which cannot be controlled,
- assignable causes, i.e. "findable" causes, which can be controlled.

Integration of process-oriented control with systematic inspection

EFFICIENCY ADJUSTMENT TO INCOMING QUALITY

■ Example : Rod scanner for detection of enrichment deviation (Δ)

■ Specification :

  ■ minimum efficiency $e_0(\Delta)$

  ■ maximum outgoing defect rate $p_0(\Delta)$ (with confidence level)

■ Inspection :

  ■ actual efficiency $e(\Delta) \geq e_0(\Delta)$

  ■ detected defect rate p_a

■ Final decision :

  ■ if $p_l = e(1-e)^{-1}p_a < p_0$ then OK

  ■ else partial or total reinspection with e' > e

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FIG. 5. Efficiency adjustment to incoming quality

Integration of process-oriented control with systematic inspection

INTRINSIC INSPECTION PERFORMANCE IMPROVEMENT EXAMPLE

Optimization of enrichment deviation signal by experimental design

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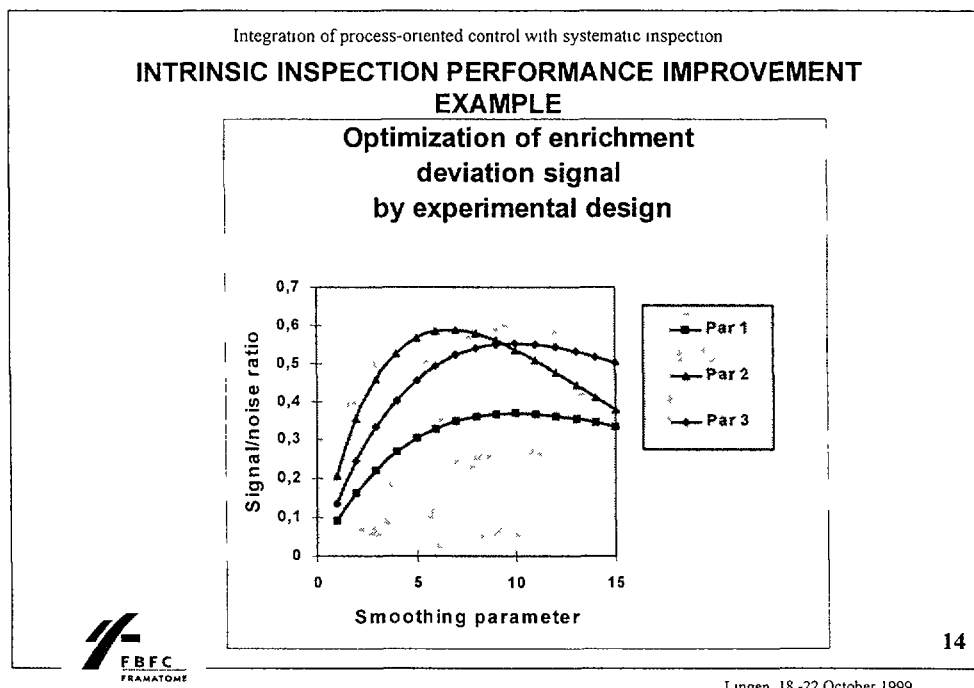
FIG. 6. Example of intrinsic performance inspection improvement

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IMPROVEMENT OF INCOMING QUALITY

Fabrication ----> P$_t$

P$_a$ <---- Inspection Efficiency e ----> P$_o$

■ **Qualitative characteristics :**

■ analysis of inspection results : examples

• rod scanner : check on stability of line cleaning conditions by long term analysis of rejection frequencies

• visual inspection : frequency and Pareto analysis based on classification of the defects detected during inspection

■ **Quantitative characteristics : SPC**

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FIG. 7. Improvement of incoming quality

Ideally, when only random causes are present in a process, the product presents the minimum possible amount of variation and the corresponding minimal or "natural" dispersion parameter of the characteristic distribution quantifies the intrinsic process performance.

Control charts are designed on the basis of this natural dispersion of process, and are used to detect, by periodic sampling, the presence of any assignable causes in the process . Sample averages are used, rather than individual values, because averages are more sensitive to process changes.

Sampling is economical in comparison with systematic inspection, but is suitable only if assignable causes are persistent, within a sample, or up to the next sample : this kind of control chart is able to detect assignable causes, even with low effects owing to averaging, but only persistent causes.

In case of short-lived causes with low frequency, even with high effects, only systematic inspection is suitable, first for defect detection , but also for process improvement by analysis of the frequency of this kind of event and the identification of their origin.

The two methods are not mutually exclusive and may be applied simultaneously. Example is pellet diameter :

- control chart for setting of grinding machine and control of the global diameter distribution,
- automated 100% inspection for the detection of "outliers",
- long term trend analysis of rejection frequencies.

Laser welding of fuel rods is an example of integration of the two methods in a quality control system.

8. INTEGRATION OF PROCESS CONTROL WITH SYSTEMATIC INSPECTION

We have seen that statistical process control, which detects process changes and is used to keep the process "under control", leading to the optimal distribution of the quality characteristics, does not protect against temporary and infrequent disturbances. On the other hand, 100% inspection, which is capable of detecting local quality troubles, is not appropriate, by itself, for obtaining homogeneous product at minimum cost. But systematic inspection on product characteristics or

process variables provides data (more than by sampling !) for process control and therefore may be used simultaneously for product sorting and process adjustment.

The two approaches may be integrated in a global quality control system where :

- 100% inspection is performed not only on final product, but also in-process and on process variables : this authorises at the same time on-line product sorting and on-line decision for manufacturing operation continuation or interruption,
- 100% inspection data of process and product variables are averaged and supervised by control charts,
- out of acceptance limit frequencies and out of control limit frequencies are both analysed in the long term for global process control and improvement.

Example : laser welding of fuel rods (see Fig. 8):

- prior checking of process variables for welding authorisation;
- on each weld, measurement of
    - total energy,
    - weld width,
    - ...
- on line weld by weld comparison with acceptance limits;
- checking the stability of welding conditions with control chart of weld width, energy, width/energy ratio;
- off-line metallographic examination of production sample : control chart of weld penetration and penetration/width ratio.
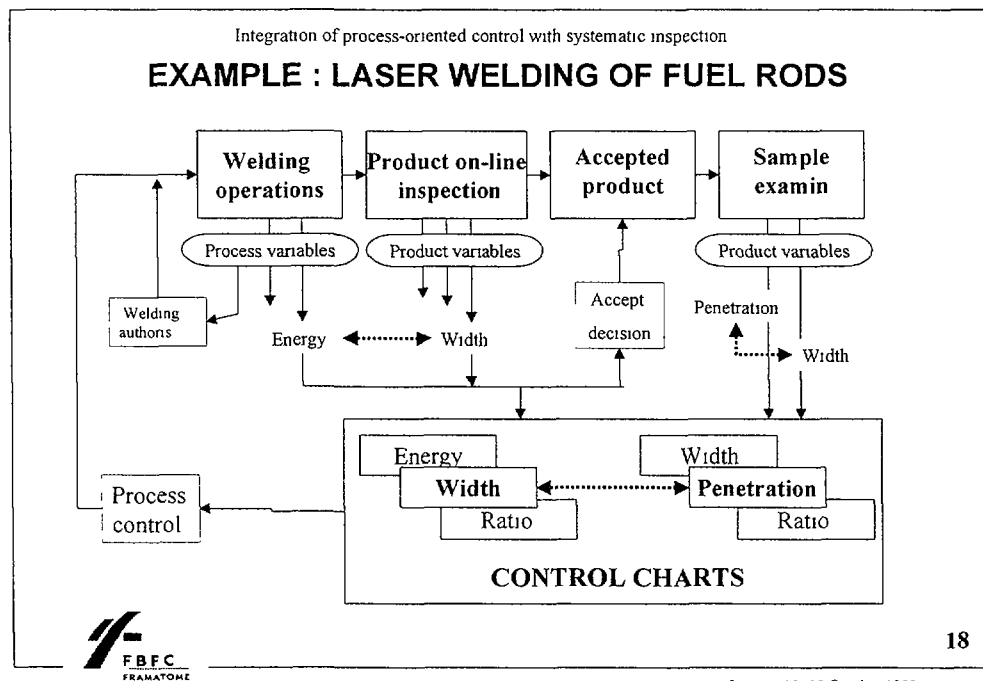
FIG. 8. Laser welding of fuel rods - an example of integration of process control with systematic inspection

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9. CONCLUSION

100% inspection is a typical tool of the traditional quality control approach. Statistical Process Control (SPC) is the main tool of the modern approach. In fact, both approaches are complementary because they are remedies for distinct causes of process and product changes, and should not be used one in place of the other : application of 100% inspection to correct a product obtained with a process out of control, or application of sampling techniques not adapted to the frequency and gravity of quality troubles and to the high reliability objectives.

The two approaches may be integrated in a global quality control system, where the same inspection and measurement data are processed at the same time :
- for sorting the product and control the process
- on the basis of product and process variables

PRESENT STATUS OF QUALITY CONTROL ON MOX FUEL FABRICATION IN JNC

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Japan

Abstract

Japan Nuclear Cycle Development Institute (JNC) has developed MOX fuels for Advanced Thermal Reactor FUGEN and Fast Reactors JOYO and MONJU for these 30 years. The total amount of MOX fuels fabricated in JNC reached to be 157 tons as of the end of March 1999. No fuel pin failure has been found in the fuels loaded in these reactors. This result shows that the fabrication technology of MOX has been established and the quality control has also been done adequately in the fabrication process. This paper describes the basic concept and associated procedures of quality control related to MOX fuel fabrication in JNC high-lighting the key procedures of quality control in MOX fuel fabrication, measurements of plutonium enriched zone, determination of plutonium concentration, and the advanced method of visual inspection for the surface appearance of the products. The homogeneity of plutonium and uranium is one of key properties from the viewpoint of local heating in reactor operation and dissolubility in reprocessing. Thus plutonium enriched zone (Pu spot) should be detected with an adequate method. The alpha autoradiography has been used to identify the characteristics of the zone. The procedure of alpha autoradiography is established and is successfully applied to the MOX fabrication process. The determination of plutonium concentration is also one of key properties for quality control. JNC has gained the experience relating to Titration, Coulometry, and Isotope Dilution Mass Spectrometry (IDMS) which are known as determination method. IDMS has been used for the determination of plutonium concentration in MOX fabricated in JNC. The advanced method for the visual inspection of the surface appearance of the product. has been developed and demonstrated. The method utilizing the VTR is considered to be well harmonized with fully automated MOX fuel fabrication process

1.INTRODUCTION

Japan Nuclear Cycle Development Institute (JNC) has developed MOX fuel for Advanced Thermal Reactor FUGEN and Fast Reactors JOYO and MONJU for these 30 years in Plutonium Fuel Center, Tokai Works. Many kinds of research and development have been carried out. The developments cover many technical fields, such as modeling code, fuel design, sample fabrication, MOX fabrication plant design and mass production of MOX fuel including measurement, analysis, and inspection technologies.

In the first stage, the Plutonium Fuel Development Facility (PFDF) was constructed in 1965. In PFDF basic research concerned with physical and chemical properties of Plutonium has been carried out. In the second stage Plutonium Fuel fabrication Facility (PFFF) was constructed in 1972 to supply MOX fuel for experimental fast reactor JOYO and prototype advanced thermal reactor FUGEN. Through this fuel fabrication, the rational fabrication process has been established. In the third stage Plutonium Fuel Production Facility (PFPF) was constructed in 1988 to supply MOX fuel for experimental fast reactor JOYO and prototype fast reactor MONJU. At present, in PFFF,

FUGEN fuel fabrication is underway according to the reactor operation. In PFPF, replacement of equipment has been carried out for preventive maintenance and operation of fuel manufacturing will start in next year for JOYO fuel. The total amount of MOX fuels fabricated in JNC reached to be 157 tons as of end of March 1999. They have been loaded in the reactors cited above and some of them have been used in the fuel irradiation tests in domestic and foreign reactors. Good irradiation fuel performance has been found in fuels loaded in reactors.

This result shows that the core technology of MOX fabrication is established, the concept of quality control and assurance is excellent and quality control and assurance has also been done adequately at each step in JNC. Quality control and assurance system of MOX fabrication was established in 1975 when fuel fabrication for FUGEN was started. Quality control is considered to be important from the following 2 points. One is for maintaining the safety of the plant; another is for achievement of performance of the product. In this paper, the outline and present status of quality control and assurance related to the performance of product, MOX fuel, are described. The basic concept and associated procedures of quality control and assurance related to MOX fuel fabrication in JNC are described highlighting measurements of plutonium enriched zone, determination of plutonium concentration in MOX fuels and the advanced method of visual inspection for the surface appearance of the products.

2. OUTLINE OF MOX FUEL FABRICATION PROCESS AND CONCEPT OF QUALITY CONTROL AND ASSURANCE

2.1 Outline of MOX fuel fabrication process

The process flow of MOX fuel fabrication in Plutonium Fuel Center is divided into 3 stages which are pellet fabrication, fuel pin fabrication and fuel assembling. At pellet fabrication process, as feed materials, 3 kinds of powder, those are plutonium dioxide, MOX powder, and uranium dioxide, are used. These materials are weighed and blended homogeneously to meet the specifications on plutonium concentration or fissile concentration of pellet. After the powder is treated and the treated powder is pressed and sintered. The pellet is obtained as a intermediate product. Pellets are inspected and it is confirmed that specification of the pellet is satisfied. At fuel pin fabrication, pellets are loaded to cladding tube with other components and welded. Completed fuel pin is inspected and transferred to fuel assembling. Completed fuel assembly is finally inspected.

Compared with Uranium dioxide (UOX) pellet fabrication from the viewpoint of safety, the typical features of MOX pellet fabrication are shielding for high radioactivity, controlling the generation of heat, the restriction of criticality, and containment of plutonium. The typical features from the viewpoint of quality control are homogeneity of feed powders after blending, small size of lot, dissolvabilty of sample for analysis, decay of plutonium isotopes. Accuracy of material accountancy is also required for non-proliferation. The development for production and inspection of MOX fuel has been carried out to harmonize the above features, to aim at the remote controlled and automated plant for MOX fabrication and to decrease human radiation exposure.

Quality control and assurance system including the procedures, such as inspection, or analysis, is also established considering the above features, adaptability to process, safety and efficiency.

2.2 Concept of quality control and assurance

The purpose of the quality control and assurance is to maintain the performance of the product and to certify that the product and fabrication process fit the requirements of quality.

Quality assurance system of MOX fabrication in Plutonium Fuel Center was established in 1975 according to the initiation of the fuel fabrication for FUGEN. The system was established based on 10CFR50 Appendix B of US and JAEG4101 of Japan with our experience till then. Recently concept of ISO 9000 series is taken in the system. The present status of main subjects in the scheme of quality control and assurance for the product is described below.

Establishment of the organization for Quality Assurance is one of the most important schemes. The distribution of the responsibility of divisions and sections are provided explicitly. Especially, the division in charge of inspection, testing and verification of product is independent from the division in charge of fuel designing and fabrication.

Inspections are carried out for the quality assurance of MOX fuel at pellet, pin and assembling process. Inspection and analysis items for pellet fabrication are shown in FIG.1. The specification of chemical and physical property of pellets is confirmed with analysis and measurement at each step. Analysis is carried out for not only quality control and assurance but also process control. Analysis is carried out mainly for confirmation that the performance of the product meets the specification and almost samples are taken from the pellets. From the viewpoint of quality control, it should be
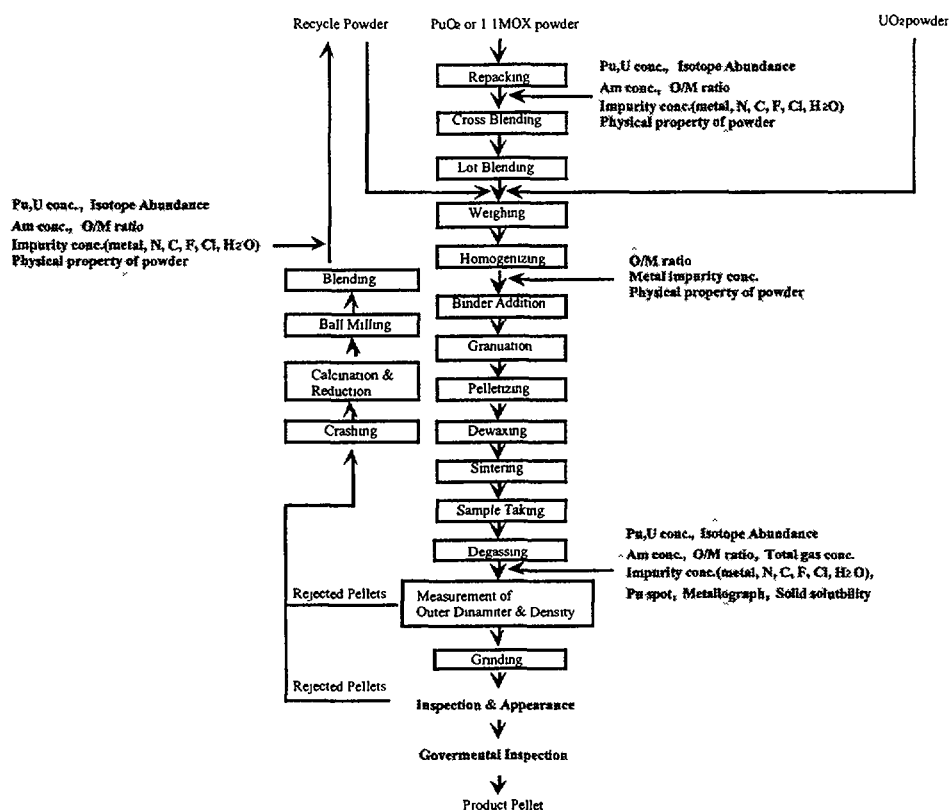
FIG. 1 Inspection and analysis items for MOX fabrication

considered that the rational sampling points and sampling timing should be examined to improve the process control in advance. Samples are taken after blending to confirm the homogeneity of feed powder at the starting of new production campaign. At pin fabrication process, surface appearance of pin, gamma scan of pellet in pin, X-ray test for welding points, etc. are inspected. At fuel assembling process, inspection for surface appearance of fuel assembly, contamination, are carried out. About

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the metal components composing the fuel assembly, such as cladding tubes, wrapper tubes, the components are also inspected. Inspection and testing are carried out for each lot. The lot is defined for each process considering the chemical and physical features. If deficiencies or deviations are obtained as the result of inspection, corrective actions are taken to repair them according to the quality assurance procedure.

Inspection for product is classified to 3 steps in Plutonium Fuel Center and inspections are carried out in order. The first step inspection is carried out by Quality assurance section in Plutonium Fuel Center (internal inspection) for the purpose of conformance to the specified requirements and quality control. The second step inspection is carried out by reactor operator for the purpose of the conformance to the specified requirements of reactor operator, and the final step inspection is carried out by Japanese government based on the laws. Procedure and purpose of inspection is different among them. In the inspection by consumer and government, verification of the records of the operator's inspection are included. Government also inspects and approves the design of the fuel before the start of fuel manufacturing.

MOX fuels fabricated in JNC have been inspected strictly by Japanese government and they all have been passed. They are loaded in the reactors and some of them have been used in the fuel irradiation tests. Good irradiation fuel performance has been found in fuels loaded in reactors. It is concluded that concept of the quality control and assurance and the procedure adopted in MOX fuel fabrication process in JNC should be correct and reasonable in fuel safety aspect.

3.TYPICAL TOPICS OF THE EXPERIENCE RELATED TO QUALITY CONTROL AND ASSURANCE

The typical examples about quality control and assurance applied to MOX fabrication are described as follows.

3.1 Measurement of Plutonium enriched zone in a MOX pellet

Concerning the physical property of MOX pellet, homogeneity of plutonium and uranium is one of key properties from viewpoint of local heating in reactor operation and dissolubility in reprocessing. Homogeneity of feed material is required in the course of the powder blending process in pellet fabrication for quality control. In MOX fuel fabrication process the blending is one of the most important process and unique process compared to UOX fabrication process. In MOX fabrication process it is necessary that several kinds of powder with different composition of plutonium and uranium should be blended homogeneously to adjust decided specification or to make the size of lot larger.

Plutonium enriched zone (Pu spot) should be detected by adequate method to secure the homogeneity. The size and plutonium concentration, which are the characteristics of the zone, should be limited within the allowable level. To identify the characteristics of the zone, the alpha auto-radiography has been used because of the simplicity of equipment. The procedure is established and successfully applied to the MOX fuel fabrication in Plutonium Fuel Center.

3.1.1 Specification of Pu spot for MOX fuel

The specification on the plutonium enriched zone (Pu spot) in MOX pellet is determined for preventing local heating in reactor. Specifications of diameter and plutonium concentration of Pu spot for three types of MOX pellets fabricated in JNC are shown in TABLE-1. In the case of thermal reactor fuels, the diameter of maximum zone is determined to be less than 200 μ m with plutonium

TABLE-1 SPECIFICATIONS OF PLUTONIUM SPOT

Fuel Type	"FUGEN" (for ATR)	"JOYO", "MONJU" (for FBR)
Diameter	≦200 μ m (if 200~800 μ m, Pu conc. is measured)	≦100 μ m (if exceed 100 μ m, Pu conc. is measured)
Plutonium Concentration	Limit is determined according to diameter from the relationship between Pu conc. and fuel temp. (see FIG.2)	

concentration up to 100%. In case that the diameter of maximum zone is larger than 200 μ m, it is permitted that plutonium concentration measured is less than a limited value that is determined based on thermal aspect.

Thus, it is concluded that the black image with a size corresponding to the range of the zone can be formed and that the degree of blackness can be related with the strength of the alpha ray that corresponds to plutonium concentration.

3.1.2 Measurement

Plutonium spots in MOX pellet are measured by alpha-autoradiography using nitro-cellulose film and the principle of the method is simple. It utilizes the reaction between alpha ray generated from plutonium and the materials composed of the film. The materials irradiated by alpha particles are dispatched from the film and then the thickness of the film becomes thin by the alpha ray damage. The procedure for MONJU pellet is shown in FIG.3. After a pellet is ground and polished, a film is
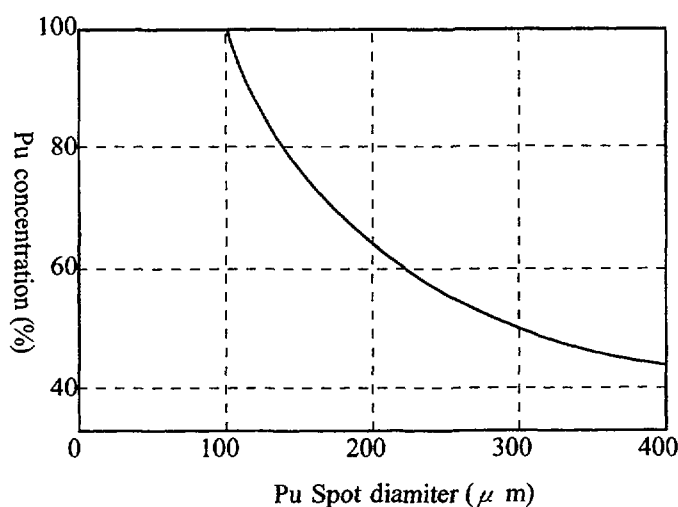

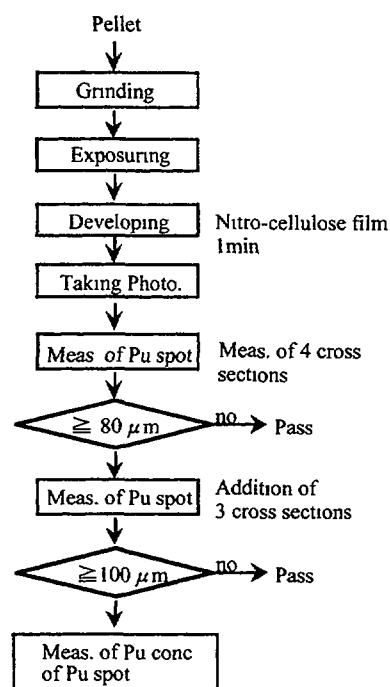FIG.2 Maximum allowable Pu content vs. Pu spot

FIG.3 Procedure for measurement
of Pu spot in FBR pellet

put on the surface of the pellet through thin Mylar. The exposed film is etched by alkaline solution, then the etch pits which show plutonium spots are observed. The measurement of the diameter is carried out for the largest spot. If the diameter is over the specification, concentration of plutonium of the spot is determined by measurement of blackness of the etched pit. The correlation formula between the blackness and plutonium concentration is obtained by measurement of standards with different plutonium concentration.

The new nitro-cellulose film for the measurement was developed by JNC and Toray Industry inc. as a substitute for the Kodak film which is not produced now. The performance of this film has been compared with the Kodak film regarding the size and concentration of observed plutonium spots. No difference in the results of the measurement between both films can be found.

3.1.3. Subjects to be considered

It takes about 2 days to measure the Pu spot because the procedure is complicated for each step. It is desirable that the shortening the measurement time and rapid response to the process is achieved.

EPMA (Electron Probe Micro Analyzer) is one of the excellent methods for the measurement of plutonium spot. Compared with alpha-autoradiography, it is possible not only to measure the plutonium concentration directly but also to improve the measurement accuracy of the size and due to less sensitivity of plutonium isotopic composition and the range of alpha-ray. JNC has implemented the equipment made by JEOL ltd. in PFPF. The test will be carried out from next fiscal year. By introduction of EPMA to measure the Pu spot, it is desired that the timeliness of response will be improved because of the simplified treatment of sample and accuracy will be improved. About the usage of alpha-autoradiography and EPMA in routine, it is considered that EPMA is applied to the sample, Pu spot of which is measured relatively large by alpha-autoradiography.

3.2. Determination of plutonium and uranium concentration

Concerning the basic property of MOX, determination of plutonium concentration is most important for process control and material accountancy. In Plutonium Fuel Center, it is necessary to analyze the many kinds of sample with various plutonium concentrations. Three types of MOX fuel with different Pu/U ratio, which are for JOYO, MONJU and FUGEN, have been fabricated. Beside these final products, there are several kinds of samples to be analyzed, such as feed material, intermediate product, and scrap. The samples to be analyzed in Plutonium Fuel Center are shown in TABLE-2. As feed material, PuO_2 powder, and 1:1 MOX powder recovered from Tokai reprocessing

TABLE-2   SAMPLES TO BE ANALYZED IN PLUTONIUM FUEL CENTER

Sample	Pu/U ratio	category	Impurity to be considered
PuO_2 powder	1/0	feed material	Am
1:1 MOX powder	1/1	feed material	Am, Np, Fe
Dry recovery powder	1/3, 1/40	feed material	Am, Np, Fe
Blended powder	1/3, 1/40	intermediate material	Am, Np, Fe
Pellet	1/3, 1/40	product	Am, Np, Fe
Clean Scrap	1/3, 1/40	scrap	Am, Np, Fe, Organic materials
Dirty Scrap	variable	scrap	Am, Np, metallic elements, Organic materials

plant, the Pu/U ratio of which is about 1/1, are used. About scrap, there are 2 kinds, one is clean scrap, and another is dirty scrap. The dirty scrap is necessary to be treated chemically because of the contamination of impurities.

In aspect of quality assurance of analysis, Isotope Dilution Mass Spectrometry (IDMS) is considered to be the best method in Plutonium Fuel Center for determination of Pu concentration with high accuracy and reliability among several methods, because any sample with different Pu/U ratio and high impurity can be analyzed with single method IDMS.

3.2.1 Adoption of IDMS as analytical method

Plutonium and uranium concentrations in MOX fuel need to be determined with high accuracy and reliability for material accountancy. Titration, coulometry and IDMS are well known as analytical techniques for the purpose. JNC has gained the experience relating to these methods. In comparison with other methods, IDMS can be applied not only for ATR and FBR fuels but also for scrap material because it is not affected by impurities contained in sample. It has been reported that titration is has a positive bias by Am or Np contained in sample and coulometry is affected by Fe and is also affected with U in case that Pu/U ratio is small. In order to simplify quality assurance of the analysis, IDMS is selected as the best method for our facilities, and has been used as a main analytical technique in the MOX facilities of JNC from 1996. By introduction of IDMS, all material treated in Plutonium Fuel Center can be analyzed for both process control and material accountancy, and the burden about the analysis members and training of them is lightened. At present 4 sets of Mass spectrometers are set at PFPF, and samples from PFDF, PFFF, and PFPF are measured.

3.2.2 Summary of IDMS

The procedure of IDMS applied in Plutonium Fuel Center is shown in FIG.4. MOX fuel is dissolved with HNO3+HF. A part of the solution is transferred to the vial contained Large Sized Dried (LSD) spike composition of which is plutonium and uranium nitrate, and then the mixed solution is heated to dissolve the spike completely. After adjusting ion valence of plutonium, plutonium and uranium is recovered independently by anion ion-exchange. Isotopic compositions of Pu and U are
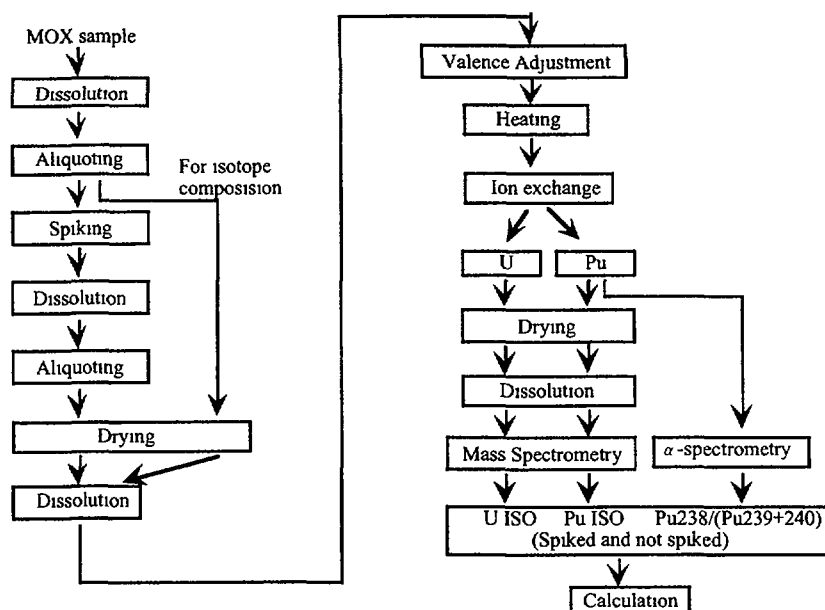

FIG.4 The flow of Pu and U determination by IDMS

measured by a mass spectrometer. Pu-238 is also measured by an alpha spectrometer in order to correct the result of mass spectrometry because there is a little possibility of contamination of U-238 in ion-exchange. Quantities of plutonium and uranium are calculated from the isotopic ratios of sample, spike and spiked sample. In these procedures of IDMS, the operators should have skill of sample treatment for accurate and reliable measurement. Three types of spike shown in TABLE-3 are used for MOX fuels with different Pu/U ratio or U-235 enrichment. These spikes have been mainly prepared in JNC.

For Quality assurance of the analysis, the following activities are carried out. Mass spectrometers are calibrated at every sample measurement by the measurement of standard materials such as NBS U-500, NBS 947. QC chart is used for daily control of bias and repeatability of isotopic measurements, and is checked monthly by a supervisor. For the assurance of reliability of analytical results, plutonium concentration of a sample is also determined by coulometry in addition to IDMS in the case of FBR fuel. An analytical result is reported if both results would be within control limit. Re-analysis is carried out if there would be out of limit. Intercomparison analysis on concentration and isotope ratio of plutonium and uranium has been performed four times per a year among IAEA-SAL, NMCC-SAL of Japan and JNC from 1994. Bias of these analyses can be checked annually by the intercomparison.

3.2.3 Subject to be considered

Timeliness of analysis is important from the process operation. It is necessary to dissolve the powder or pellet to analyze the sample and it takes a longer time to dissolve the MOX sample rather than UOX sample and to treat samples for IDMS. Almost 3 or 4 days are necessary to obtain the results of analysis. For process control it is desirable to supply the results of analysis to operation section timely. Introduction or establishment of rapid analysis method should be considered for MOX fabrication. X-ray fluorescence analysis (XRFA) is one of the best methods in this viewpoint because Pu/U ratio in MOX is measured rapidly with XRFA. XRFA is not installed in our MOX plant, however, because it does not have enough precision and accuracy for the material accountancy in the case of plutonium concentration in MOX fuel. Non destructive assay (NDA) equipment such as neutron measurement is also useful for rapid measurement of plutonium quantity. It is necessary to investigate the improvement of the precision and accuracy of these methods and adaptability to the process.

For introduction of IDMS, the initial costs are expensive rather than other methods. The running cost is also expensive because expensive expendables and standard are necessary. At plutonium fuel center IDMS is used for all samples regardless of the composition and for process control and material accountancy. It is seem necessary to select the method considering the

TABLE-3 COMPOSITION OF LSD SPIKE

	"A" spike	"B" spike	"C" spike
Pu/U ratio	1/20	1/3	2/1
U-235 Enrichment	18	0.7	18
Object	"FUGEN" fuel	"JOYO" fuel	"MONJU" fuel
		1:1 MOX	1:1 MOX

composition of the sample in future plant. For example, it is considered that IDMS is used only for the samples that are not measured with other methods, to reduce the cost.

Additionally, securing spike for IDMS and standard material for calibration should be considered for introduction of IDMS. Standard material is important for analysis, not only for IDMS but also other analytical methods. At present it is very difficult to obtain the some amount of the certificated nuclear material, such as plutonium metal, which is used for spikes or standard, from foreign countries because of the restriction of the transportation. It is necessary to keep the raw material to make the spikes and investigate the means to get it.

3.3 Visual inspection of surface appearance of the products

The visual inspection for the surface appearance of the products is carried out at each production stage as a inspection item. It takes a long time and it disturbs a process operation because this inspection is treated as a hold point. The inspection of operator is stopped because the single equipment for visual inspection of pellet is installed. The rational method and procedure of inspection should be developed for mass production.

3.3.1. Purpose of Visual inspection

In the inspection of surface appearance, it is certified that there is no defect on the product, such as harmful scratch. It is necessary in quality control scheme that the inspection of surface appearance is carried out for all products, not for some samples randomly selected, basically. The visual inspection is sensuous test by comparing with the standard or limit model and the judgement of pass or fail on the product is carried out by inspector. Inspection by Japanese government is carried out finally after the inspection by reactor establisher is completed. Product is hold and next fabrication process is stopped until the final inspection finished in previous process.

3.3.2. Development of the advanced method

Visual inspection is carried out for all products at each step and inspection time is piled up. It takes long time to certify the all object visually, especially pellet. In plant designing, the single equipment for visual inspection of pellet is installed. Therefore, the inspection by fabricator is stopped when the inspection by government or reactor establisher is carried out, and manufacturing schedule is disturbed. It is necessary to develop and introduce the new method to reduce the inspection time and radiation exposure, and to reduce the influence of the inspections carried out by government and reactor establisher. The rational procedure should be developed.   .

The advanced method, in which the VTR is utilized, has been developed.   This method is considered well harmonized with fully automated MOX plant because of no disturbance to operation and remote inspection.   Fabricator takes video images of surface appearance in advance and these video images are used for the inspector, instead of direct visual inspection. Inspector selects the videotapes randomly and inspection activity is independent from process line.

The developed system and example of the video image for pellet inspection are shown in FIG.5. Pellet are inspected during transfer to pallet and identified by specific number of the pallet which receives pellets. The video images for inspection are composed of three independent scenes which are surface appearance of pellet, pellet transfer to pallet and pallet number. It is necessary that inspection by video image should be the same as inspection directly. The high-resolution cameras were introduced. About the video image, by improvement of image processing, many images are

| Layout of cameras | Video image for inspection of pellet |
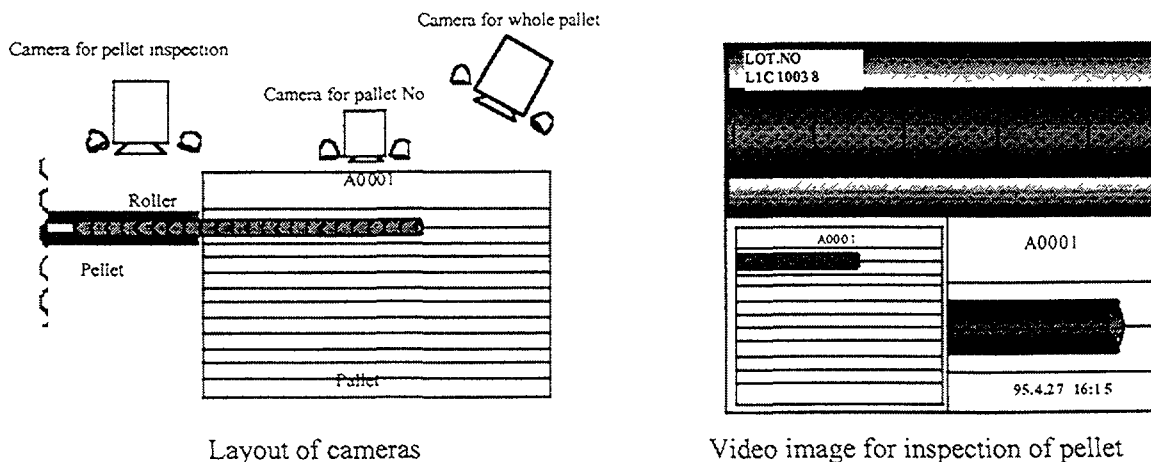
FIG.5 Layout of cameras and Video image for inspection

coupled in one picture for inspector to understand and verify the sample. The video images taken by fabricator are used for the inspection carried out by reactor establisher and government. About the authentication of image data taken by operator, it is necessary that the video images are not modified artificially. To maintain the traceability of actual products to video images for inspection, video recording time is indicated on the video image continuously. As another techniques adopted in developed system, images of sample to be inspected and limit model taken with the same condition are shown in just one picture or additional information is added to the picture for inspection.

3.3.3. Results of the introduction of the system

It is confirmed through the actual inspection that the following advantages have been obtained. It can enhance the reliability of visual inspection because every inspector can have inspection results as a common database. The inspection gives no disturbance to operations of the fabrication process. It can also reduce time and manpower needed for the inspection and the reduction of manpower is estimated to be about one fourth. For inspector this system makes judgement easier and criteria of judgement clear. It makes the inspector understanding the situation of the objects easier.
It can reduce the radiation exposure of operators and no exposure of inspector can be expected, because inspectors have no need to enter the radiation controlled area and no transportation of objectives from the storage to inspection position is needed for inspection.

This VTR method is adopted for not only inspection of pellet but also that of fuel pin and fuel assembly. It is concluded that the new method using VTR for visual inspection has been established.

4. DEVELOPMENT FOR FUTURE

The quality control and assurance system shall be modified adequately and timely according to the requirement of quality. It is considered that the inspection procedures should be developed in future on the following viewpoints.

The existence of hold point is important for quality control and assurance. It is necessary to stop the process operation until the result of inspection is obtained. From the viewpoint of process control, if the timeliness of inspection or analysis is secured, the flexibility, efficiency of process operation and productivity will be improved because of the rapid feedback and reduction of waiting

time. Therefore, it should be considered that the speed-up of evaluation of inspection, such as speed-up of analysis with high accuracy, or introduction of new analysis and in-line analysis on the assumption of high accuracy would be necessary. It should be considered that XRFA and NDA are used for process control besides for material accountancy. In future it will be desirable to improve the accuracy and precision of such measurement methods for rational process control. About the introduction of in-line analysis, it should be considered that the relationship between requirements from the process operation and performance of analysis is important.

Rationality and cost effectiveness should be considered in inspection procedures. Analysis is necessary for each lot and the size of lot of MOX fuel is small rather than that of UOX fuel fabrication. The number of analysis in MOX fabrication plant is extremely large and effects the cost. It is necessary to develop the analysis methods with low cost and to introduce automated process.

5. CONSIDERATION

It is concluded that concept of the quality control and the procedure adopted in MOX fuel fabrication process in JNC should be correct and reasonable in fuel safety aspect. Based on the experience, the present quality control and assurance system is satisfied to the requirement of quality. It is, however, considered that the current procedure for quality control may have a conservative margin for fuel safety and seems to lose rationality in economic point of view. Therefore, it will be requested that the more rational procedure and the inspection method should be developed and established for the future. The direction of quality control in the future is also discussed mainly based on the improvement of economy with maintaining the safety confidence level.

In future the necessity of MOX fuel fabrication should be increased and capability of the MOX fuel plant should be increased. The experience of UOX fuel fabrication plant, the capability of that is huge rather than that of MOX plant, should be taken in quality control scheme of MOX fuel fabrication for the improvement of the rationality.

"QUALITY AT THE SOURCE" (QATS) SYSTEM DESIGN UNDER SIX SIGMA METHODOLOGY

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Abstract

One of the main objectives in the manufacturing of fuel assemblies, is to fulfill the customer expectations with a product that assures its reliability during its stay in the NPP.

By mean of the QATS System design under 6-Sigma methodology, all the customer requirements are included in the product specifications and drawings.

Product characteristics and process variables are classified and process capability is evaluated. All this information permits to identify CTQ's (Critical to Quality) product characteristics and process variables, and to define a quality system (QATS) based in the process and on-line characteristics control handled by the manufacturing workers.

At the end, this system ensures a continuous product quality improvement, and a strong commitment with the customer requirements.

1. INTRODUCTION

Continuing with its *Quality* Policy, *ENUSA* has taken the leadership of a project of Quality Assurance system for pellets, based on the "Quality at the Source" (*QATS System*). According to this system, the manufacturing worker is responsible for the quality of the product. He becomes involved with process control and its variables. He carries out inspections of the product on line checking the process and stopping, if necessary. Quality organization carries out process and product verifications, analyses periodically process capability and certifies the product.

2. METHODOLOGY

For the implementation of this project a *continuous improvement methodology* called *6-Sigma* has been applied. This project has been developed in working teams. Experts in 6-Sigma, Quality, Manufacturing Process and Fuel Assembly Design have participated in it. The project has been implemented the following steps:

- ## 2.1. Define

- *ELABORATION OF THE DESIGN QFD*

The *design QFD* ("Quality Function Deployment") evaluates:

- *The importance of Functional Requirements.* (First House of Quality)

- *The importance of Product Characteristics.* (Second House of Quality)

It starts with a deployment of Functional Requirements of the fuel rod. These are: *energy production, integrity* (the existence of a barrier to prevent fission products to pass on the primary circuit), *growth* (compatibility with the fuel assembly) and *traceability.*

Evaluation of the importance of Functional Requirements is made by means of one "Comparison Matrix" (Requirements vs Requirements) The results are shown in Figure 1

QFD - UO₂ PWR PELLET - COMPARISON MATRIX (REQUIREMENTS VS REQUIREMENTS)																				
FUNCTIONAL REQUIREMENTS (Fuel Rod Functional Requirements)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Importance	Importance 1 5
ENERGY	Energy Generation (1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16	50
INTEGRITY	Internal Pressure (2)	0		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	48
	Fuel Temperature (3)	0	0		1	1	1	1	1	1	1	1	1	1	1	1	1	1	14	45
	Mechanical Strength (4)	0	0	0		1	1	0	0	0	0	1	0	1	1	0	1		7	28
	Deformation EOL (5)	0	0	0	0		1	0	0	0	0	1	0	1	0	0	0	1	4	20
	Tube Fatigue (6)	0	0	0	0	0		0	0	0	0	1	0	1	0	0	0	1	3	18
	PCI (7)	0	0	0	1	1	1		0	0	0	1	1	1	0	1	1		8	33
	Internal Corrosion (8)	0	0	0	1	1	1	1		0	0	1	1	0 5	1	0	1		9 5	34
	External Corrosion/Hydryding (9)	0	0	0	1	1	1	1	1		1	1	1	1	1	1	1	1	13	43
	Internal Hydriding (10)	0	0	0	1	1	1	1	1	0		1	1	1	1	1	1	1	12	40
	Instantaneous Collapse (11)	0	0	0	0	0	0	0	0	0	0		0 5	1 0	0	0	1		1 5	14
	Tubing Collapse (12)	0	0	0	1	1	1	0	0	0	0	1		1	0	0	1		6	25
	Plenum Collapse (13)	0	0	0	0	0	0	0	0	0	0	0 5	0		0	0	1		1 5	14
	Welding Integrity (14)	0	0	0	0	1	1	0	0 5	0	0	1	1		0	1	1		7 5	29
	Column Integrity (15)	0	0	0	0	1	1	1	0	0	0	1	1	1	1		1	1	9	33
OTHERS	Growing (16)	0	0	0	1	1	1	0	1	0	0	1	1	0	0		1		8	30
	Trazability (17)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	10

FIG 1 Comparison matrix - Requirements vs Requirements

It starts with a deployment of Functional Requirements of the fuel rod These are *energy production*, *integrity* (the existence of a barrier to prevent fission products to pass on the primary circuit), *growth* (compatibility with the fuel assembly) and *traceability*.

Evaluation of the importance of Functional Requirements is made by means of one "Comparison Matrix" (Requirements vs Requirements) The results are shown in Figure 1

Once the functional requirements have been evaluated, the evaluation of the dimensional and visual characteristics of the pellets selected to be put in QATS is done according to the degree of expected improvement in the Functional Requirements, as a result of the direct modification of the characteristics The functional requirement "z" is a function of the product characteristics "y", z = f (y₁, y₂, ... , yₙ) The results are shown in Figure 2

Once the product characteristics have been evaluated a *"Pareto Chart"* is made and the *design CTQs* ("Critical to Quality Characteristics") are selected bearing in mind that the whole of the CTQs implies a high percentage in importance of the total number of the characteristics evaluated It must also be considered that there is a big gap in importance between CTQ and NON-CTQ characteristics The results obtained can be shown in Figure 3
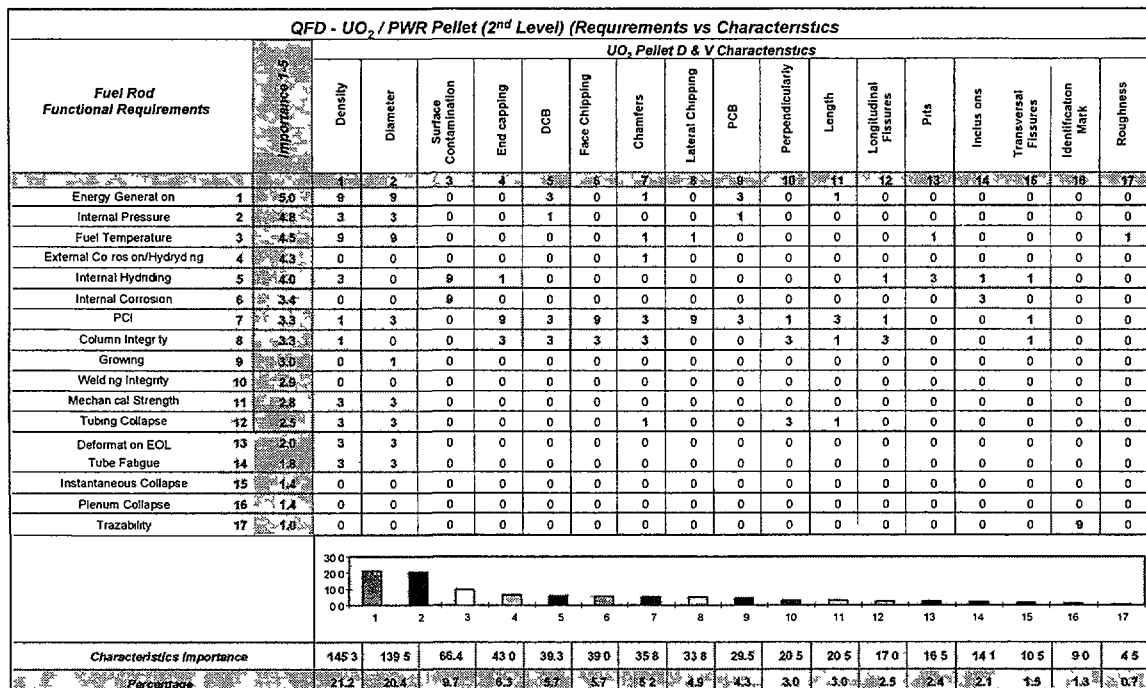
44

QFD - UO₂ / PWR Pellet (2nd Level) (Requirements vs Characteristics)

Fuel Rod Functional Requirements	Importance	Density	Diameter	Surface Contamination	End capping	DCB	Face Chipping	Chamfers	Lateral Chipping	PCB	Perpendicularity	Length	Longitudinal Fissures	Pits	Inclusions	Transversal Fissures	Identification Mark	Roughness
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Energy Generation	1 — 5.0	9	9	0	0	3	0	1	0	3	0	1	0	0	0	0	0	0
Internal Pressure	2 — 4.8	3	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Fuel Temperature	3 — 4.5	9	9	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1
External Corrosion/Hydryding	4 — 4.3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Internal Hydriding	5 — 4.0	3	0	9	1	0	0	0	0	0	0	0	1	3	1	1	0	0
Internal Corrosion	6 — 3.4	0	0	9	0	0	0	0	0	0	0	0	0	0	3	0	0	0
PCI	7 — 3.3	1	3	0	9	3	9	3	9	3	1	3	1	0	0	1	0	0
Column Integrity	8 — 3.3	1	0	0	3	3	3	3	0	0	3	1	3	0	0	1	0	0
Growing	9 — 3.0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Welding Integrity	10 — 2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mechanical Strength	11 — 2.8	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubing Collapse	12 — 2.5	3	3	0	0	0	0	1	0	0	3	1	0	0	0	0	0	0
Deformation EOL	13 — 2.0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tube Fatigue	14 — 1.8	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Instantaneous Collapse	15 — 1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plenum Collapse	16 — 1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trazability	17 — 1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
Characteristics Importance		145.3	139.5	66.4	43.0	39.3	39.0	35.8	33.8	29.5	20.5	20.5	17.0	16.5	14.1	10.5	9.0	4.5
Percentage		21.2	20.4	9.7	6.3	5.7	5.7	5.2	4.9	4.3	3.0	3.0	2.5	2.4	2.1	1.5	1.3	0.7

FIG 2 Matrix for UO₂ pellets - Requirements vs Characteristics
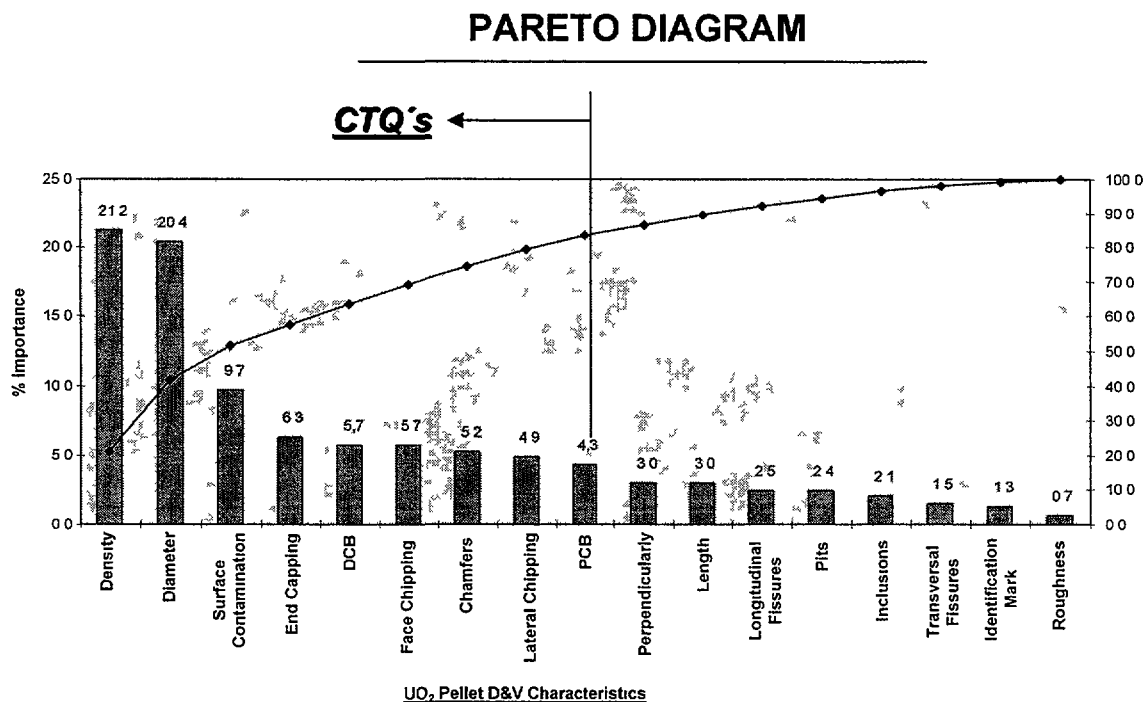
PARETO DIAGRAM

CTQ's ◄

FIG 3 PARETO digram - UO₂ pellet D&V characteristics

2.2. Measure

• *PROCESS CAPABILITY EVALUATION*

To assess the process capability of each characteristic, *Z. Quality Indexes* of the <u>six-sigma</u> methodology are used. Processes are classified according to the following Table 1 based on the normal distribution N(0,1)

TABLE 1 CLASIFICATION OF PROCESSES

Process	*Z. Quality Index (Short Term) Z. Shift = 1,5*	*Defects per Million (Long Term)*
Excellent	**6,0**	**3,4**
Good	**5,0**	**233**
	4,5	**1350**
Fair	**4,0**	**6210**
	3,0	**66807**
	2,0	**308537**
Poor	**1,0**	**691462**
	0,0	**933193**

Note: Z shift is the difference in the process capability between short term and long term By default 1,5 Zs

To calculate Z quality indexes two different methods have been used *Continuous Data* when the average and the standard deviation are known and *Discrete Data* considering as units all the pellets of a reload and only one opportunity of failure for each characteristic In some cases, when making calculations to continuous data a very high Z is obtained, in this case, this value is limited according to the population inspected. The results obtained can be shown in Fig 4
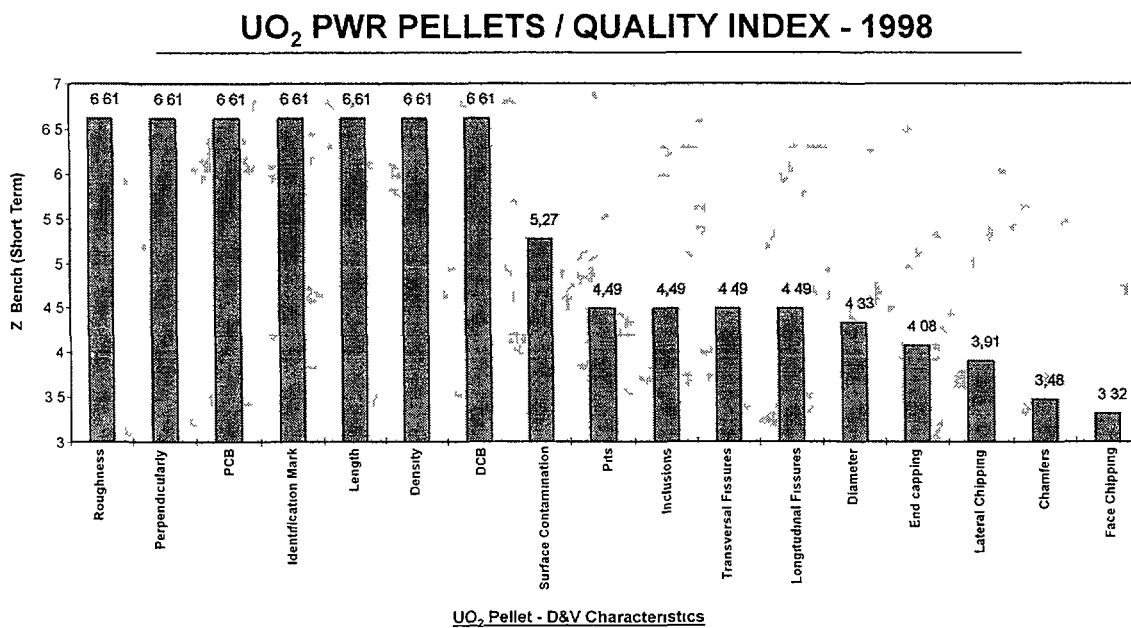

UO₂ PWR PELLETS / QUALITY INDEX - 1998

FIG 4 Quality index for UO₂ PWR pellets in 1998

2.3. Analyze, improve and control

- *ELABORATION OF PROCESS QFD*

The *process QFD* ("Quality Function Deployment") evaluates:

> ➤ *The importance of variables of the manufacturing process.* (Third House of Quality)

It starts with deployment of the variables of the following steps in the manufacturing process of the pellets:

Blending, prepressing and granulation, conditioning, pressing, sintering and grinding.

The evaluation of the process variables is done according to the expected grade of improvement in the characteristics, already evaluated in the design QFD, as a result of the direct modifications of the process variables The characteristics of a product "y" is a function of the process variables "x"; $y = f(x_1, x_2, ... , x_n)$

Once the process variables have been evaluated a *"Pareto Chart"* is done and the *process CTQs* ("Critical to Quality variables") are selected It must be taken into account that the whole of the CTQs implies a high percentage in importance of the total number of the characteristics evaluated. It must also be considered that there is a big gap in importance between CTQ and NON-CTQ variables and that there is a strong correlation with CTQ design characteristics: The results obtained are shown in Figure 5
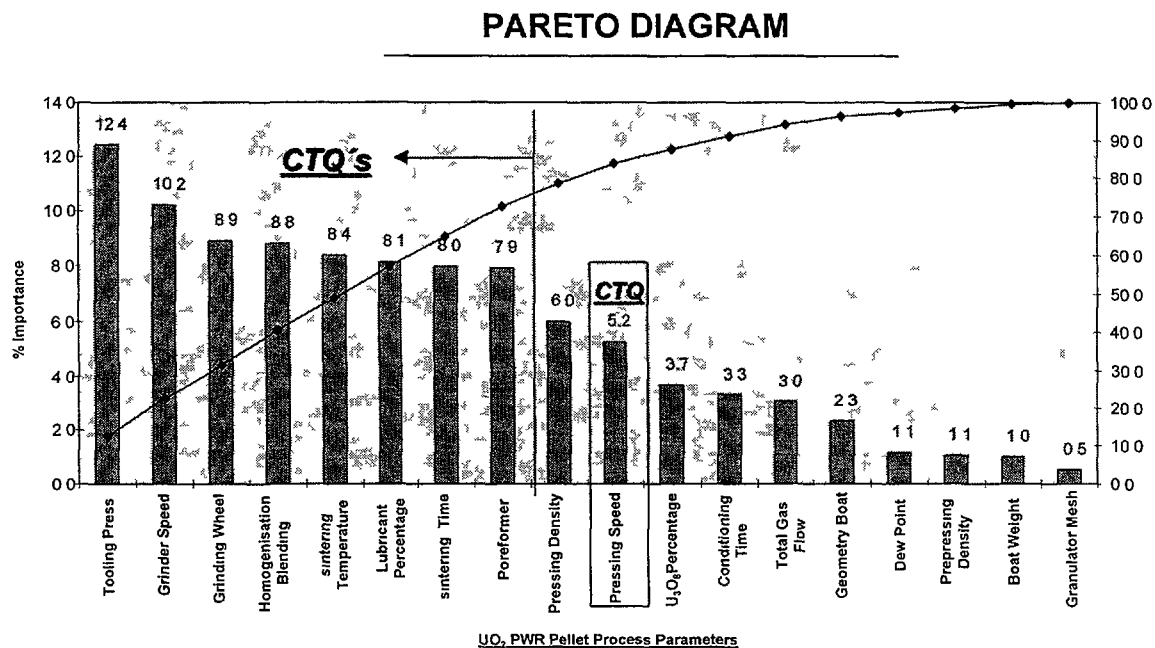
PARETO DIAGRAM

FIG 5 PARETO diagram - UO₂ PWR pellet process parameters

- *CLASSIFICATION OF THE CHARACTERISTICS*

The characteristics of the pellets to be put in QATS are classified as follows in Table 2

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TABLE 2. CLASSIFICATION OF THE CHARACTERISTICS

Factor	- 1	+ 1
"X" Process Capability (Z. Index)	$4.5 \geq Z > 3$	$Z > 4.5$
"Y" Characteristic Importance (According to design QFD)	NON-CTQ	CTQ

Regarding the above classifications four different groups are made (Table 3):

TABLE 3. CLASSIFICATION IN FOUR DIFFERENT GROUPS

Group	Factor "X"	Factor "Y"
1	- X	- Y
2	+ X	- Y
3	- X	+ Y
4	+ X	+ Y

This classification in four groups is the one that is used to define the different verification to be carried out on each characteristic. The results obtained are shown in Figure 6.

A criteria to select the different types of action in each characteristic are also defined:

➢ *To rationalize the design* of the less important characteristics with a low capability (- X, -Y),
➢ *To keep the process* of less important characteristics with a high capability (+X, -Y),
➢ *To improve the process* of important characteristics with a low capability (-X, +Y),
➢ *To control the process* of important characteristics with high capability (+X, +Y).

UO₂ / PWR - D&V CHARACTERISTICS CLASSIFICATION
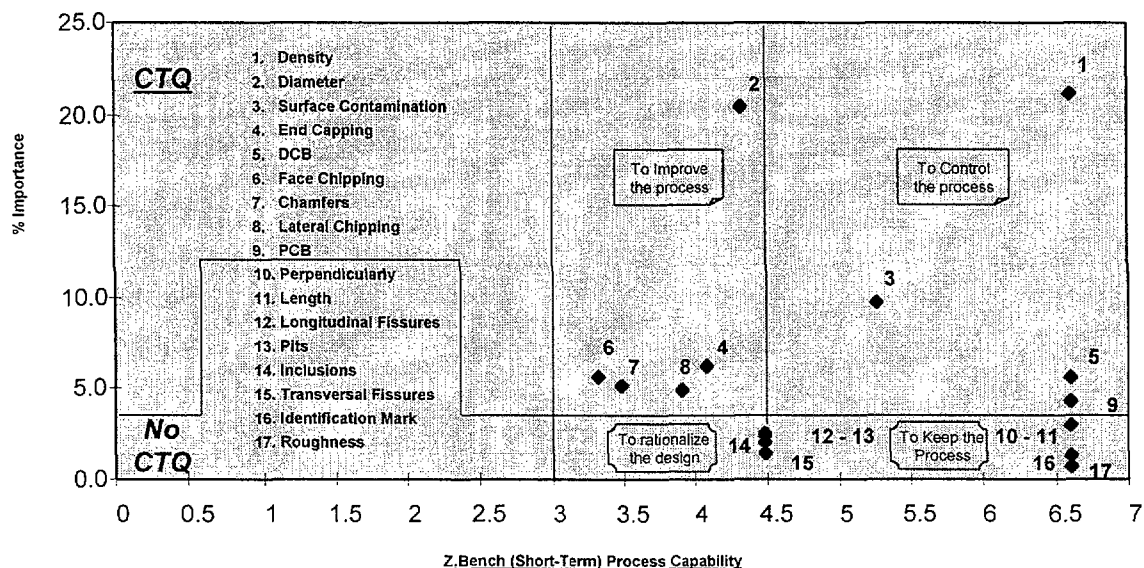
FIG. 6. D&V characteristics classification for UO₂ PWR pellets

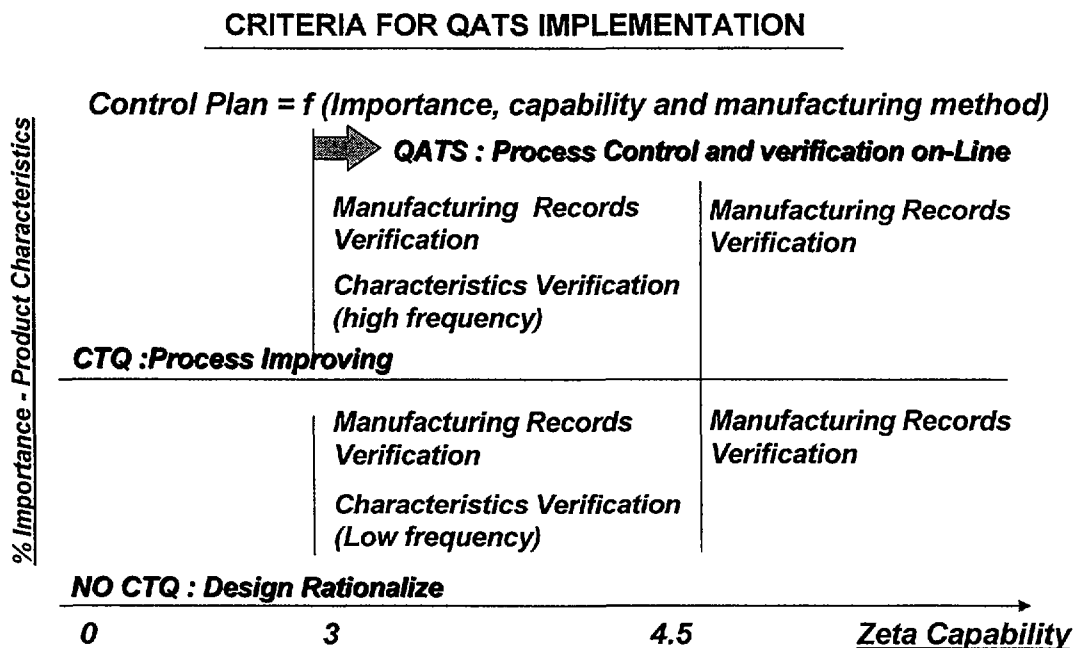● *DEFINITION OF THE IMPLEMENTATION CRITERIA*

To put a characteristic in QATS it is necessary that its process capability is higher than 3 Zs. The Quality organization should carry out the following activities:

➢ *Qualifications of manufacturing workers* to do inspections,

➢ *Verification of the records* in order to check that inspections have been carried out,

➢ *Product characteristics inspection* by means of random sampling of the product,

➢ *Verification of process variables* to check manufacturing process control,

➢ *Z. Quality index control* to make sure that it is within the initial qualification.

● *VIGILANCE AND VERIFICATION OF THE PRODUCT CHARACTERISTICS*

The manufacturing workers, qualified by the quality organization, should inspect the product according to design documents; this condition has to be fulfilled. The Quality organization should carry out periodical random samplings to verify the product characteristics already inspected by manufacturing. The Control Plan is defined according to the importance of the characteristics, the process capability and the manufacturing methods. The implementation criteria can be show in Table 4.

TABLE 4. CRITERIA FOR QATS IMPLEMENTATION

CRITERIA FOR QATS IMPLEMENTATION

Control Plan = f (Importance, capability and manufacturing method)

➡ *QATS : Process Control and verification on-Line*

% Importance - Product Characteristics		
CTQ :Process Improving	*Manufacturing Records Verification* *Characteristics Verification (high frequency)*	*Manufacturing Records Verification*
	Manufacturing Records Verification *Characteristics Verification (Low frequency)*	*Manufacturing Records Verification*

NO CTQ : Design Rationalize →

| 0 | 3 | 4.5 | <u>Zeta Capability</u> |

● *VIGILANCE AND VERIFICATION OF THE PROCESS VARIABLES*

The qualified manufacturing workers should check all the variables defined in the process QFD except those with "Mistake Proofing devices" called **"Poka Yoke"**.
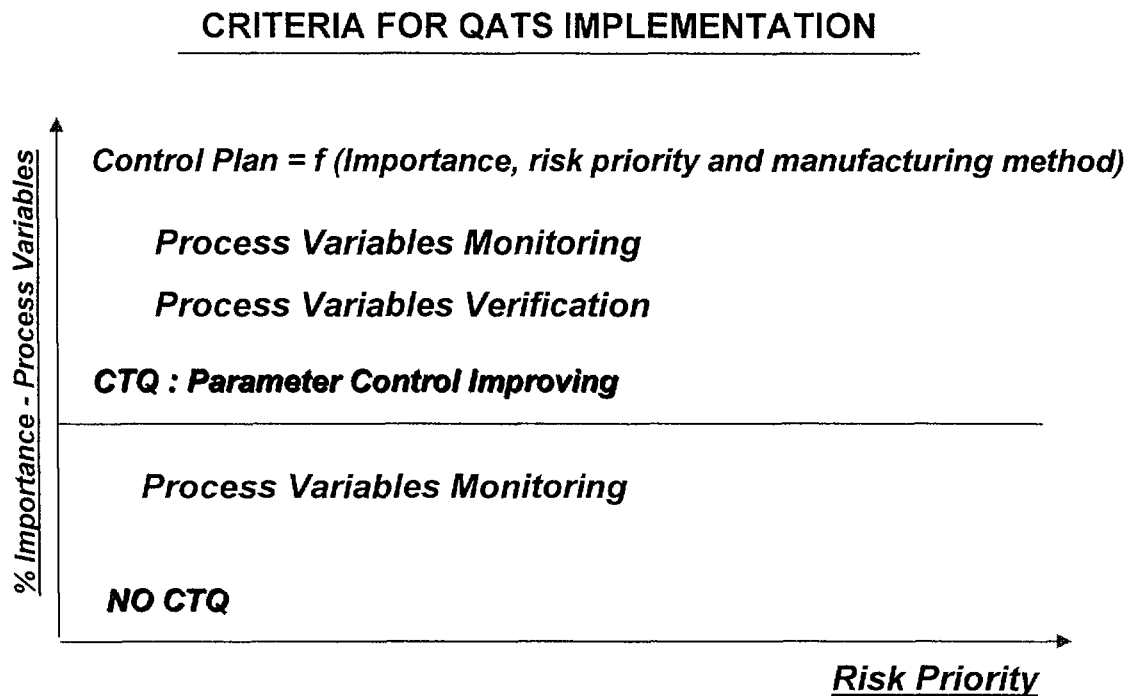
The Control Plan is defined according to the importance of the process variable, the risk priority number (RPN) and the manufacturing method. The risk priority number (RPN) is calculated by developing and using an **FMEA** (Failure Modes and Effects Analysis). RPN = Likelihood of Occurrence (O) x Degree of Severity (S) x Ability to Detect. (D).

The quality organization should verify periodically the variability of the process and the register of tool changes. The implementation criteria are shown in Table 5.

• *ACTION IN CASE OF DEVIATION*

In the case of any deviation in any verification, the quality organization should notify manufacturing to **stop the process** for immediate correction. They should keep and evaluate the product and should submit the product for evaluation to the design organization in case the product does not meet the design requirements or in case it does not meet the requirements of a critical parameters of the process.

TABLE 5. CRITERIA FOR QATS IMPLEMENTATION

CRITERIA FOR QATS IMPLEMENTATION

Control Plan = f (Importance, risk priority and manufacturing method)

Process Variables Monitoring

Process Variables Verification

CTQ : Parameter Control Improving

Process Variables Monitoring

NO CTQ

(Y-axis: *% Importance - Process Variables*)

Risk Priority

2.4. Modifications in applicable documentation

Before implementing the QATS system it is necessary to modify the documentation indicating the *design CTQs* on the drawing and specifications and the level of inspection required. The *process CTQs*, the inspection frequency and the process control plans of vigilance and verification of the product and the process should be indicated in the manufacturing and inspection plans.

3. QATS SYSTEM IMPLEMENTATION-SUMMARY & CONCLUSIONS

After all the above mentioned steps are completed:

➢ QATS implementation criteria are established.
➢ Product characteristics classified according to its importance and its capability.
➢ Process variables classified in order to its importance.
➢ Process FMEA (Failure Mode and Effects Analysis) developed.
➢ RPNs (Risk Priority Numbers) of each process variable calculated.

The following control plans are elaborated for each characteristic of the product and for each variable of the process:

➢ *Process Control* by manufacturing
➢ Monitoring of the *Process Variables* by manufacturing
➢ Verification of K *Manufacturing records* by quality

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➤ Verification of the *Product Characteristics* by quality
➤ Verification of *Process Variables* by quality.

Furthermore, Quality has to *qualify the manufacturing workers* in order to carry out inspections and calculate the *Z. Quality Indexes* periodically, making sure that each characteristic in QATS keeps its index in the initial classification.

This system makes the manufacturer responsible for the quality; it provides him with the necessary tools to avoid manufacturing defects, and consequently, it ensures continuous *quality improvement and productivity*.

DATA MANAGEMENT AS A BASIS FOR EFFICIENT PROCESS AND QUALITY CONTROL MODELLING

(Session II)

DIGITAL IMAGE PROCESSING IN THE NUCLEAR FIELD WITH IMAWIN 5.0

XA0055752

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Abstract

ImaWin is a software project designed to cover a broad set of applications of Digital Image Processing in the Nuclear Field. Since 1994 the system has evolved in a complete tool that helped to face problems like densitometry calculus, quality control in pellets, deposit administration and surveillance. Neural network kernel and ImaScript scripting language are included within the package. The open and incremental development of ImaWin software has been allowing easy expansion upon a common re-engineering framework.

1. INTRODUCTION

The ImaWin Project was launched in 1994 with the purpose of specifying a unified strategy to solve several Digital Image Processing (DIP) tasks in Nuclear Field. Until then, standard commercial software had been tried with high cost and poor results.

The basic approach was to build a basic framework and to apply permanent re-engineering to adapt to concrete problems.

The cases are:

- Pellet image analysis under non-homogeneous illumination conditions,
- Axial quality control of pellets using linear and heuristic tools,
- Deposit surveillance and control,
- Radiography inspection.

2. PELLET IMAGE ANALYSIS

Grey-scale pellet microscopic image processing is one of the most common applications of DIP in nuclear field. ImaWin 1.0 was able to segment images following simple intensity thresholding techniques and to calculate distribution of particle parameters like powder particle distribution and pore area distribution in a pellet. ImaWin 1.2 incorporated expressivity to build user defined segmentation criteria.

In one of the laboratories the optic system generated an inhomogeneous luminosity pattern that troubled common segmentation criteria.

With little extra programming, a specific filter for that strange deviation was implemented, allowing standard segmentation procedure (Photos 1 and 2).

ImaWin 5.0 includes a complete set of pellet analysis tools including standard and user defined filters, drawing tools, interactive segmentation with intensity, grain detection enhancer, texture, channel and user defined criteria.
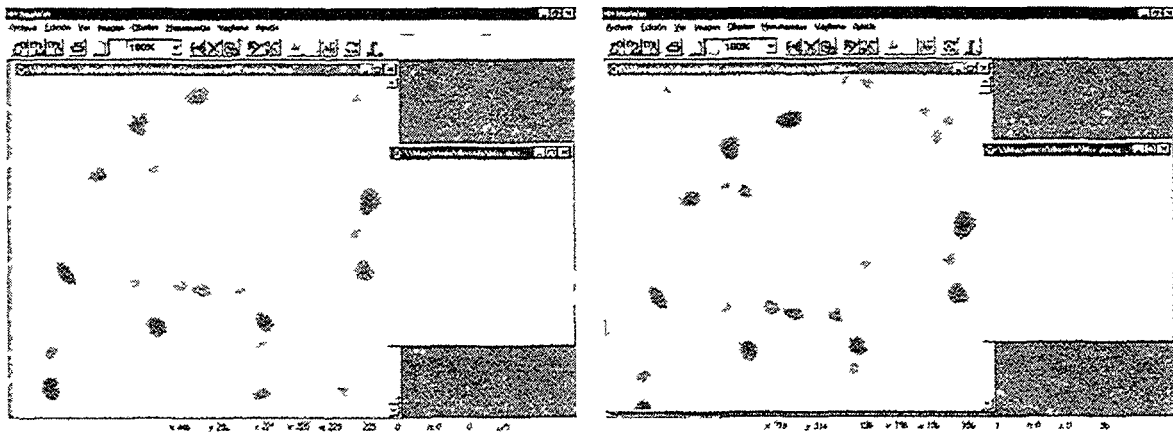
Photos 1 and 2 Pellet image with unbalanced illumination and same image corrected

## 3 PELLET QUALITY CONTROL (LINEAR AND HEURISTIC CASES)

3 1 LINEAR CASE

In 1996 pellet quality control was visually performed via human operation The objective was to develop functions to accomplish and integrate it automatically to the growing ImaWin project

The system was thought to analyse the axial surface of rotating pellets given homogeneous and diffuse illumination conditions

The test is done looking for discontinuities of two types

(1)   Discontinuities along profiles of intensity levels from axial surface (Photo 3)
(2)   Discontinuities between average values of adjacent profiles (Photo 4)
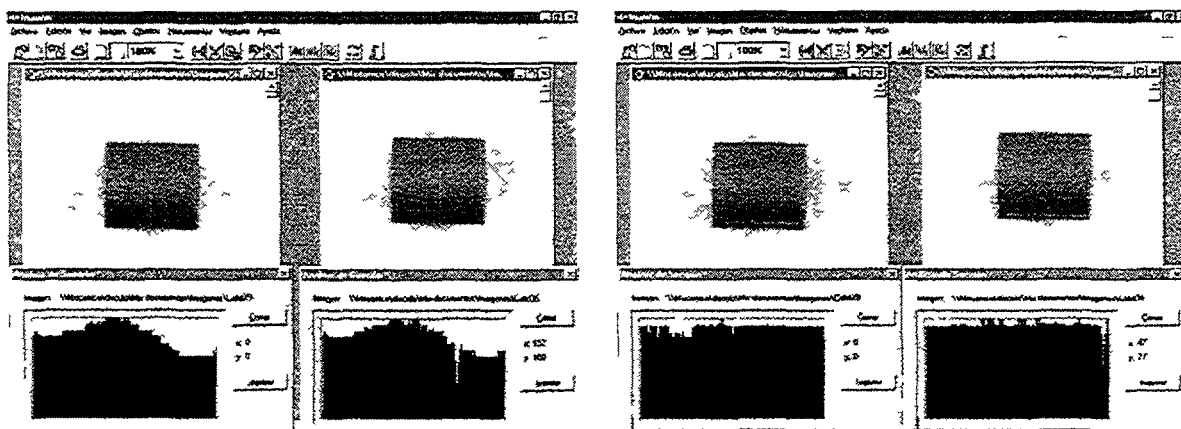
Photos 3 and 4 Profile analysis for detecting both vertical and horizontal failure components

3.2. HEURISTIC CASE

Since linear approach determines the need for defining concrete parameters and limits, neural networks allows to heuristically guess limits and also, in some cases, parameters.

A three layered back propagation network was fed with the parameters determined in the linear case and was trained using 300 archive images.

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In a very short time – 2000 training cycles - the net was able to recognise with 100% confidence the 150 images of the Training Test Set.

4. DEPOSIT CONTROL AND SURVEILLANCE

The increasing of Intranet connectivity along with the availability of ImaWin allowed starting analysing sequences of live images on-line and using ImaWin scripting procedures and data management tools to integrate event registering.

Cameras were located in two different deposits. The system was powered with intelligent algebraic operations capable to detect significative alterations in the placement of objects regardless of variations of illumination (Photos 5 and 6).

Regions of Interest (ROI) were created to relate events with different priorization levels.

Once specified the given parameters, the system is able to notice events and evaluate further authorisation.

The sequence of occured events is reported and saved to a database, allowing remote management of the deposit. On line monitoring and administration is being tested with an Internet web based interface.
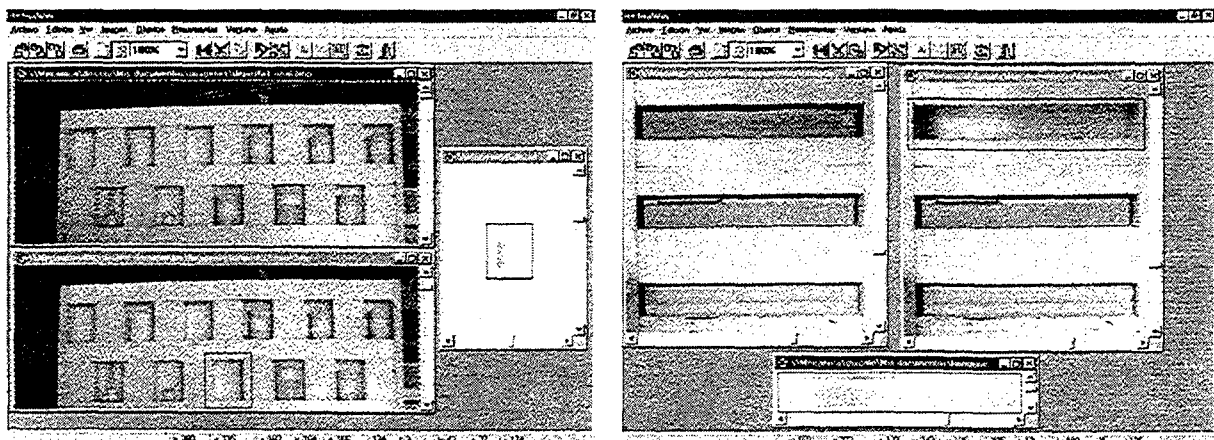
Photos 5 and 6. The system detects the absence of an enriched uranium container in a non-critical array arrangement and of a fuel plate for a research reactor. In both cases the sequence windows show the ROI affected by the event. A third window displays the result of the activation filter.

5. RADIOGRAPHY INSPECTION AND QUALIFICATION

The quantitative analysis of X-ray radiography of fuel plates allows the measurement of local Uranium density and overall homogeneity as well as the determination of anomalous conditions of fabrication.

Independence from the radiographic conditions of operation is accomplished by the simultaneous screening of calibration samples.

In Photo 7 aluminide miniplate density profile of U is showed displaying the detection of an inhomogeneity.

The system makes historical research and comparison of different batches workable via the incremental building of a permanent database.
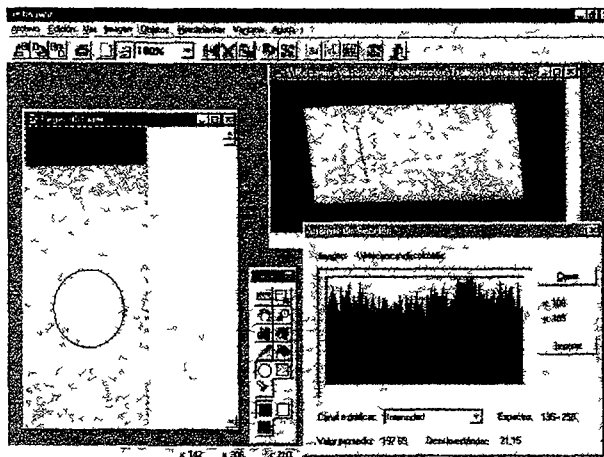
Photo 7 Inhomogeneity detected in aluminide miniplate.

6. CONCLUSION

Digital Image Processing in the nuclear field implies very different problems, and even in related problems, subtle conditions makes difficult to generate static devices that help solving them.

The Project ImaWin based its strategy on incrementally setting up an open framework for ulterior re-engineering.

Tools like neural network kernel or scripting languages were bundled when were needed to approach concrete instances.

Now ImaWin 5 0 is both a complete set of tools and an eventual starting point for newer applications.

MICROSCOPIC DETERMINATION OF THE PuO_2 GRAIN SIZE AND PORE SIZE DISTRIBUTION OF MOX PELLETS WITH AN IMAGE ANALYSIS SYSTEM

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Abstract

The industrial way to obtain the Pu distribution in a MOX pellet is by Image Analysis. The PuO_2 grains are made visible by alpha-autoradiography. Along with the Pu distribution the pore structure is an item which is examined, the latter is determined on the unetched sample. After the visualization of the sample structure, the sample is evaluated with an Image Analysis System. Each image is enhanced and a distinction is made between the objects to be measured and the matrix. The relevant parameters are then analyzed. When the overall particle distribution is wanted, all identified particles are measured and classified in size groups, based on a logarithmic scale. The possible conversion of two-dimensional diameters to three-dimensional diameters is accomplished by application of the Saltykov algorithm. When a single object is of interest, the object is selected interactively, and the result is reported to the user.

1. INTRODUCTION

MOX (Mixed OXide) is a nuclear fuel that contains depleted uranium oxide (usually 95 to 93%), a by-product from the enrichment of uranium and plutonium oxide (usually 5 to 7%), a product from nuclear reactors. One of the most important items in a MOX pellet specification is the Pu distribution in the pellet. Along with the Pu distribution the pore structure is an item which has to be examined. The industrial way to obtain this information is by Image Analysis.

2. VISUALIZATION

2.1. Pu distribution

To make the PuO_2 grains visible a replica technique (alpha-autoradiography) is used: the sample (donor) affects the structure of another surface (receptor). For alpha-autoradiography, contact is made between the polished ceramographic sample and a cellulose nitrate film during a given period. The film is sensitive to alpha particles, emitted by the plutonium and americium, resulting in a change of transparency of the film.

2.2. Pore size distribution

The pore structure is determined directly on the unetched sample.

3. EVALUATION

3.1. Configuration

After the visualization of the sample structure, the sample is evaluated with an Image Analysis System. A CCD-camera projects microscopic images to the Image Analysis System via a frame grabber. For each item to be evaluated, an image is acquired.

3.2. The algorithm

3.2.1. Enhancement of the region edges

Since blurred edges (transitions) can occur in an image due to the bandwidth restrictions of electronic and optical systems, edge transitions between a light and a dark region extend over several pixels with descending (ascending) grey values. This can lead to a so-called halo effect (rings around a region). To avoid this effect, a function is applied to sharpen the region edges.

3.2.2. Generation of binary regions

In order to be able to measure the regions, segmentation is used to generate binary regions.
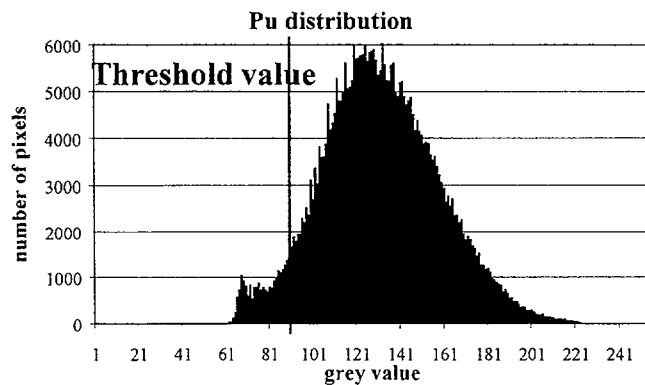
3.2.2.1. Pu distribution

FIG. 1. Grey value distribution before segmentation

First, the number of regions is calculated with a fixed threshold value, determined by experience (Figure 1.). If the number of regions is larger or smaller than a predetermined maximum or minimum, the threshold value is changed automatically until this condition is fulfilled. Afterwards, the operator has still the possibility to adjust this value. Fig. 2 shows an example of an image before segmentation and Fig. 3 the same image after segmentation.
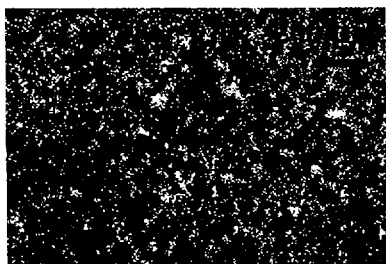

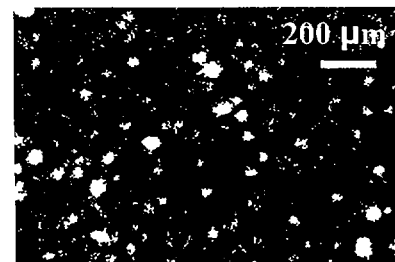FIG. 2. Image of the Pu distribution
before segmentation

FIG. 3. Image of the same Pu
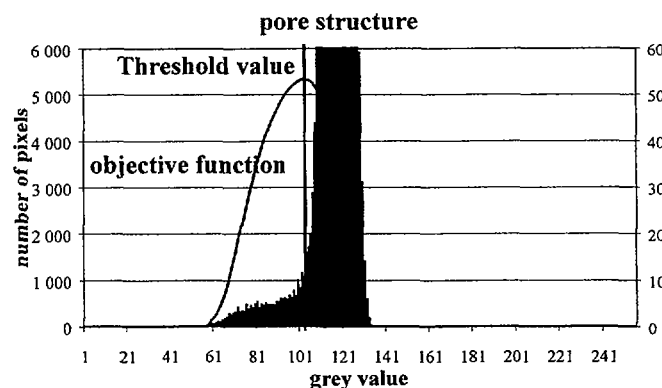distribution after segmentation

FIG. 4. Grey value distribution before segmentation

The threshold value is calculated by maximization of the interclass variance (Fig. 4): the image is partitioned into two connected sets (classes) of grey values. The objective is to separate the classes as much as possible and to regroup them as much as possible around their center. Here also, the operator has still the possibility to adjust this value after the calculation. Fig. 5 contains an image before and Fig. 6 the same image after segmentation.

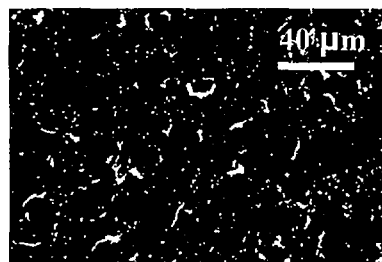*FIG. 5. Image of the pore structure before segmentation*

FIG. 6. Image of the pore structure after segmentation

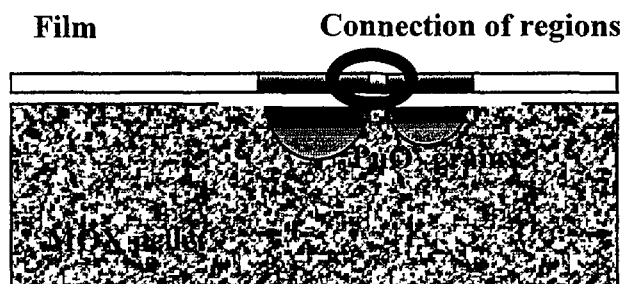### 3.2.3. Separation of connected regions (only for the Pu distribution)

FIG. 7. Connection of regions

Since the areas on the film, which are affected by the plutonium and the americium, are slightly larger than the PuO$_2$ grain sections, black regions from separate PuO$_2$ grains may get connected, as shown in Figure 7.

To undo these connections, the regions are partitioned into different size groups and eroded and dilated a number of times, depending on their size.

3.2.4. Actual measurement

According to the settings of the measurement properties, automatic measurement of the regions is executed.

3.2.5. Extrapolation of the results to 3-D space

The Johnson-Saltykov method is used to determine the size distribution of particles in unit volume of an aggregate from a distribution of section areas.

This model assumes that:
- the 3-D particles are spherical in shape.
- each 3-D particle size distribution can be represented by a discontinuous distribution.

The latter makes the calculation less time-consuming and less complex. There is neither a sequential dependence upon previous calculations of other particle sizes, so errors will not propagate through the calculation.

Saltykov sets the interval limits of both the sphere diameters and the section area diameters equally spaced on a logarithmic scale. This ensures that the finest subdivisions occur at small diameters, where they are needed. If necessary, the scale can be extended easily in the direction of either larger or smaller diameters.
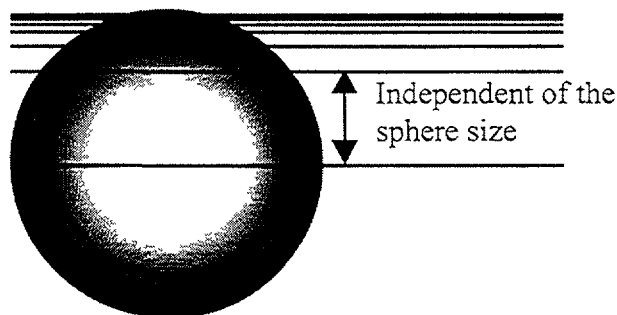

FIG. 8. The probability to cut a sphere between its maximum limits is independent of the sphere diameter

The probability to cut a sphere between two interval limits is independent of the diameter of the sphere (Fig. 8); consequently, the distribution of relative areas (for a monodispersed system of spheres) is independent of the absolute dimensions of the sphere. The calculation for a polydispersed system starts with the largest section area and ends with the smallest one.

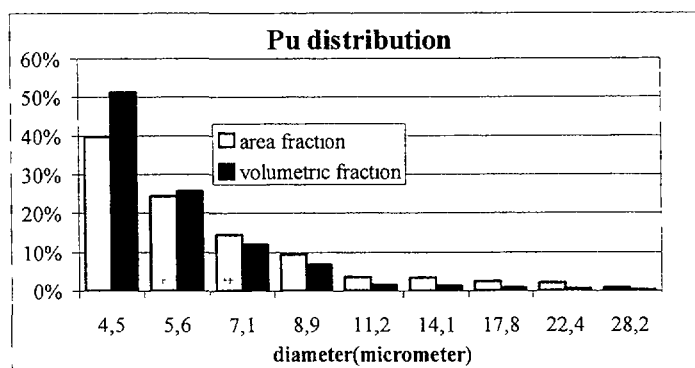Figs 9 and 10. show the result of the analysis of a typical MOX pellet.

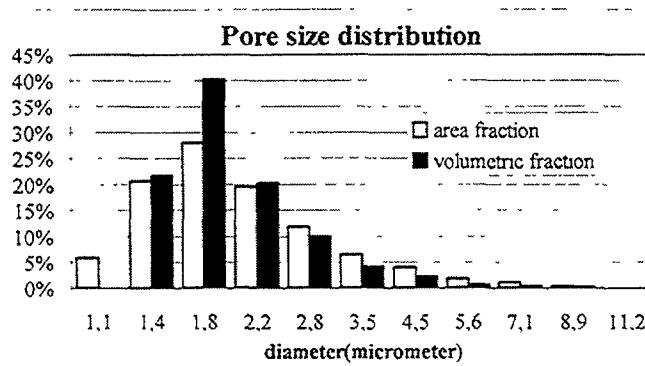*FIG. 9 Area and volumetric fraction of the PuO2 grains*

FIG. 10. Area and volumetric fraction of the pores

4. CONCLUSIONS

• This way of determining the Pu distribution and pore structure makes statistical analysis possible, since large areas are studied. This makes the method more accurate and representative.

• Once the image is acquired, the automated part of the analysis is perfectly reproducible.

• Finally, the acquisition and the analysis of images are non-time consuming activities, so the results are rapidly available.

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A MECHANISNISTIC APPROACH FOR THE
MODELLING OF MOX FUEL PELLET SINTERING

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Abstract

Within the framework of their common R and D MOX fuel fabrication program, the CEA and the COGEMA have undertaken an important project to model the different stages of MOX fuel fabrication process. The objectives of this work are a better understanding of the complicated physico-chemical mechanisms which occur simultaneously during the reactive sintering of MOX fuel pellets; the modelling of this stage should ultimately allow the accurate prediction of the influences of fabrication parameters on the characteristics of the fabricated MOX fuel, thus reducing the number of research laboratory fabrication tests together with an optimisation of the process. A code is under construction, taking into account the physical mechanisms at the grain size scale (Pu concentration, grain size, shape of grains and motion of the grain boundaries); once validated by experimental and parametric tests, this code will describe the Pu distribution and local density of the pellets as functions of the sintering conditions, helping further developments of the fabrication process such as the obtention of advanced microstructures of improved MOX fuels.

1. INTRODUCTION

In order to improve the fabrication of MOX fuel, a numerical modelling of the sintering stage has been undertaken. In order to design a code which could be adapted to the needs (addition of elements other than U, Pu and O), a mechanistic approach has been adopted. This document describes the physical model that has been developed.

The physical phenomena taken into account are: volume diffusion, surface diffusion, grain boundary diffusion, solid/gas exchanges, diffusion-reaction in gas phase and the development (or the relaxation) of mechanical stresses.

The evolution of concentrations and strain are modelled at a scale smaller than grain size (0,1 μm for green pellets, 10 μm after sintering) and involves a set of grains large enough to be representative of a pellet area, master blend area, matrix area, or interface between matrix and master blend areas.

Initial conditions are the following: the outer limits of the grains are given [1], solid phase concentrations ($UO_{2\pm x}$ or $PuO_{2\pm x}$) gas phase concentrations (Ar, H_2, H_2O) are known, as well as stress distributions. The computed parameters are: the evolution of the outer limits of the grains, the evolution of the grain composition, the pore composition evolution, the evolution of the stress field in the grains.

It is then possible to obtain local density evolution, grain size and Pu homogenisation.

2. MECHANICAL BEHAVIOUR

2.1. Context

The green fuel pellet possesses internal stresses due to the pressing stage which precedes the sintering stage. Uniaxial compacting is carried out under a pressure of 500 MN·m^{-2}. These internal stresses play a major role in grain boundary diffusion. Stresses are also to be taken into account when porosity is closed, before enclosed gas diffuses out of the pellet. The pressure inside the pores may reach a high level.

2.2. Mechanical equations

The stress tensor $\overline{\overline{T}}$ is given by the dynamics fundamental relation applied to a small volume element inside a grain, which leads to the following equation:

$$\forall i \in \{1,2,3\} \quad \sum_{j=1}^{3} \frac{\partial T_{ij}}{\partial x_j} = 0 \quad \text{(quasi-static equilibrium)}.$$

At this point, grain orientation has to be taken into account, as the relationship between stress and strain takes a simple form in the crystal referential (crystal axes). Stresses are related to strain through elastic constants c_{11}, c_{12} and c_{44}.

Grain g orientation is given by two angles θ^g and φ^g.

The laboratory referential is $R\left(O, \vec{e_1}, \vec{e_2}, \vec{e_3}\right)$, grain g <100> axes are orientated by vectors $\left(\vec{e}_1^g, \vec{e}_2^g, \vec{e}_3^g\right)$ usually denoted $\left(\vec{a}, \vec{b}, \vec{c}\right)$ in crystallography. P^g denotes the change of basis matrix from $\left(\vec{e_1}, \vec{e_2}, \vec{e_3}\right)$ to $\left(\vec{e}_1^g, \vec{e}_2^g, \vec{e}_3^g\right)$.

$$P^g = \begin{pmatrix} \cos\varphi^g & -\sin\varphi^g \cos\theta^g & -\sin\theta^g \sin\varphi^g \\ \sin\varphi^g & \cos\varphi^g \cos\theta^g & \sin\theta^g \cos\varphi^g \\ 0 & -\sin\theta^g & \cos\theta^g \end{pmatrix}$$

$\vec{u}$ is the displacement at point M in grain g, the quasi-static equilibrium condition is given by:

$$\begin{cases} \dfrac{\partial T_{11}^g}{\partial x_1^g} + \dfrac{\partial T_{12}^g}{\partial x_1^g} + \dfrac{\partial T_{13}^g}{\partial x_1^g} = 0 \\[2mm] \dfrac{\partial T_{21}^g}{\partial x_2^g} + \dfrac{\partial T_{22}^g}{\partial x_2^g} + \dfrac{\partial T_{23}^g}{\partial x_2^g} = 0 \\[2mm] \dfrac{\partial T_{31}^g}{\partial x_3^g} + \dfrac{\partial T_{32}^g}{\partial x_3^g} + \dfrac{\partial T_{33}^g}{\partial x_3^g} = 0 \end{cases}$$

Lack of temperature gradient is assumed. We suppose the system is at an isothermal stage. This hypothesis associated with those of an elastic behaviour of the grain with a cubic symmetry reads in the crystal axes:

$$\begin{cases} c_{11}\dfrac{\partial^2 u_1^g}{\partial x_1^{g2}} + c_{12}\dfrac{\partial^2 u_2^g}{\partial x_1^g \partial x_2^g} + c_{12}\dfrac{\partial^2 u_3^g}{\partial x_1^g \partial x_3^g} + \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_1^g}{\partial x_2^{g2}} + \dfrac{\partial^2 u_2^g}{\partial x_1^g \partial x_2^g}\right) + \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_1^g}{\partial x_3^{g2}} + \dfrac{\partial^2 u_3^g}{\partial x_1^g \partial x_3^g}\right) = 0 \\[3mm] \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_1^g}{\partial x_1^g \partial x_2^g} + \dfrac{\partial^2 u_2^g}{\partial x_1^{g2}}\right) + c_{12}\dfrac{\partial^2 u_1^g}{\partial x_1^g \partial x_2^g} + c_{11}\dfrac{\partial^2 u_2^g}{\partial x_2^{g2}} + c_{12}\dfrac{\partial^2 u_3^g}{\partial x_2^g \partial x_3^g} + \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_2^g}{\partial x_3^{g2}} + \dfrac{\partial^2 u_3^g}{\partial x_2^g \partial x_3^g}\right) = 0 \\[3mm] \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_1^g}{\partial x_1^g \partial x_3^g} + \dfrac{\partial^2 u_3^g}{\partial x_1^{g2}}\right) + \dfrac{1}{2}c_{44}\left(\dfrac{\partial^2 u_2^g}{\partial x_2^g \partial x_3^g} + \dfrac{\partial^2 u_3^g}{\partial x_2^{g2}}\right) + c_{12}\dfrac{\partial^2 u_1^g}{\partial x_1^g \partial x_3^g} + c_{12}\dfrac{\partial^2 u_2^g}{\partial x_2^g \partial x_3^g} + c_{11}\dfrac{\partial^2 u_3^g}{\partial x_3^{g2}} = 0 \end{cases}$$

The useful expression for the code being developed is the one in the laboratory referential. It is as follows:

$$\begin{cases} \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3} A_{i,j,k,1}\frac{\partial^2 u_i}{\partial x_j \partial x_k}=0 \\[2mm] \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3} A_{i,j,k,2}\frac{\partial^2 u_i}{\partial x_j \partial x_k}=0 \\[2mm] \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3} A_{i,j,k,3}\frac{\partial^2 u_i}{\partial x_j \partial x_k}=0 \end{cases}$$

Coefficients $A_{i,j,k,l}$ are not given here, they are functions of c_{11}, c_{12}, c_{44} θ^g and φ^g.

The boundary conditions for this partial derivative equation are the following:

2.2.1. Case of an interface gaseous pore p/solid grain g

At the surface level of the grain g, the stress $\overline{\overline{T}}^g$ is hydrostatic and is due to total pressure p in the gaseous phase: $\overline{\overline{T}}^g(\vec{n}) = -\left(\gamma_{SV}\left(\frac{1}{R_1} + \frac{1}{R_2} \right) + p \right)\vec{n}$ where $\vec{n}$ is the outer normal

of the grain. $-\gamma_{SV}\left(\frac{1}{R_1} + \frac{1}{R_2} \right)\vec{n}$ term is linked to the small grain size. Surface energy $\gamma_{SV}(\neq 0)$ and

curvature radii R_1 and R_2 (very small) make the gas applied pressure differ from grain applied stress.

Gas is described by the Rand-Markin model [2] where 1 through 13 species have a partial pressure p_i, and a concentration c_i^p. They are: U, Pu, O, Ar, H, UO, UO_2, UO_3, PuO, PuO_2, O_2, H_2, H_2O.

$$p = \sum_{i=1}^{13} p_i^p = RT\sum_{i=1}^{13} c_i^p$$ where T is the temperature and R the perfect gas

constant. The upperscript p denotes the number of the pore.

This can be written in terms of displacements :

$$\begin{cases} \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,1}^g \frac{\partial u_i^g}{\partial x_j} - Kn_1\int_{T_0}^{T}\alpha\; dT = -\left(\gamma_{SV}\left(\frac{1}{R_1}+\frac{1}{R_2} \right) + RT\sum_{i_0=1}^{13} c_{i_0}^p \right)n_1 \\[3mm] \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,2}^g \frac{\partial u_i^g}{\partial x_j} - Kn_2\int_{T_0}^{T}\alpha\; dT = -\left(\gamma_{SV}\left(\frac{1}{R_1}+\frac{1}{R_2} \right) + RT\sum_{i_0=1}^{13} c_{i_0}^p \right)n_2 \\[3mm] \displaystyle\sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,3}^g \frac{\partial u_i^g}{\partial x_j} - Kn_3\int_{T_0}^{T}\alpha\; dT = -\left(\gamma_{SV}\left(\frac{1}{R_1}+\frac{1}{R_2} \right) + RT\sum_{i_0=1}^{13} c_{i_0}^p \right)n_3 \end{cases}$$

n_1, n_2 and n_3 are the components of the normal vector $\vec{n}$. The $B_{i,j,k}^g$ expression

is not given here, it is a function of c_{11}, c_{12}, c_{44} θ^g and φ^g. In the cubic case, $K = \dfrac{(c_{11}+2c_{12})}{3}$.

is the thermal expansion coefficient.

2.2.2. Case of an interface solid grain g/solid grain g'

Two partial derivative equations are solved simultaneously:

$$\forall i \in \{1,2,3\} \quad \sum_{j=1}^{3}\frac{\partial T_{ij}^g}{\partial x_j} = 0 \quad \text{and} \quad \forall i \in \{1,2,3\} \quad \sum_{j=1}^{3}\frac{\partial T_{ij}^{g'}}{\partial x_j} = 0.$$

The relationship between displacements (u_n is the normal component of the displacement u, and u_{t1} and u_{t2} its tangential components) of grains g and g' along their common boundary is due to continuity:

$$\begin{cases} u_1^g = u_1^{g'} \\ u_2^g = u_2^{g'} \\ u_3^g = u_3^{g'} \end{cases}$$

On the other hand one assumes that forces are opposite along the boundary of two grains:

$$\overline{\overline{T^g}}(\vec{n}) = -\overline{\overline{T^{g'}}}(\vec{n}), \text{ or:}$$

$$\begin{cases} \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,1}^{g}\dfrac{\partial u_i^g}{\partial x_j} = \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,1}^{g'}\dfrac{\partial u_i^{g'}}{\partial x_j} \\ \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,2}^{g}\dfrac{\partial u_i^g}{\partial x_j} = \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,1}^{g'}\dfrac{\partial u_i^{g'}}{\partial x_j} \\ \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,3}^{g}\dfrac{\partial u_i^g}{\partial x_j} = \sum_{i=1}^{3}\sum_{j=1}^{3} B_{i,j,1}^{g'}\dfrac{\partial u_i^{g'}}{\partial x_j} \end{cases}$$

We assume that once two grains meet, they remain in contact. Signorini contact conditions [3] are not used.

3. TRANSPORT PHENOMENA

3.1. Solid description

The solid solution is an ideal solid solution between Ar whose atoms would be on the sites of a CFC lattice and the (U, Pu)O_2 solid solution.

$$\left[Ar_x\left(\left(U_M^{'}, U_M^{X}, U_M, U_M, Pu_M^{X}, Pu_M^{'}, V_M^{4'}\right)_1\left(O_{i1}^{''}, V_{i1}^{X}\right)_{16}\left(U_{i2}^{4}, Pu_{i2}^{4}, V_{i2}^{X}\right)_1\left(O_O^{X}, V_O, H_O\right)_2\right)_{1-x} \right]$$

The following structure elements have been taken into account to describe the structure of the material.

1. $O_i^{''}$: interstitial oxygen,

2. V_i^{X} : empty interstitial oxygen site,

3. V_O : oxygen vacancy,

4. O_O^{X} : oxygen in a normal site,

5. $U_M^{'}$: uranium 3+ on a cationic site,

6. U_M^{X} : uranium 4+ on a cationic site,

7. U_M : uranium 5+ on a cationic site,

8. U_M : uranium 6+ on a cationic site,

9. $V_M^{4'}$: cationic vacancy 4-,

10. $O_{i1}^{''}$: oxide ion on an interstitial anionic site (both anionic interstitial sites are mixed),

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11. V_{i1}^x : empty anionic interstitial site,

12. U_{i2}^4 : uranium 4+ on a cationic interstitial site,

13. Pu_{i2}^4 : plutonium 4+ on a cationic interstitial site,

14. V_{i2}^x : empty cationic interstitial site,

15. O_O^x : oxide ion on an anionic site,

16. V_O : empty anionic site,

17. H_O : atomic hydrogen on an anion site.

The species H_O is pointed out in [4] and is taken into account: atomic hydrogen diffuses in the empty anionic sites in UO_2 single crystals.Argon is located in empty cells [5].

The structure elements can be arranged in relative building units whose electrochemical potential can be expressed as a function of the chemical potential of the involved elements. Here are some of the relative building units U_i:

$$U_1 \equiv \left\{ U_M + U'_M - 2U_M^x \right\}$$

$$U_2 \equiv \left\{ U_M + 2U'_M - 3U_M^x \right\}$$

$$U_3 \equiv \left\{ Pu_M^x - U_M^x \right\}$$

$$U_4 \equiv \left\{ -U'_M + Pu'_M \right\}$$

$$U_5 \equiv \left\{ -4U'_M + 3U_M^x + V_M^{4'} \right\}$$

$$U_6 \equiv \left\{ -2U'_M + 2U_M^x + O_{i1}^" - V_{i1}^x \right\}$$

$$U_7 \equiv \left\{ 4U'_M - 4U_M^x + U_{i2}^4 - V_{i2}^x \right\}$$

$$U_8 \equiv \left\{ 4U'_M - 4U_M^x + Pu_{i2}^4 - V_{i2}^x \right\}$$

$$U_9 \equiv \left\{ 2U'_M - 2U_M^x - O_O^x + V_O \right\}$$

$$U_{10} \equiv \left\{ 2U'_M - 2U_M^x - O_O^x + H_O \right\}$$

In this case the entropy volumic production is:

$$T\sigma = -\vec{J}_O^T.\vec{\nabla}\mu_O - \vec{J}_U^T.\vec{\nabla}\mu_U - \vec{J}_{Pu}^T.\vec{\nabla}\mu_{Pu} - \vec{J}_H^T\vec{\nabla}\mu_H - \vec{J}_{Ar}^T\vec{\nabla}\mu_{Ar}$$

This makes the flux $\vec{J}_i^T$ and the forces appear. The forces are the potential gradients of chemical elements and not of structure elements. Irreversible processes linear thermodynamics gives a linear relationship between flux and forces whose coefficients are Onsager coefficients. In practice, interdiffusion coefficients $\tilde{D}$ are used and flux are given in the laboratory referential. A simplification is made for Ar and H fluxes:

$$\begin{cases} \vec{J}_{U\,lab}^T = -\tilde{D}_{UU}\vec{\nabla}c_U - \tilde{D}_{UPu}\vec{\nabla}c_{Pu} - \tilde{D}_{UO}\vec{\nabla}c_O \\ \vec{J}_{Pu\,lab}^T = -\tilde{D}_{PuU}\vec{\nabla}c_U - \tilde{D}_{PuPu}\vec{\nabla}c_{Pu} - \tilde{D}_{PuO}\vec{\nabla}c_O \\ \vec{J}_{O\,lab}^T = -\tilde{D}_{OU}\vec{\nabla}c_U - \tilde{D}_{OPu}\vec{\nabla}c_{Pu} - \tilde{D}_{OO}\vec{\nabla}c_O \\ \vec{J}_{Ar\,lab}^T = -\tilde{D}_{ArAr}\vec{\nabla}c_{Ar} \\ \vec{J}_{H\,lab}^T = -\tilde{D}_{HH}\vec{\nabla}c_H \end{cases}$$

I.-e. the influence of U, Pu and O on Ar or H diffusion only appears through $\tilde{D}_{HH}$ and $\tilde{D}_{ArAr}$ variation with U, Pu and O contents. C_X is the concentration of X.

3.2. Bulk diffusion in grains

$\vec{j}_{V,i}^g$ denotes the bulk diffusion flux for species i in grain g. Species 1 through 5 (U, Pu, O, Ar and H) exist in the solid phase. Bulk diffusion leads to the following relationship between fluxes and forces:

$$\vec{j}_{V,i}^g = -\sum_{k=1}^{5} \tilde{D}_{ik}^V \vec{\nabla} c_k^g - \sum_{\alpha=1}^{6} E_{i\alpha}^V \vec{\nabla} T_\alpha - c_i^g \vec{v}_G^g, \quad i \in \{1,\cdots,5\}$$

$\tilde{D}_{ik}^V$ are the bulk diffusion coefficients, and T_α the α-th component of the stress tensor with Voïgt notations. $E_{i\alpha}^V$ is due to i bulk diffusion under the influence of stresses. $E_{i\alpha}^V$ is

approximated by: $E_{i\alpha}^V = \dfrac{\overline{V}_i \tilde{D}_{ii}^V S_\alpha}{\dfrac{\partial \mu_i^c}{\partial c_i} + \dfrac{1}{2}\dfrac{\partial \overline{V}_i}{\partial c_i}\sum_{\gamma=1}^{6} S_\gamma T_\gamma}$ [6], S_α is the αth component of the strain tensor in

Voïgt notations, μ_i^c is the chemical part of the potential of i in the solid, and $\overline{V}_i$ is the molar partial volume of i. $\vec{v}_G^g$ is the velocity of the mass centre of a grain g in the referential of the laboratory.

3.3. Surface and grain boundary diffusion

$\vec{j}_{S,i}^g$ denotes the surface flux of the grain g for the species i. We notice that this surface flux is different from the tangential part of the bulk flux on the surface because the coefficients $\tilde{D}_{ik}^S$ are different from the bulk diffusion coefficients due to binding variations of atoms from surface to bulk.

$$\vec{j}_{S,i}^g = -\sum_{k=1}^{5} \tilde{D}_{ik}^S \vec{\nabla}_S c_k^g - \sum_{\alpha=1}^{6} E_{i\alpha}^V \vec{\nabla} T_\alpha - F_i^S \vec{\nabla}_S \overline{\rho} - \delta c_i^g \vec{v}_G^g, \quad i \in \{1,\cdots,5\}$$

c_k^g is the concentration of species k taken at the surface, $\vec{\nabla}_S$ denotes the surface

gradient operator: $\dfrac{\partial}{\partial s_1}\vec{u}_1 + \dfrac{\partial}{\partial s_2}\vec{u}_2$ and $\overline{\rho}$ is the mean curvature radius: $\overline{\rho} = 2\dfrac{R_1 R_2}{R_1 + R_2}$.

$E_{i\alpha}^S$ is approximated by $E_{i\alpha}^S = \dfrac{\overline{V}_i \tilde{D}_{ii}^S S_\alpha}{\dfrac{\partial \mu_i^c}{\partial c_i} + \dfrac{1}{2}\dfrac{\partial \overline{V}_i}{\partial c_i}\sum_{\gamma=1}^{6} S_\gamma T_\gamma - \dfrac{\partial \overline{V}_i}{\partial c_i}\gamma_{SV}\dfrac{2}{\overline{\rho}}}$ [6].

F_i^S is approximated by: $F_i^S = \dfrac{\overline{V}_i \tilde{D}_{ii}^S \gamma_S}{\overline{\rho}^2\left(\dfrac{\partial \mu_i^c}{\partial c_i} + \dfrac{1}{2}\dfrac{\partial \overline{V}_i}{\partial c_i}\sum_{\gamma=1}^{6} S_\gamma T_\gamma - \dfrac{\partial \overline{V}_i}{\partial c_i}\gamma_{SV}\dfrac{2}{\overline{\rho}}\right)}$ [6].

In these two equations, thermo-elasticity bounds are used; i.e. in crystal axes:

$$
\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} =
\begin{bmatrix}
c_{11} - K\int_{T_0}^{T}\alpha dT & c_{12} & c_{12} & 0 & 0 & 0 \\
c_{12} & c_{11} - K\int_{T_0}^{T}\alpha dT & c_{12} & 0 & 0 & 0 \\
c_{12} & c_{12} & c_{11} - K\int_{T_0}^{T}\alpha dT & 0 & 0 & 0 \\
0 & 0 & 0 & c_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & c_{44} & 0 \\
0 & 0 & 0 & 0 & 0 & c_{44}
\end{bmatrix}
\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix}
$$

A grain boundary flux is defined accordingly by replacing subscript S by GB.

3.4. Gas diffusion

Let $\vec{j}_i^{\,p}$ be the bulk flux of species i in the pore p (all 13 species exist in gaseous phase).

$$\vec{j}_i^{\,p} = -\sum_{k=1}^{13} D_{ik}^p \vec{\nabla} c_k^p - c_i^p \vec{v}_G^p$$

where D_{ik}^p is a bulk diffusion coefficient for the gaseous phase.

The gas kinetics theory gives the interdiffusion coefficients for species i and k in the pores p: D_{ik}^p. We assume that the more probable shocks are the ones where two particles are involved, thus these coefficients can be used in the case where the gas posseses more than two species. The literature [7] gives:

$$D_{ik}\,(m^2 s^{-1}) = 1.858 \times 10^{-7}\, \frac{\left(T^3\left(M_i + M_k\right)\Big/\left(M_i M_k\right)\right)^{\frac{1}{2}}}{p\sigma_{ik}^2 \Omega_{ik}^{(1,1)*}} \text{ with}$$

$\Omega_{ik}^{(1,1)*} = \Omega^{(1,1)}$ for $T^* = \dfrac{kT}{\varepsilon_{ik}}$ with $\left(\dfrac{\varepsilon_{ik}}{k}\right)^2 = \left(\dfrac{\varepsilon_i}{k}\right)\left(\dfrac{\varepsilon_k}{k}\right)$ where ε is the depth of the Lennard-Jones potential [8], M is the molar weight in 10^{-3} kg·mol^{-1}, T temperature in K, σ the diameter in Å and p pressure in N·m^{-2}.

3.4.1. For a non-polar gas:

$$\Omega^{(1,1)*} = 1.06036\left(T^*\right)^{-0.1561} + 0.19300 e^{-0.47635 T^*} + 1.03587 e^{-1.52996 T^*} + 1.76474 e^{-3.89411 T^*}$$

3.4.2. For a polar gas:

$$\Omega^{(1,1)*} = 1.06036\left(T^*\right)^{-0.1561} + 0.19300 e^{-0.47635 T^*} + 1.03587 e^{-1.52996 T^*} + 1.76474 e^{-3.89411 T^*} + 0.19\frac{\delta^2}{T^*}$$

δ depends on the dipolar moment μ: $\delta = \dfrac{1}{2}\mu^{*2}$ with $\mu^* = \mu\left(\sigma^3 \varepsilon\right)^{-1/2}$. On the other hand: $\delta = \sqrt{\delta_i \delta_k}$.

The values given by [7] are summarised in Table 1.

Pressure p is linked to gas phase concentrations by the perfect gas law.

Table 1 : gas diffusion parameters

	δ	M (g·mol^{-1})	σ (Å)	ε/k (K)
Ar		39.95	3.451	119.5
H$_2$		2.016	2.827	59.7
O$_2$		32	3.323	137.0
H$_2$O	1,0	18.1	2.52	775

3.5. Continuity equations

3.5.1. Inside grains g and g':

$$\begin{cases} div\left(\vec{j}_{V_i}^g\right)+\dfrac{\partial c_i^g}{\partial t}=0 \\[2mm] div\left(\vec{j}_{V_i}^{g'}\right)+\dfrac{\partial c_i^{g'}}{\partial t}=0 \end{cases} \quad \text{for } i \in \{1,\cdots,5\}$$

with coupling conditions:

$$\mu_1^{solid}\left(c_1^g,\cdots,c_5^g,T_1^g,\cdots,T_6^g,\overline{p}^g\right)=\mu_1^{solid}\left(c_1^{g'},\cdots,c_5^{g'},T_1^{g'},\cdots,T_6^{g'},\overline{p}^{g'}\right)$$

$$\vdots$$

$$\mu_5^{solid}\left(c_1^g,\cdots,c_5^g,T_1^g,\cdots,T_6^g,\overline{p}^g\right)=\mu_5^{solid}\left(c_1^{g'},\cdots,c_5^{g'},T_1^{g'},\cdots,T_6^{g'},\overline{p}^{g'}\right)$$

$$\left(\vec{j}_{V,1}^g-\vec{v}_{int\,er}^{gg'}c_1^g\right).\vec{n}+\left(\vec{j}_{V,1}^{g'}-\vec{v}_{int\,er}^{gg'}c_1^{g'}\right).\vec{n}+div_S\left(\vec{j}_{GB,1}^g+\left(\left(\vec{\delta j}_{V,1}^g-\vec{v}_{int\,er}^{gg'}\delta c_1^g\right).\vec{t}\right)\vec{t}-\vec{v}_{int\,er}^{gg'}\delta c_1^g\right)$$

$$-div_S\left(\vec{j}_{GB,1}^{g'}+\left(\left(\vec{\delta j}_{V,1}^{g'}-\vec{v}_{int\,er}^{gg'}\delta c_1^{g'}\right).\vec{t}\right)\vec{t}-\vec{v}_{int\,er}^{gg'}\delta c_1^g\right)=0$$

$$\vdots$$

$$\left(\vec{j}_{V,5}^g-\vec{v}_{int\,er}^{gg'}c_5^g\right).\vec{n}+\left(\vec{j}_{V,5}^{g'}-\vec{v}_{int\,er}^{gg'}c_5^{g'}\right).\vec{n}+div_S\left(\vec{j}_{GB,5}^g+\left(\left(\vec{\delta j}_{V,5}^g-\vec{v}_{int\,er}^{gg'}\delta c_5^g\right).\vec{t}\right)\vec{t}-\vec{v}_{int\,er}^{gg'}\delta c_5^g\right)$$

$$-div_S\left(\vec{j}_{GB,5}^{g'}+\left(\left(\vec{\delta j}_{V,5}^{g'}-\vec{v}_{int\,er}^{gg'}\delta c_5^{g'}\right).\vec{t}\right)\vec{t}-\vec{v}_{int\,er}^{gg'}\delta c_5^{g'}\right)=0$$

where δ denotes the « thickness » of the grain boundary.

The last 5 equations are differential equations which mean that the fluxes of the species are nil through the interface in the referential of the interface:

$$\iint_\Sigma\left(\vec{j}_{V,1}^g-c_1^g\vec{v}_{int\,er}^{gg'}\right).\vec{n}\,dS+\iint_\Sigma\left(\vec{j}_{V,1}^{g'}-c_1^{g'}\vec{v}_{int\,er}^{gg'}\right).\vec{n}\,dS+\int_\Gamma\left(\vec{j}_{GB,1}^g-\delta\vec{v}_{int\,er}^{gg'}c_1^g+\left(\delta\left(\vec{j}_{V,1}^g-\vec{v}_{int\,er}^{gg'}c_1^g\right).\vec{t}\right)\vec{t}\right).\vec{n}_\Gamma\,ds-$$

$$\int_\Gamma\left(\vec{j}_{GB,1}^{g'}-\delta\vec{v}_{int\,er}^{gg'}c_1^{g'}+\left(\delta\left(\vec{j}_{V,1}^{g'}-\vec{v}_{int\,er}^{gg'}c_1^{g'}\right).\vec{t}\right)\vec{t}\right).\vec{n}_\Gamma\,ds=0$$

where Σ, Γ, $\vec{n}$ and $\vec{n}_\Gamma$ are defined in Fig. 1.
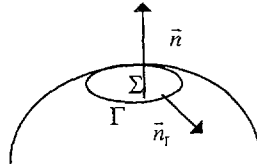

Fig.1 : Surface of a grain

3.5.2. Inside grain g and pore p:

For the gaseous phase species 1 through 13 are defined in the following way:

1. U
2. Pu
3. O
4. Ar
5. H
6. UO
7. UO_2
8. UO_3
9. PuO
10. PuO_2
11. O_2
12. H_2
13. H_2O

Matter conservation in both pore p and grain g leads to:

$$
\begin{cases}
div\left(\vec{j}_1^{\,p} + \vec{j}_6^{\,p} + \vec{j}_7^{\,p} + \vec{j}_8^{\,p}\right) + \dfrac{\partial c_1^p}{\partial t} + \dfrac{\partial c_6^p}{\partial t} + \dfrac{\partial c_7^p}{\partial t} + \dfrac{\partial c_8^p}{\partial t} = 0 \\[2mm]
div\left(\vec{j}_2^{\,p} + \vec{j}_9^{\,p} + \vec{j}_{10}^{\,p}\right) + \dfrac{\partial c_2^p}{\partial t} + \dfrac{\partial c_9^p}{\partial t} + \dfrac{\partial c_{10}^p}{\partial t} = 0 \\[2mm]
div\left(\vec{j}_3^{\,p} + \vec{j}_6^{\,p} + 2\vec{j}_7^{\,p} + 3\vec{j}_8^{\,p} + \vec{j}_9^{\,p} + 2\vec{j}_{10}^{\,p} + 2\vec{j}_{11}^{\,p} + \vec{j}_{13}^{\,p}\right) + \dfrac{\partial c_3^p}{\partial t} + \dfrac{\partial c_6^p}{\partial t} + 2\dfrac{\partial c_7^p}{\partial t} + 3\dfrac{\partial c_8^p}{\partial t} \\[2mm]
+ \dfrac{\partial c_9^p}{\partial t} + 2\dfrac{\partial c_{10}^p}{\partial t} + 2\dfrac{\partial c_{11}^p}{\partial t} + \dfrac{\partial c_{13}^p}{\partial t} = 0 \\[2mm]
div\left(\vec{j}_4^{\,p}\right) + \dfrac{\partial c_4^p}{\partial t} = 0 \\[2mm]
div\left(\vec{j}_5^{\,p} + 2\vec{j}_{12}^{\,p} + 2\vec{j}_{13}^{\,p}\right) + \dfrac{\partial c_5^p}{\partial t} + 2\dfrac{\partial c_{12}^p}{\partial t} + 2\dfrac{\partial c_{13}^p}{\partial t} = 0 \\[2mm]
and: \\[2mm]
\forall i \in \{1,\cdots,5\}\; div\left(\vec{j}_{V,i}^{\,g}\right) + \dfrac{\partial c_i^g}{\partial t} = 0
\end{cases}
$$

In gas, total concentrations of elements are linked with individual concentrations through:

$$
\begin{cases}
c_1^{Tp} = c_1^p + c_6^p + c_7^p + c_8^p \\[4pt]
c_2^{Tp} = c_2^p + c_9^p + c_{10}^p \\[4pt]
c_3^{Tp} = c_3^p + c_6^p + 2c_7^p + 3c_8^p + c_9^p + 2c_{10}^p + 2c_{11}^p + c_{13}^p \\[4pt]
c_4^{Tp} = c_4^p \\[4pt]
c_5^{Tp} = c_5^p + 2c_{12}^p + 2c_{13}^p \\[6pt]
K_1 = \dfrac{c_3^p}{c_{11}^{p\,1/2}} \\[14pt]
K_2 = \dfrac{c_6^p}{c_1^p c_{11}^{p\,1/2}} \\[14pt]
K_3 = \dfrac{c_7^p}{c_6^p c_{11}^{p\,1/2}} \\[14pt]
K_4 = \dfrac{c_8^p}{c_7^p c_{11}^{p\,1/2}} \\[14pt]
K_5 = \dfrac{c_9^p}{c_2^p c_{11}^{p\,1/2}} \\[14pt]
K_6 = \dfrac{c_{10}^p}{c_9^p c_{11}^{p\,1/2}} \\[14pt]
K_7 = \dfrac{c_{13}^p}{c_{12}^p c_{11}^{p\,1/2}} \\[14pt]
K_8 = \dfrac{c_5^p}{c_{12}^{p\,1/2}}
\end{cases}
$$

Reactions between species 1 through 13 are those given by the Rand-Markin model. The coupling conditions for the differential continuity equations are:

$$\mu_1^{\text{solid}}\left(c_1^g,\cdots,c_5^g,T_1^g,\cdots,T_6^g,\overline{\rho}^{\,g}\right) = \mu_1^{\text{gas}}\left(c_1^p\right)$$

$$\vdots$$

$$\mu_5^{\text{solid}}\left(c_1^g,\cdots,c_5^g,T_1^g,\cdots,T_6^g,\overline{\rho}^{\,g}\right) = \mu_5^{\text{gas}}\left(c_5^p\right)$$

$$\left(\vec{j}_{V,1}^{\,g} - \vec{v}_{int\,er}^{\,gg'}c_1^g\right).\vec{n} + \left(\left(\vec{j}_{V,1}^{\,p} + \vec{j}_{V,6}^{\,p} + \vec{j}_{V,7}^{\,p} + \vec{j}_{V,8}^{\,p}\right) - \vec{v}_{int\,er}^{\,gp}c_1^{Tp}\right).\vec{n} + div_S\left(\vec{j}_{GB,1}^{\,g} + \left(\left(\delta\vec{j}_{V,1}^{\,g} - \vec{v}_{int\,er}^{\,gp}\delta c_1^g\right).\vec{t}\right)\vec{t} - \vec{v}_{int\,er}^{\,gp}\delta c_1^g\right)$$

$$- div_S\left(\left(\left(\delta\left(\vec{j}_{V,1}^{\,p} + \vec{j}_{V,6}^{\,p} + \vec{j}_{V,7}^{\,p} + \vec{j}_{V,8}^{\,p}\right) - \vec{v}_{int\,er}^{\,gp}\delta c_1^{Tp}\right).\vec{t}\right)\vec{t}\right) = 0$$

$$\vdots$$

$$\left(\vec{j}_{V,5}^{\,g} - \vec{v}_{int\,er}^{\,gp}c_5^g\right).\vec{n} + \left(\left(\vec{j}_{V,5}^{\,p} + 2\vec{j}_{V,12}^{\,p} + 2\vec{j}_{V,13}^{\,p}\right) - \vec{v}_{int\,er}^{\,gp}c_5^{Tp}\right).\vec{n} + div_S\left(\vec{j}_{GB,5}^{\,g} + \left(\left(\delta\vec{j}_{V,5}^{\,g} - \vec{v}_{int\,er}^{\,gp}\delta c_5^g\right).\vec{t}\right)\vec{t} - \vec{v}_{int\,er}^{\,gp}\delta c_5^g\right)$$

$$- div_S\left(\left(\left(\delta\left(\vec{j}_{V,5}^{\,p} + 2\vec{j}_{V,12}^{\,p} + 2\vec{j}_{V,13}^{\,p}\right) - \vec{v}_{int\,er}^{\,gp}\delta c_5^{Tp}\right).\vec{t}\right)\vec{t}\right) = 0$$

3.6. grain interface velocity

The solid interface velocity is given by:

3.6.1. Case of a grain/grain interface:

$$v_{inter}^{gg'} = \left(\frac{1}{c_k^g} \, \vec{j}_{V,k}^g + \frac{1}{c_k^{g'}} \, \vec{j}_{V,k}^{g'} \right) . \vec{n} + \overline{V}_k^g \, \mathrm{div}_S \left(\vec{j}_{S,k}^g + \left(\delta \vec{j}_{V,k}^g . \vec{t} \right) \vec{t} \right) - \overline{V}_k^{g'} \, \mathrm{div}_S \left(\vec{j}_{S,k}^{g'} + \left(\delta \vec{j}_{V,k}^{g'} . \vec{t} \right) \vec{t} \right)$$

3.6.2. Case of a grain/gas interface:

$$v_{inter}^{gg'} = \left(\frac{1}{c_k^g} \, \vec{j}_{V,k}^g + \frac{1}{c_k^{g'}} \, \vec{j}_{V,k}^{Tp} \right) . \vec{n} + \overline{V}_k^g \, div_S \left(\vec{j}_{S,k}^g + \left(\delta \vec{j}_{V,k}^g . \vec{t} \right) \vec{t} \right) - \overline{V}_k^{g'} \, div_S \left(\left(\delta \vec{j}_{V,k}^{Tp} . \vec{t} \right) \vec{t} \right)$$

with, for instance: $\vec{j}_{V,1}^{Tp} = \vec{j}_{V,1}^p + \vec{j}_{V,6}^p + \vec{j}_{V,7}^p + \vec{j}_{V,8}^p$.

These expressions have to be valid for all k (1 through 5).

3.7. Multiple points

Fluxes have to be continuous at triple (or multiple) points.

grain g:

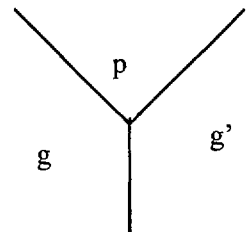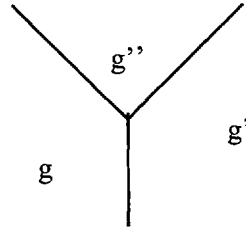*Fig 2 : a triple point made of three grains*

Fig 3 : a triple point made of two grains and a pore

In the case of a triple point due to the intersection of three grains:

$$\left(\lim_{P\in g/g''\to M} \bar{j}^g_{GB,k} + \delta\left(\bar{j}^g_{V,k}\cdot \bar{t}^{gg''}\right)\bar{t}^{gg''}\right).\bar{t}^{gg''} = \left(\lim_{P\in g/g'\to M} \bar{j}^g_{GB,k} + \delta\left(\bar{j}^g_{V,k}\cdot \bar{t}^{gg'}\right)\bar{t}^{gg'}\right).\bar{t}^{gg'}$$

and in the case of two grains and a pore:

$$\left(\lim_{P\in g/g''\to M} \bar{j}^g_{S,k} + \delta\left(\bar{j}^g_{V,k}\cdot \bar{t}^{gp}\right)\bar{t}^{gp}\right).\bar{t}^{gp} = \left(\lim_{P\in g/g'\to M} \bar{j}^g_{GB,k} + \delta\left(\bar{j}^g_{V,k}\cdot \bar{t}^{gg'}\right)\bar{t}^{gg'}\right).\bar{t}^{gg'}$$

pore p:

$$\left(\bar{j}^p_{V,k}\cdot \bar{t}^{gp}\right) = \left(\bar{j}^p_{V,k}\cdot \bar{t}^{pg'}\right)$$

4. THERMODYNAMIC MODELS

The gas is an ideal mixing of perfect gases.
The solid thermodynamic potential for species i is given by:

$$\mu_i^{solid} = \mu_i^{chemical} + \frac{\bar{V_i}}{2}\sum_{\alpha=1}^{6}\sum_{\beta=1}^{6} T_\alpha S_\beta - 2\bar{V}\frac{\gamma_{SV}}{\rho}_i$$

with T_i the ith component of the stress thermo-elastic tensor.

The chemical part of the potential will be given by a four ionic sub-lattice ideal model, taking into account 15 structure elements of the solid. It is not given here.

Partial molar volumes are not given here. Their expression comes from the value of the lattice parameter variations with composition, obtained by X-ray diffraction at room temperature, and from the value of the thermal expansion coefficient expression.

5. CONCLUSION

A physical model of MOX sintering has been written. It takes into account the physical phenomena given by literature. It is a tool to understand which phenomenon plays a role at any time during sintering. It takes into account the microstructure and the chemistry of the material. It gives the evolution of U, Pu, O, Ar and H concentrations as well as the stress field in a pellet.

Hence macroscopic information such as density evolution during sintering can be computed, as well as U-Pu homogeneisation.

A discretisation stage has been done, it will be followed by programming using C++, as a DIFFPACK™ application, in order to create the SALAMMBO computation code. This code will then have to be validated by a set of experimental studies to be defined. Its mechanistic design should make it adaptable.

The model will be improved to take into consideration the appearance and disappearance of solid phases such as U_3O_8 or U_4O_9, as well as liquid phases when Cr_2O_3 is added.

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THE CURRENT STATE OF DEVELOMENT WORKS FOR MANUFACTURING AND METHODS OF CONTROLLING THE NUCLEAR FUEL FOR NPPs OF UKRAINE

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Abstract

The paper presents the results of NSC KIPT researches on manufacturing the fuel microspheres and pellets based on uranium dioxide. The data on fuel characteristics for different manufacturing stages are given. The problems of improving the fuel quality with changing the structure characteristics of pellets are considered. Demonstrated is the hardware for pellet controlling and presented are the new ways for developing the methods of controlling the nuclear fuel: X-ray fluorescent analysis; complex of nuclear-physical methods on the base of accelerators; laser-excitation energy-mass-spectrometer.

1. INTRODUCTION

Fuel elements are the most important and the most stressed structures of the core in a nuclear power reactor of current designs. The cost of electric energy production at NPPs is determined by achievement of improved characteristics of burning, duration of campaign and reliability of fuel element operation with minimum expenditures for nuclear fuel production.

Over a long period of time NSC KIPT develops the nuclear fuel materials for heavy-water, fast and high-temperature reactors. After the former USSR collapse Ukraine has adopted the Program of creating the own nuclear fuel cycle including production of nuclear fuel elements for the water-water reactor of WWER-1000 type.

It is commonly known that the operating characteristics of fuel elements depend on the following parameters of the pellet-like fuel provided by the production technology: density, moisture content,grain size, pore size and pore distribution in bulk, chemical composition, mechanical strength, radiation stability, geometric dimensions of fuel pellets. To determine these parameters one uses the commercial control devices.

2. MANUFACTURING OF PELLETS

Using the experience accumulated in production of fuel elements for heavy-water, fast and high-temperature reactors the researchers of NSC KIPT promoted the work on developing the fuel components for the WWER-1000 reactor. These research works are limited because of the financing deficit. However, over a short period of time we developed the techniques for manufacturing the fuel pellets from UO_2, components from zirconium alloy and fuel assemblies, developed the original methods to control the composition of materials utilized in the nuclear fuel cycle.

Besides the development of a basic process for manufacturing the fuel pellets from UO_2 we studied the processes of UO_2 pellet production from microspheres with a burnable absorber based on gadolinium using the pore-forming materials (polyethylene, black and uranous-uranic oxide), without a complexing agent from preliminary milled powder, with complexing methyl cellulose and polyethylene glycol.

Pellets from microspheres of uranium dioxide. At NSC KIPT for manufacturing microspheres of uranium dioxide one use the technique of microsphere formation from thermoplastic masses that allows to obtain microspheres with a wide range of sizes. In the present work we used one of a variety of above techique, i.e. the method of mechanical spheroidizing which

consists in the mechanical milling the measured billets from plasticized powder mass of high-melting actinide compounds. The existing technology of manufacturing the fuel microspheres for purposes of creation of microspheric fuel for HTGR includes the following basic operations (on the example of uranium dioxide): mixing the powder of high-melting actinide compound in required condition, with a complexing agent based on paraffine at 70-80 °C followed by cooling to room temperature for production of the plasticized mass; cutting the mass into measured billets of a cylindrical form (obtaining the granulate); spheroidizing the measured billets; controlling the "green" microspheres; heat treatment of microspheres by two steps (vacuum sublimation of plastificator at ~ 300 °C and final sintering of microspheres in vacuum or inert atmosphere at 1450-2000 °C). The quality control of produced fuel particles is performed by the form and size on special separators.

According to a set of requirements providing the necessary density values of "green" fuel pellets we chose as optimum: microspheres with a granulometric content of 200-630 μm, moulding pressure 4.0 t/cm².

We studied the conditions of high-temperature sintering of uranium dioxide pellets manufactured from microspheres in the temperature range from 1600 to 1800 °C (sintering time was 60 min) and in different steady operating atmospheres (hydrogen-argon, hydrogen-nitrogen and vacuum). In the case of pellet sintering in vacuum the pores took place along the grain boundaries and in the case of sintering in hydrogenous atmosphere the porosity was formed in the grain interior. The pore sizes at sintering in hydrogeneous atmosphere were less than in vacuum. We chose the sintering in hydrogen-nitrogen atmosphere at T=1800 °C and the process duration at this temperature was 60 min. The pellets were placed in bulk in molibdenum cylinders . The main characteristics of a pilot lot of pellets manufactured from microspheres are given in Table 1.

TABLE 1 SOME CHARACTERISTICS OF UO₂ PELLETS MOULDED FROM MICROSPHERES

Parameter	Parameter value	
	"Green" pellets	Sintered pellets
^{235}U content, %	2,4	2,4
Diameter, mm	8,9 ± 0,01	7,57
Height, mm	-	$10^{\pm1}$
Density, g/cm³	6,05±0,05	10,59±0,02
Oxygen coefficient	2,05±0,05	2,01
Mean grain size, μm	-	4-8

Pellets with burnable absorber. To suppress the initial excess reactivity we introduced in the bulk of the fuel or deposited on the lateral surface of pellets the burnable absorber. The burnable absorber Gd₂O₃ was introduced into the bulk of fuel pellets.

The manufacturing of pellets with burnable absorber consisted in the folllowing. The powders of uranium dioxide (crystallite sizes of 10-15 μm) and gadolinium oxide (crystalline sizes of 5-8 μm) sieved through the 005 sieve and taken in a required quantity were mixed by 100 g portions in cups of the planetary centrifugal mill. The prepared portions of mixtures were charged into the mill reservoir for blending. After the mixing operation we performed the control of gadolinium content and uniformity of its distribution in the bulk of mixture obtained. The prepared mixture was also controlled by the in-bulk mass without shaking.

The mixing of the prepared powder mixture of uranium and gadolinium oxides with the complexing agent (7.5 wt %) was performed in the universal Z-bladed mixer during 2 hours. The 10 % aqueous solution of polyvinyl alcohol + 1 % glycerine was used as a complexing agent. In the same mixer the mixture was dried at 80 °C during one hour.

Then the prepared mixture was conveyed for the compaction operation where it was first subjected to threefold pressing (compaction) on the hydraulic press at a specific pressure of 3 t/cm² in the steel press mould and to sieving through the 0.630 sieve.

Pressing of pellets with the burnable absorber was performed on the hydraulic press using the steel moulding-tool at a specific pressure of 2.5 t/cm². The height of pressed pellets was 11.5-14.5 mm and the density of 5.7-6.2 g/cm³.

Prepared semi-finished pellets satisfying the control values of parameters of density, geometric dimensions and appearance went to the sintering operation in hydrogen-nitrogen atmosphere.

Some characteristics of prepared semi-finished pellets with burnable absorber are given in Table 2.

TABLE 2 CONDITIONS OF MANUFACTURING AND CHARACTERICS OF UO₂ PELLETS WITH BURNABLE ABSORBER

Parameter	Parameter value
^{235}U content, %	2.4
Gd_2O_3 absorber content, wt %	8.0
Complexing agent content, wt %	7.5
Time of mixing the moulding-mix, min	120
Time of drying the moulding-mix, min	60
Compaction pressure, t/cm²	3.0
In-bulk weight, g/cm³	2.6±0.1
Granulometric composition, µm	50-630
Moulding pressure, t/cm²	2,5
Density of semi-finished pellets, g/cm³	5,9-6.1
Sintering temperature, °C	1700
Diameter of pellets, mm	7.57
Height of pellets, mm	10±1
Density of pellets, g/cm³	10.45
Oxygen coefficient	2.05
Main grain size, µm	8-20

2. METHODS OF ELEMENT CONTROL OF FUEL MATERIALS

For development and production of the fuel and other materials utilized in the nuclear fuel cycle the problems of product certification, improvement of product quality and necessary process monitoring are currently urgent. Without regard the methods of controlling such parameters as a level, density, material consumption, granulometric composition of powders, presence of cracks and pores etc., let us consider the analytic control of fuel production. The analysis of elementary and isotope composition of a fuel and materials in full volume is a rather complicated analytic problem. The problems of nondestructive analytic analysis are not worked in total though in the last few years the modern analytic methods are developed on the base of induction- bound plasma excitation, mass-spectrometry etc.

At NSC KIPT for the analytic control of production and certification of materials of nuclear fuel cycle the following set of methods is used: traditional chemical-spectral methods, mass-spectrometry, laser fluorescence spectroscopy, X-ray fluorescence spectroscopy, nuclear-physical methods.

None of mentioned analytic methods does not allow one to solve the problem in total But, good possibilities for this can be obtained with the use of the complex of nuclear-physical methods based on the interaction between ions accelerated to the ion energy of several millions of electron volts and a material with detecting the characteristic X-ray radiation (PIXE) and gamma-radiation (PIGE) The PIXE method is designed, mainly, for analysis of elements with an order number Z > 19, and PIGE for analysis of gas impurities and light elements These methods used together allows one to overlap almost all the range of necessary elements In NSC KIPT the works on development and application of nuclear-physical methods of analysis (NFMA) are carried out over 20 years During this period of time a number of instalations were designed and necessary techniques were developed

In modern world practice the installations with the use of NFMA are developed and produced in quantity Most of them permit to use simultaneously several methods, some installations are automatic measuring complexes However, all of them are not perfect and one of main disadvantages is a high heat load onto the target together with a low factor of accelerator utilization The fact is that because of low counting rate in spectrometric channels the most part of time for object irradiation is wasted The situation may be better by introducing a high-acting device into the measuring system that allows one to irradiate a number of objects simultaneously by bending periodically the beam at small angles

In NSC KIPT a versatile installation composed of four modules was devised and constructed (The block diagram of the installation is given in Fig 1) The first module consists of two analytic channels and is designed for analysis of the material composition by the PXX method, based on detection of the characteristic X-ray radiation which arises under irradiation of the object analyzed with the quasi-monochromatic X-ray radiation of the secondary emitter (SE) As the SE used is the water-cooled diaphragm forming the beam size and configuration, and the quasi-monochromatic X-ray radiation arises due to settling in the diaphragm a part of the beam of accelarated ions There is provided the use of a set of four changeable diaphragms manufactured of ultrapure metals Ti, Cu, Mo, Ta, that makes it possible to overlap almost all the range of energies of exciting X-ray radiation The availability of two analytic channels enables one to analyze two object simultaneously

The second module is a principal element of the installation since it realizes the idea that permits to increase the efficiency of ion beam utilization It comprises a system of electrostatic bending the ion beam which is controlled with pulses from the Si(Li) detector of X-ray radiation as well as two analytic channel for object analysis by the PIXE method The objects being analyzed are arranged at small angles relatively to the axis of ion beam , and the bending system provides a rational distribution of irradiation time between the targets of the second and third modules
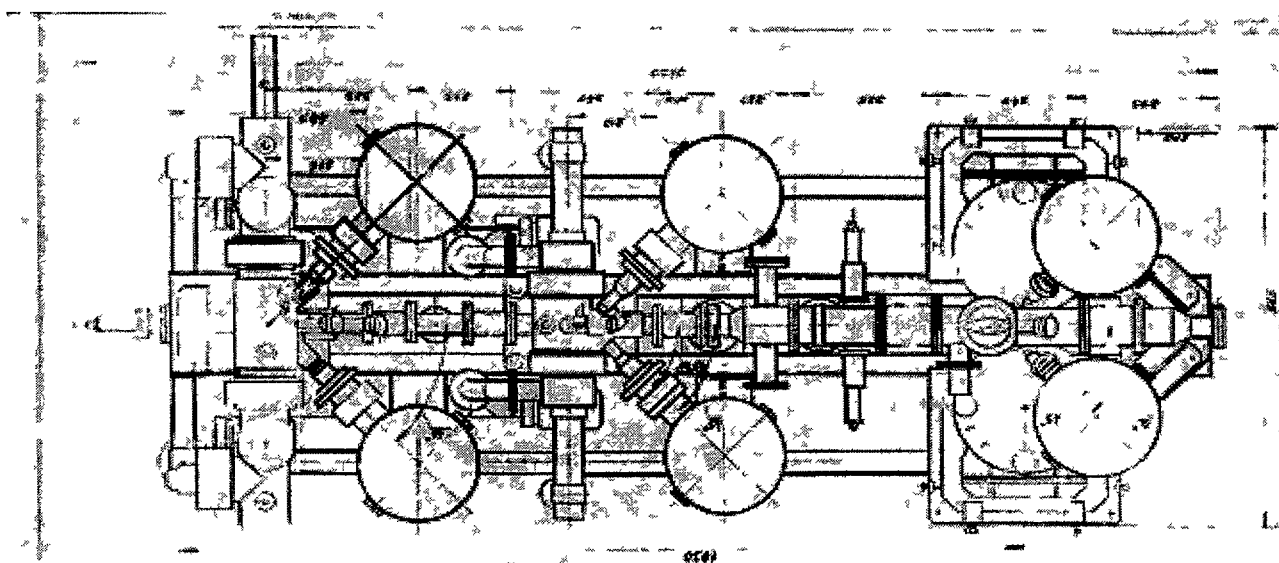

FIG 1 The block diagram of installation NFMA (NSC KIPT)

The third module contains a chamber with which the possibility to analyze the object simultaneously by PIXE and PIGE methods is realized. The chamber is provided with two locks for preliminary evacuation of cassettes enclosing the object analyzed. It makes it possible to perform the replacement of cassettes without vacuum degradation and nonproductive time waste.

The fourth module is designed for the ion beam ejection into the atmosphere that permits to analyze by the PIXE and PIGE methods the objects of large size not destined to destruction as well as the materials in liquid condition.

All the modules can be used separately as independent installations or together, as a unit. In the latter case the potentialities of application of the modules are widened due to improvement of analytic characteristics and decrease of production cost at the expense of the most effective use of the accelerated ion beam.

In the last few years the method of laser- excitation atomic - fluorescent analysis (LEAFA) is developed very intensively. The method is based on resonance excitation of atoms in the range 220- 1100 nm with detection of the resonant fluoroscence or radiation at the instant the atom transfers from the excited state into the intermediate state. The method having a high sensitivity can be successfully applied for the analysis of superlow contents of impurity (up to 10^{-8} %) in a wide range of elements.A standard installation for analysis by LEAFA method comprises: pulse laser system, device controlling the laser emission frequency, atomizer of samples under testing, detecting system, systems for data processing and control of the complex. In Fig. 2 shown is the installation "TILANA" (NSC KIPT) designed for determining , in an instrumental variant , the low contents of impurities in process solutions and materials.

The installation composed of a mass-spectrometer with laser excitation is very effective for analysis of low contents of impurities. The optics of the installation is based on the quadruple and allows one to carry out the analysis with an upper range of masses analyzed equal to 350, and the mean- square deviation of a random error component in measurements of isotope ratios ^{235}U / ^{238} U is 0.02 %.
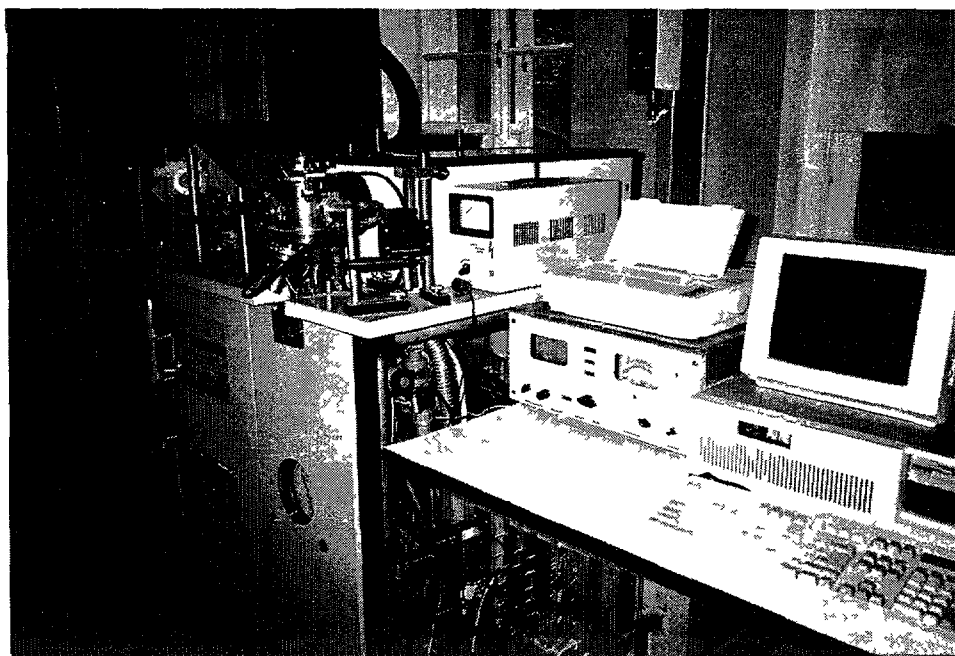

FIG. 2. The installation "TILANA" (NSC KIPT)

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Analysis of the macrocontent and some elements in the range of Z > 20 is performed with the use of the X-ray fluorescent method on the installation devised and constructed at NSC KIPT (Fig 3) In order to improve the signal - to - background ratio the X-ray optic system of the installation is arranged with polarization of the primary X-ray beam This installation makes it possible to determine the concentration by measurements of X-ray fluorescent intensity of L-series lines for elements of an atomic number Z > 48
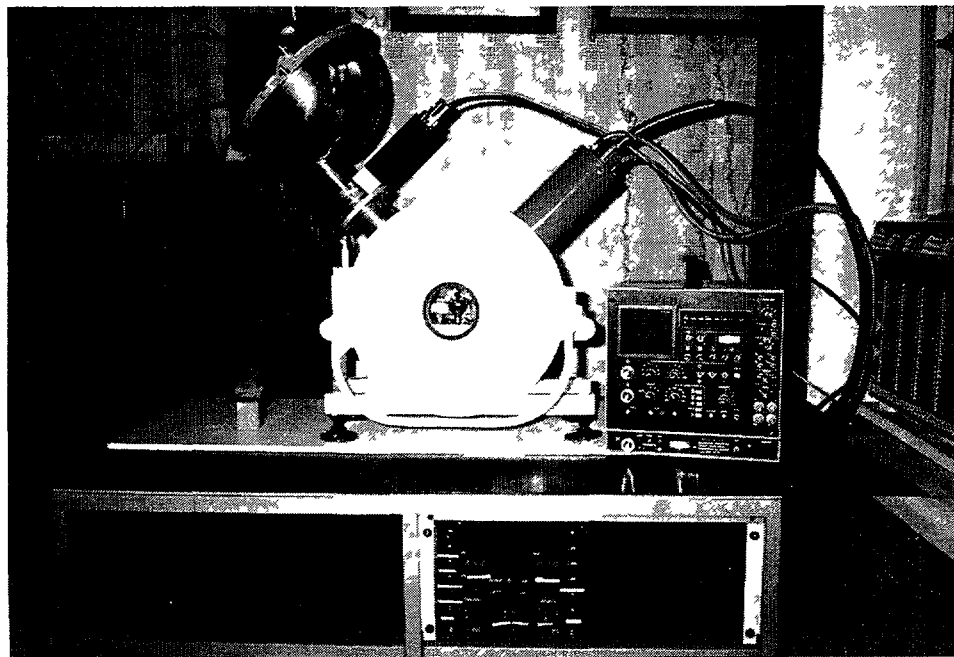

FIG 3 The installation of X-ray fluorescent method analysis (NSC KIPT)

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LEU FUEL ELEMENT PRODUCED BY THE
EGYPTIAN FUEL MANUFACTURING PILOT PLANT

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Abstract

The Egyptian Fuel Manufacturing Pilot Plant, FMPP, is a Material Testing Reactor type (MTR) fuel element facility, for producing the specified fuel elements required for the Egyptian Second Research Reactor, ETRR-2.
The plant uses uranium hexaflouride (UF$_6$, 19.75 % U^{235} by wt) as a raw material which is processed through a series of the manufacturing, inspection and test plan to produce the final specified fuel elements.
Radiological safety aspects during design, construction, operation, and all reasonably accepted steps should be taken to prevent or reduce the chance of accidents occurrence.

1. INTRODUCTION

In the 1950s and 1960s, low power research reactors were built around the world which utilized MTR-type fuel elements containing <20 wt % U^{235} enriched uranium (LEU). This value was chosen in accordance with IAEA recommendations.

As a result of the long delay to be committed to a definite and defined nuclear fuel cycle, the activities associated with nuclear fuel materials processing and characterization have been practiced in the form of discrete R & D studies.

R & D were oriented to nuclear materials rather than the fuel fabrication technology.
The Atomic Energy Authority has started a program for the integration of these activities into what could be considered as a " Nuclear Fuel Development Program".
The program aims to acquire the know how associated with fuel fabrication technology and hence the capability to support the National Nuclear Power Program.

As a result of the above-mentioned program, Egypt built the FMPP plant.
FMPP, is the first Egyptian nuclear fuel plant in a productive scale, producing an MTR-type fuel element for the Egyptian Second Research Reactor, ETRR-2.
The FMPP project started in 1995, different commissioning stages were applied, beginning with plant systems pre-operational tests in 1997, integrated performance tests, process qualifications, training with natural uranium, and finally a complete production with low enriched uranium (19.75 %) on December, 1998.

2. PLANT GENERAL DESCRIPTION

The FMPP is a MTR-type fuel element manufacturing plant, which due to its characteristics, may be associated on one side with a chemical processing (powder manufacturing), and on the other side with a light products metallurgical and mechanical processing (structural components, plates manufacturing, and final fuel assemblies).

Technological Requirements

MTR-type fuel element manufacturing involves managing and organizing a very different technological activity.
The FMPP plant has been conceived integrally regarding production, this means that it comprises all activities for obtaining MTR-type fuel elements from UF$_6$ and aluminium consumables.

All these activities require specific spaces with constructive characteristics defined by the type of the processes, which take place in them

The following tasks, necessary to conduct the process, administrative activities, and support, take place in the plant

- UF_6 reception and storage
- Non-nuclear materials reception and storage
- Conversion from UF_6 to U_3O_8
- U_3O_8 – Al powders compacting
- Fuel plates manufacturing
- Al structural components manufacturing
- Al components surface treatment
- Fuel element assembly
- Consumables, components, and final product quality control
- Intermediate nuclear materials and fuel element storage
- Administrative services
- Production support services
- Operation auxiliary services
- Radiological waste treatment
- Chemical waste treatment
- Security services

Production Capacity

The nominal production capacity of the plant is about 40 fuel element /year, with a total uranium content of 2054 g each
The estimated annual working time is 220 days, two - 8 hours - shift

Building General Description

The building is divided into four sectors, each with specific environmental characteristics and working conditions
SECTOR I   (Administration)
SECTOR II   (General services)
SECTOR III (Production activities)
SECTOR IV (Maintenance)

3 SAFETY FEATURES

Fundamental Requirements and Safety Philosophy

The basic safety concepts applied in facilities handling uranium powders are taken into consideration during the various stages of planning and implementation of the plant

Design, construction, and operation of the components and systems of the fuel plant are to secure that in natural operation the recommendations of the International Commission on Radiological Protection, and the basic safety standards for radiation protection of the IAEA are fulfilled with regard to radiation protection of personnel and environment

All reasonably accepted steps shall be taken to prevent or reduce the chance of accidents occurrence
It must be known that all safety regulations are implemented with regard to materials collection, transportation, and storage

All safety features of an efficient ventilation system are considered This ensures, for example, securing local Ventilation, efficient filtration and air monitoring, minimization of the amounts of respired dust, etc

The relevant safety regulations must be applied to all types of radioactive wastes in the solid and liquid forms

Staff Health Protection

Doses resulting from sources and practices involving exposure to ionizing radiation or a radioactive material shall be restricted by:

- a system of dose limitation which shall include justification of the practice, optimization of radiation protection, and individual dose limitation,

- responsibilities and administrative requirements, which define responsibilities of plant management, health experts and workers,

- Two working conditions, namely, work condition A and work condition B, as defined by IAEA standards shall be recognized. Working Condition A applies to areas where annual exposure might exceed three tenths of the dose equivalent, while working condition B applies to areas where it is unlikely to exceed this limit.

- planned special exposure such as working with enriched uranium is considered a working condition A, and the appropriate regulation in such case,

- a physical surveillance system to determine the nature of precautions which must be taken to ensure compliance with the system of dose limitation,

- an appropriate system of inspection and intervention.

Procedures currently used for the fabrication of uranium fuel to ensure the accountability of uranium in accordance with commercial and IAEA standards shall be implemented.

4. SPECIFICATIONS

Al-powder

The starting material for manufacturing the powder shall contain at least 99.5 % in mass of pure aluminium. The maximum impurities content are as follows:

B	<10	ppm
Cd	<30	ppm
Co	<60	ppm
Li	<40	ppm
Al_2O_3	<1.7 wt %	

The aluminium powder particles shape must be spherical with smooth surface, in a size less than 150 μm, the particles with a size <53 μm must not exceed 80 wt %.
The aluminium powder density is 2.7 g/cm^3.

Al-6061 alloy

Al-6061 alloy is a magnesium base alloy used in the structural components manufacturing for the fuel element produced, in different geometrical shapes, as sheet, plate, rod, and rectangular bar, with the standard composition stated in U.N.S. A96061 as per ANSI H 35.1 M, and in compliance with ASTM B 209 M-95.

The plates and sheets used for covers and frames manufacturing shall be with an annealing thermal treatment (state T0). While the others shall be with a solubilizing and artificial aging thermal treatment (state T6 or T51).

The nuclear impurities must not exceed the same limits as mentioned before for the aluminium powder.

The advantage of the Al-based magnesium alloy 6061 is their increased corrosion resistance.

U_3O_8 Enriched Powder

The uranium oxide powder as U_3O_8 must fulfil the requirements of the fuel element produced for our reactor.

The uranium content shall be at least, 84.5 wt %.

The isotopic content as U^{235} in the powder must be 19.75 +/- 0.20 wt % of the total uranium.
The impurity contents shall not exceed those specified in the following table (in $\mu g/g$ U):

ELEMENT	SYMBOL	CONTENT
Aluminium	Al	500
Barium	Ba	10
Boron	B	2
Cadmium	Cd	0.5
Calcium	Ca	250
Cobalt	Co	3
Copper	Cu	20
Fluoride	F	20
Phosphors	P	100
Lithium	Li	5
Manganese	Mn	5
Magnesium	Mg	100
Potassium	K	20
Silicon	Si	250
Sodium	Na	250
Vanadium	V	5
Chromium + Nickel + Iron	Cr+Ni+Fe	150

The powder particle size shall be less than 90 μm, the particles smaller than 45 μm shall not exceed 50 wt %.
The powder density shall be equal to 8.0 g/cm^3 or more.
The oxygen / uranium ratio must be in the range of 2.62 – 2.72.

U_3O_8-Al Compact

The fuel compact has the following dimensions and weight:
- Width,   60.5 + 0 / - 0.3 mm
- Length   69.0 + 0 / - 0.3 mm
- Thickness 8.5 + 0 / - 0.2 mm
- Weight   171.6 + / - 1.5 g

The compact density is about 4.8 g/cm^3, equivalent to 3.1 g U_t / cm^3.
The content of the isotope U^{235} must be 21.3 + / - 0.2 g for the standard fuel element produced.
The compact surface must be free of any defects such as, large pores, cavities, fissures, scaling, cracks, and / or any other type of material discontinuity.

Fuel Plate

Two types of fuel plates are produced in the plant. The only difference between the two types is the overall length, which is 1010 mm in the case of external plate instead of only 840 mm in the case of internal one.

The fuel plate has the following specifications:
Fuel meat thickness   0.7   mm
Fuel meat width   64.5   mm
Fuel meat length   800   mm
Fuel plate thickness   1.5   mm
Cladding thickness   0.4   mm
U^{235} isotope content   21.3   g
The surface contamination with uranium in the finished fuel plate must have an activity less than 2 * 10^{-4} Bq / cm^2.
The finished fuel plate must be free of any internal defects.

Fuel Element

Standard fuel element of the ETRR-2 is a MTR-type of a square section 80 * 80 mm.
Each one has 19 fuel plates, 17 inner plates and 2 outer ones .
The gab spacing between each two-fuel plate is 2.7 mm (coolant channel).
The end box has a centered cylindrical hole to allow the coolant flow. In its lower part, it has four chamfered parts in each corner to allow the insertion and griping of the clamp that fix the fuel element in the reactor core grid.
Total mass of U^{235} in the standard fuel element produced is 404.7 g.

5. MANUFACTURING PLAN

Wet Process

Uranium hexaflouride (UF_6, 19.75 wt % U^{235}), is a solid material at room temperature, heated above its triple point to increase its vapor pressure.
Uf_6 is then added to a desired amount of demineralized water produced in the plant in a special closed agitated vessel (Hydrolizer).
A solution of uranyl fluoride and hydrofluoric acid produced.
Uranyl fluoride solution is then precipitated by ammonia solution, 25-wt %.
Washing and filtration steps are also applied by adding ethanol, and 1 wt % ammonia solution, to produce a clean and dry Ammonium Diurinate (ADU).

Dry Process

The ADU obtained from the last stage is calcinated in 800°c furnace to produce U_3O_8 powder, after that, milling and sieving treatment occurs.
A second grain growth furnace at 1400°c is applied to get the dense powder at a required particle size after another milling and sieving processes.

Mixing and compacting

U_3O_8 and Al-metal powders are mixed together in a rotating device at 16 rpm for 3.5 hrs, the mixing ratio is, 48 volume % of U_3O_8, and 52-volume % of Al-metal powder.
The mixture is then compacted by applying a 4.5 Ton / cm^2 pressure to produce the fuel compact with the mentioned specifications.

Framing and welding

The fuel compact is then put in the 6061-aluminium alloy frame; two covers of the same material cover the frame with the compact inside.
Welding of the above mentioned set, which is called (sandwich), takes place by means of TIG method from the four sides, except a small distance from the two sides in the rolling direction, to allow the release of gases in the rolling stage.

Plate Manufacturing

The set of 10 sandwiches are put in a furnace at 500°c, passing through a 9 hot rolling steps, in order to reduce the thickness from the initial of 18.1 mm to 1.65 mm.
Blister test takes place in the same furnace at 490 °c for one hour, the furnace temperature will decay after that, while the plates are still inside.
One pass of cold rolling is then applied to reach the required thickness of 1.5 mm.
Before cutting the plate to the required dimensions, X-ray has to be applied to help in the proper marking on the plate surface. Another one has to be applied to assure the correctness of the cutting process. Straightening process is also applied to improve the flatness of the plate. Then the last X-ray takes place for quality purposes (homogeneity).

Surface Treatment

The produced fuel plates, as well as, the structural Al-6061 components are passed through different steps in order to remove the lubricants, oils, greases, or any other materials, and the oxide film which may attack the aluminium on the surface, as follows:

1- cleaning with TCDE (tricloro diethylene)
2- pickling in an alkaline hot NAOH solution
3- washing with normal water
4- neutralization by cold HNO_3
5- washing with normal water
6- final washing with hot demineralized water
7- repeating, if necessary, from step 3, one or two times
8- drying in air stove

Fuel Element Assembly

The type and quantity of the components required to produce one fuel element are as follows:

External fuel plates	2
Internal fuel plates	17
Side plates	2
End box 80 * 80 mm	1
Screw M6 * 9	6
Handling pin	1

The 19 plates are mechanically fixed to the 2 side plates by a roll of swaging technique .The two side plates and the outer fuel plates are fixed to an end box by means of screws. Handling pin with the fuel element identification connects the two side plates by means of TIG welding.

6. INSPECTION AND TEST PLAN

6.1 Fuel compact

U^{235} isotope content

The content of the isotope in each fuel compact is determined by weighing the compact, and then multiplying the obtained weight by three factors; the fuel compact U_3O_8 content, the total uranium content in the U_3O_8, and the total uranium content of the isotope.
The last two values are obtained from the release certificate of the powder. The fuel compact weight must be with a minimum accuracy of + / - 0.05 g.

Dimensional and geometrical control

The fuel compact dimensions and geometry must be controlled to assure the required values mentioned before.

Visual control

The fuel compact visual control must be done carefully, to verify the absence of any surface defects or hair cracks.

6.2 Fuel plate

Blister test

The most effective quality check on bonding is the blister test. The blister test must be performed before the cold rolling, to verify the metallurgical bond between the fuel compact and its cover.
The heating temperature is 490°c during one hour, followed by slow cooling inside the furnace, then visual inspection occurs.

Radiographic inspection

Radiographic inspection must be applied in order to:
- determine the fuel core position
- verify that the core dimensions and geometry are in compliance with the required specifications
- check the presence of any internal defects, or homogeneity problems inside the fuel core
- check the presence of any nuclear materials outside the core (white spots)

Dimensional and geometrical control

The fuel plate dimensions and geometry must be controlled to assure the required values mentioned before.

Visual control

The fuel plate visual control must be done carefully to verify the absence of any surface defects or scratches.
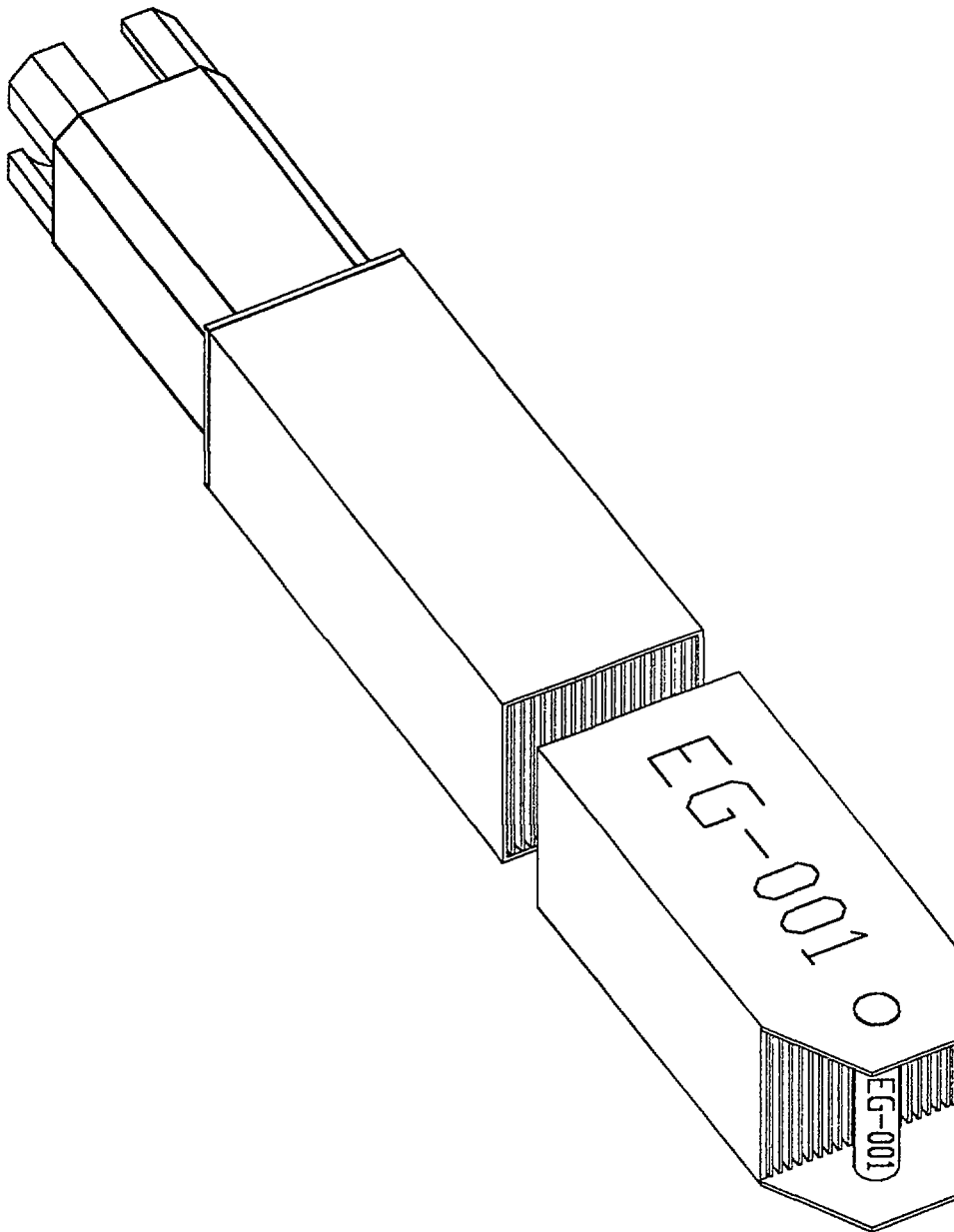
Surface contamination

A sweep test must be performed to measure the fuel plate surface contamination with uranium.
If the fuel plate surface is contaminated, the surface must be cleaned and inspected again to verify that the contamination is removed.

Destructive testing

Fuel plate sample must be taken either from the rejected plates or one plate from each 100 accepted ones. The samples must be extracted from the edges of the plate, as well as any place including any defects needs to be studied.
The main benefit is to measure the thickness of the cladding, as well as, the fuel core.

6.3 Fuel element

Coolant channel gap spacing

The gab spacing between each two-fuel plates has to be measured, to assure the design value at 2.7-mm (coolant channel).

Dimensional and geometrical control

The fuel element parallelism, flatness, and concentricity must be controlled, using CMM, three – axes - machine, to assure the required design values.

Visual control

The fuel element visual control must be done carefully, to verify the absence of any surface defects.

Surface contamination

A sweep test must be performed to measure the fuel element surface contamination with uranium.
If the fuel element surface is contaminated, the surface must be cleaned and inspected again to verify that the contamination is removed.

7. CONCLUSION

FMPP is a new MTR-type fuel element facility. It produces the required fuel assemblies for the Egyptian Second Research Reactor, ETRR-2.
The plant is considered as a success of the R & D program in the field of nuclear fuel fabrication in Egypt.
The plant has a capacity to produce fuel assemblies for any other customers, with the same type, and enrichment percent or lower, as well as, the conventional tasks in the industry, mainly due to the advanced computerized machines and quality control laboratories.

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    IAEA, Vienna, 1988.

IMPLEMENTATION OF ADVANCED METHODS IN PROCESS AND QUALITY CONTROL

(Session III)

PROCESS AND QUALITY CONTROL IN MANUFACTURING OF NUCLEAR FUEL ASSEMBLIES OF LWRs

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Abstract:

Manufacturing of nuclear fuel assemblies requires a multitude of different process and quality methods to assure and maintain a high quality level. In recent years methods have been applied which prevent deviations rather than detect deviant products. This paper gives an example on how to control a complex manufacturing process by using a small number of key parameters and second, it demonstrates the importance of graphical data evaluation and presentation methods.

In the past many product and product characteristics were inspected in comparison with specification limits only. However, todays methods allow the early identification of trends, increase of variation, shifts disturbances etc. before the product characteristics exceed the specification limits. These methods are process control charts, x-y-plots, boxplots, failure mode and effect analysis (FMEA), process capability numbers and others.

This paper demonstrates the beneficial use of some of the methods by presenting selected examples applied at Advanced Nuclear Fuels GmbH (ANF).

1. INTRODUCTION

Advanced Nuclear Fuels GmbH (ANF) is part of the global nuclear fuel business of Siemens. With three facilities, located in Lingen, Duisburg and Karlstein fuel assemblies for the European market are manufactured. While cladding is produced in Duisburg and structural components such as spacer grids and tie plates are manufactured in Karlstein, the Lingen facility performs the fuel production and the final assembling.
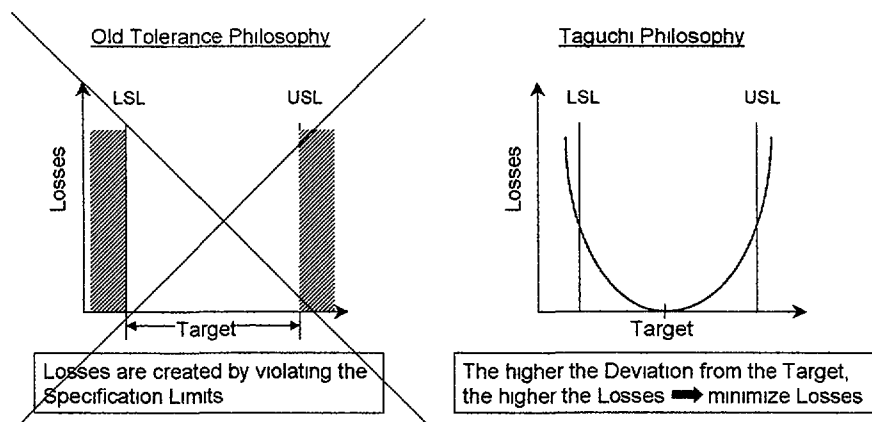

Figure 1: Tolerance Philosophie

2. PHILOSOPHY IN FUEL MANUFACTURE

In the past a process was treated to be stable, when all inspected parts are within the specification limits. That means, that costs for rework or for rejected products appear only when the specification limits are violated. This point of view is not helpful for process improvement

To find ways for improving the manufacturing process we have to understand, that each deviation from the process target creates losses.
The goal "minimizing of losses" can only be reached, if we are able to control the manufacturing processes in a way that the process target is met.
The use of tools for statistical process control helps us to prevent losses:

- Avoid serial product failures
- Indication of trends, shifts and disturbances
- Find relationships between process parameters and product characteristics

These tools help us to reduce our production costs: If there are no losses, there are no failure costs. The tools also help to improve our manufacturing capacity planning and are the basis for an improvement in customer satisfaction.

3. PELLET FABRICATION AT ANF GmbH

The manufacturing of pellets at ANF Lingen is one of the key processes in fuel manufacturing.

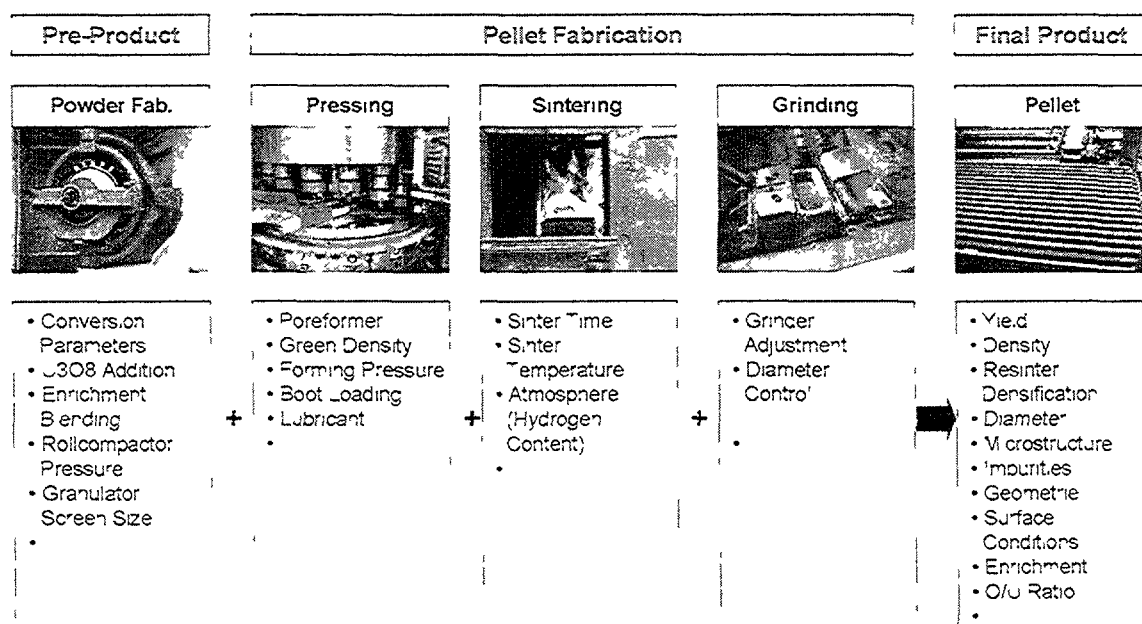| Pre-Product	Pellet Fabrication			Final Product
Powder Fab.	Pressing	Sintering	Grinding	Pellet
• Conversion Parameters • U3O8 Addition • Enrichment Bending • Rollcompactor Pressure • Granulator Screen Size •	• Poreformer • Green Density • Forming Pressure • Boot Loading • Lubricant •	• Sinter Time • Sinter Temperature • Atmosphere (Hydrogen Content) •	• Grinder Adjustment • Diameter Control •	• Yield • Density • Resinter Densification • Diameter • Microstructure • Impurities • Geometrie • Surface Conditions • Enrichment • O/u Ratio •

Figure 2: Process parameters and product characteristics at pellet fabrication

An important prerequisite for stabilizing the process is to find quantitative relationships between product characteristics and process parameters.

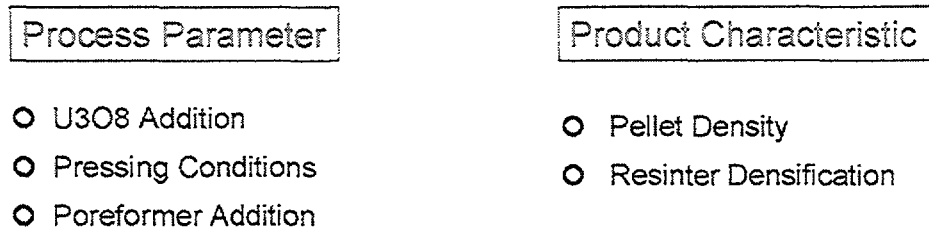| Process Parameter	Product Characteristic
O U3O8 Addition	O Pellet Density
O Pressing Conditions	O Resinter Densification
O Poreformer Addition	

Figure 3: Relationship between process parameters and product characteristics

Different tools such as
- Parameter studies
- Ishikawa diagrams
- Design of experiments
- Process qualification and the definition of qualified parameters (incl. qualified ranges)
- Relationship modelling (e.g. with x-y-plots)

can be used to find such relationships .

For pellet manufacturing the density is one of the most important product characteristics. In order to find relevant process parameters influencing the pellet density we used an Ishikawa diagram.
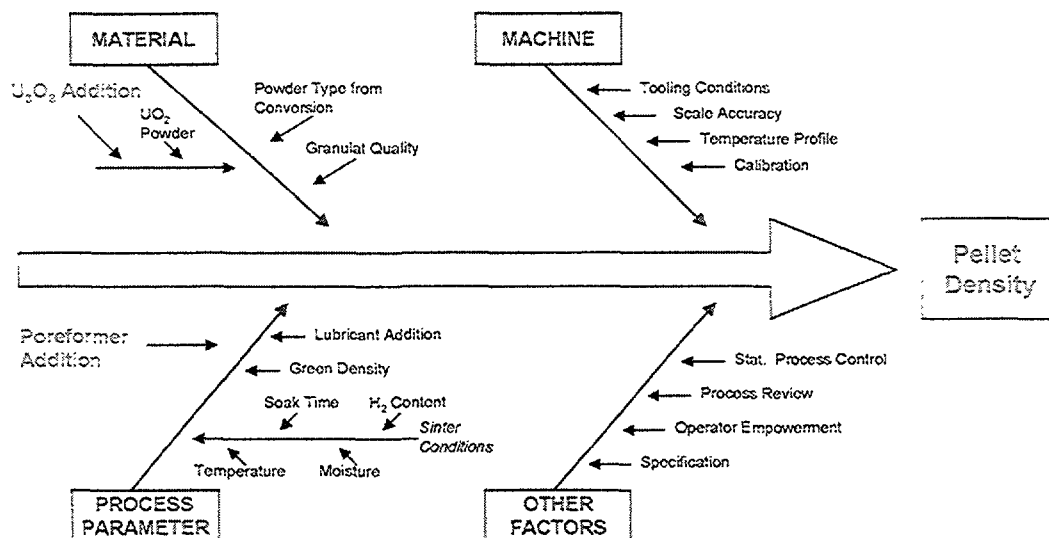
Figure 4: Ishikawa diagram for pellet density

After the definition of relevant process parameters the quantitative relationship with regard to the pellet density .was evaluated.

During the process qualification several parameter studies were performed, for example with variations of U3O8 and poreformer addition to quantify their influence on the density.
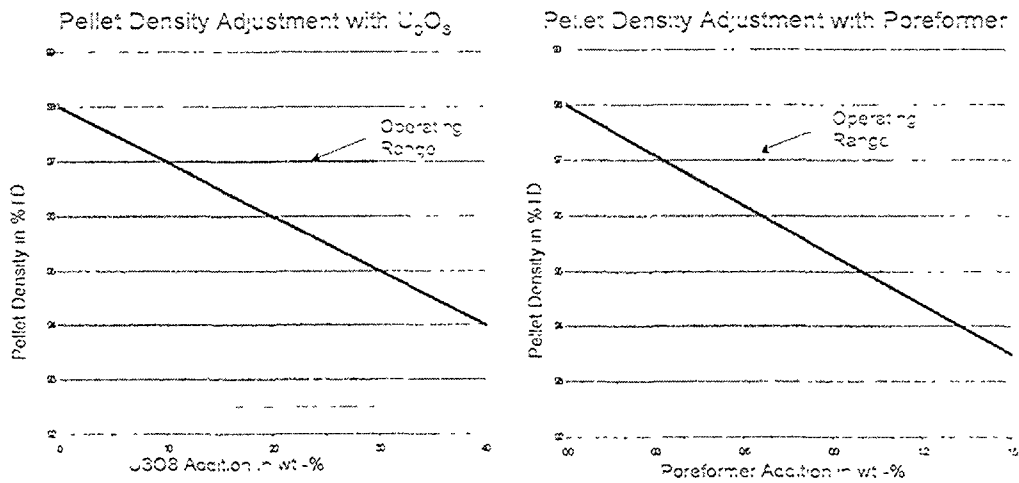
Figure 5: Parameter study for pellet density

Several requirements must be fulfilled to perform such parameter studies and to make a continuos process review possible.

- Process and inspection equipment must be designed for quantitative process and quality control. This can be integrated software modules in manufacturing for process data recording.
- Manual or automated control loops must be defined for product characteristics near to the process. Using only a final inspection does not help to prevent serial failures.
- Products and processes must be robust. If the process dispersion is to large in relation to the tolerance, there is no room left for process control.
- Operators need to be motivated and qualified. They should have the understanding how process control works and what the tools are to record process parameters(f.e. control charts)

At the pellet presses a system was installed to record process parameters and product characteristics.

Figure 6: Process control at pellet pressing

With this system all relevant process parameters and product characteristics are recorded and stored in a central database. These data are used for process review and for process control in a small control loop using control charts.
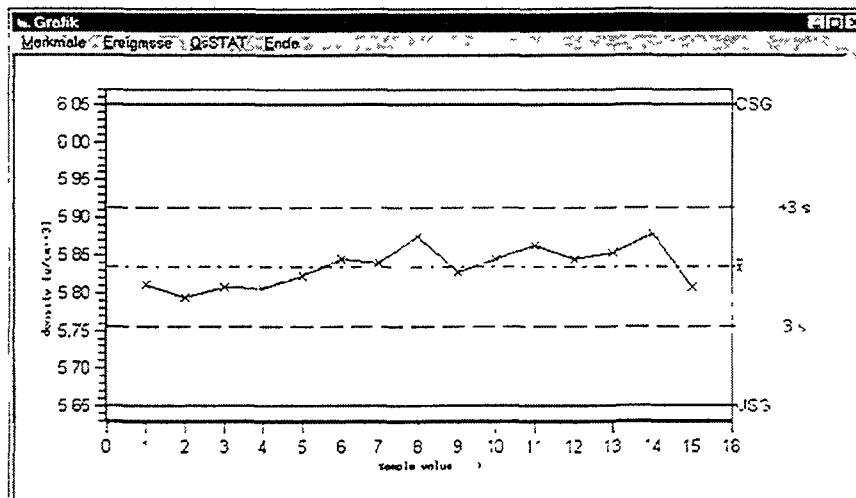
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Figure 7: Control chart at pellet pressing

In addition various tools for process analysis and process review have been implemented. Some of them are:

- Statistical analysis of the results for process optimization
- Failure mode and effect analysis
- Continuous process review including vizualisation of important process parameters and product characteristics
- Modern vizualisation methods, like Pareto diagrams, box plots, x – y –plots, process capability analysis etc.
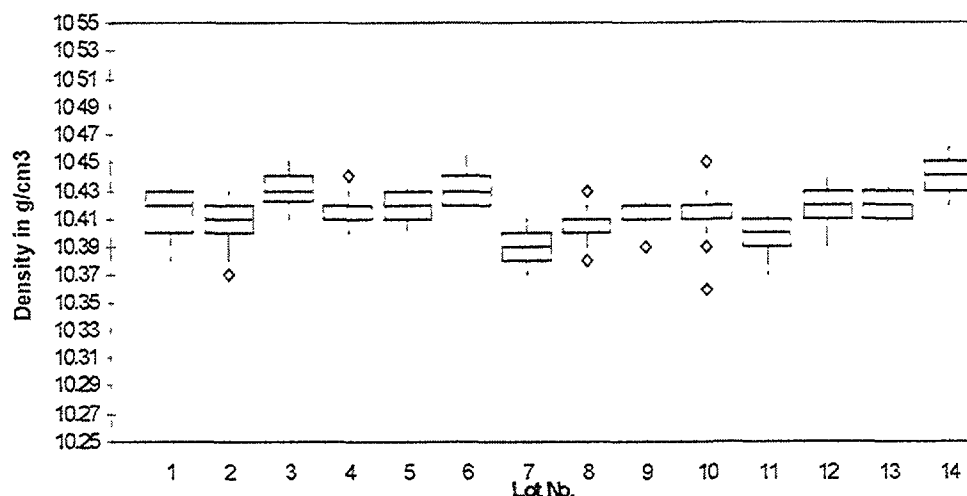

Figure 8: Process review using box - plots

4. FUEL ROD END CAP WELDING

Modern methods of statistical process control have also been applied in fuel rod end cap welding For this purpose, effective data recording systems have been installed in the welding machine.

All relevant process parameter, like welding current, force, and geometrical positions are recorded online. Additionally the geometry of the weld seam is measured. All these data are visualised to the operator and stored in a central database for process reviews.
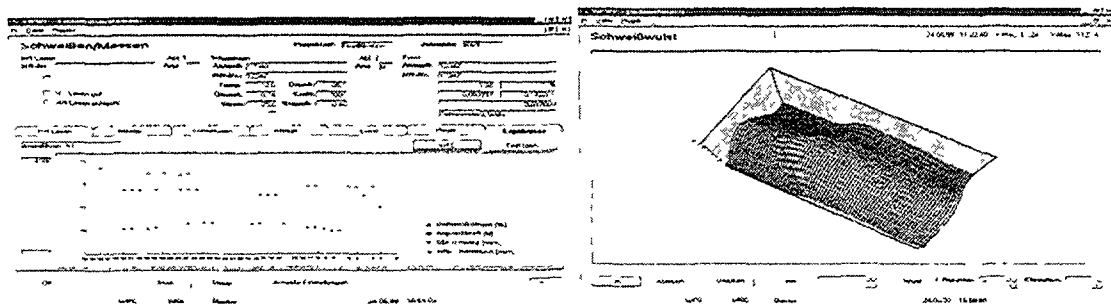
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Figure 9: Process data recording for End cap welding

The recorded process and product data are used to find a calculation model for the upset width. This model allows to forecast the process results depending on the process parameters. The knowledge what the process sensitivities are relative to the relevant process parameters helps optimizing the process. It also helps to define process tolerances based on the influence of each process parameter

5. OUTLOOK

ANF will use modern methods of process and product design for all new manufacturing equipment. In addition to the examples above, ANF is introducing statistical process control for all main parts of the fuel assembly.

- "Weld Watcher" for Laser beam welding of water channels
- Process control for Laser beam welding of spacers
- In – line diameter measurement for cladding tubes
- Automated control of the dry conversion process
- Automated diameter control for pellet grinding
- "Soft loading" of fuel pellets into cladding tubes
- Automated welding of skeleton
- Automated fuel rod assembling
- Diameter control in end cap fabrication

We strongly believe that our customers as well as ANF will benefit from the implementation of statistical process control by increasing product quality and reduction of failure costs.

QC METHODS AND MEANS DURING PELLETS AND FUEL RODS MANUFACTURING AT JSC "MSZ"

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Abstract

The report contains the description of the main methods and devices used in fabrication of pellets and fuel rods to prove their conformity to the requirements of technical specifications.

The basic principals, range and accuracy of methods and devices are considered in detail, as well as system of metrological support of measurements. The latter includes the metrological certification and periodical verification of the devices, metrological qualification of measurement procedures, standard samples provision and checking the correctness of the analyses performance.

If one makes an overall review of testing methods used in different fuel production plants he will find that most part of methods and devices are very similar. There are still some variations in methods which could be a subject for interesting discussions among specialists.

This report contains a brief review of testing methods and devices used at our plant. More detailed description is given to methods which differ from those commonly used.

1.   QC METHODS AND MEANS FOR PELLET CONTROL

Technical specification for UO_2 pellets is given in Table 1.

1.1   Isotopic content

The main characteristic of the fuel is isotopic uranium content. This analysis is performed at our enterprise on both powders and pellets. The well-known mass-spectrometric method is used. We operate mass-spectrometers ÌÈ-1201AT, made in Ukraine and MAT 262 of "Finigann" company. Simultaneously content of U^{235}, U^{236} and U^{234} isotopes are determined.

The measuring range for U^{235} is 0,01... 21%, relative error – 0,002. The control range for U^{236} – 0,004 ... 0,3% at the relative error 0,24 in the range less then 0,2 %. For U^{234}: range – 0,01 ... 1,0% at the relative error 0,08 in region less then 0,3%.

1.2.   Total uranium content and O/U ratio

The most convenient method is thermogravimetric analysis. The sample is weighed before and after the conversion of UO_2 pellets to U_3O_8. Difference of masses allows to calculate the total uranium content and O/U-ratio. Of course one must take into account the influence of deferent impurities which can be measured by spectral analysis. In some cases we measure uranium content by gravimetric determination at peroxide sedimentation or by potentiometric titration according to Devis-Gray method.

Alternative method for O/U-ratio is polarographic method.

TABLE I. UO₂ PELLET CHARACTERISTICS

Parameter:	Value:
Outside diameter, mm	7.54...7.57
Inside diameter, mm	$1.4^{+0.3}$
Pellet height, mm	9...11
Chamber along the end face, mm	$(0.1...0.4)*(15^0 \pm 3^0)$ or $(0.1...0.4))*(25^0 \pm 5^0)$
Roughness, Ra, µm, not more	1.8
Pellet appearance	According to the Atlas of the allowed deviations of fuel pellet appearance
Density, g/cm³	10.4...10.7
U235, % to U	2.4 ± 0.05 3.3 ± 0.05 3.6 ± 0.05 4.0 ± 0.05
U236 % to U, not more	0.1
Uranium isotopes mixture, %, not less	88.0
O/U Ratio	2.000....2.005
H Hydrogen, ppm, not more	0.6
B Boron, pm to U, not more	0.4
N Nitrogen, ---- // ----	130
Fe Iron, ---- // ----	400
Si Silicon, ---- // ----	150
Mn Manganese, ---- // ----	20
Cu Copper, ---- // ----	40
Ni Nickel, ---- // ----	100
C Carbon, ---- // ----	100
F Fluorine, ---- // ----	17
C Chromium, ---- // ----	100
Cl Chlorine, ---- // ----	15
Al Aluminium, ---- // ----	230
Mg Magnesium, ---- // ----	50
Mo Molybdenum, ---- // ----	110
Cd Cadmium, ---- // ----	0.6
P Phosphorus, ---- // ----	220
V Vanadium, ---- // ----	110
W Tungsen ---- // ----	110
Ca Calcium ---- // ----	150
Er Erbium ---- // ----	10
Average conditional grain size, µm	8...20
Open porosity, %, not more	1
Resintering, %, not more	(-1)...0.4

1.3. Impurity determination

1.3.1 B, Fe, Si, Mn, Er

The content of the impurities –B, Fe, Si, Mn..., etc. is checked by means of optical spectrometry.

Most part of analysis we perform by impurity fractional distillation method, which allows to separate in time impurities and uranium excitation in the arc. This method is described in ASTM standards. The only difference is that we use indium oxide instead of stroncium fluoride and silver chloride to decrease the temperature of arc. The determination limit of the main part of impurities for this method is ≈10 ppm that is fairly enough for the limit content of impurities under typical specification.

We reach deeper determination of the impurities up to 1 ppm on atomic-absorption devices and multi-channel spectrometer with the emission source – inductively coupled plasma. To reach the limit values of the impurities determination the uranium is separated from the sample after it is dissolved in nitric acid by means of extraction by 30% solution of tri-butyl-phosphate in dodecane.

Particularly, namely with the separation of uranium we determine Er on the ICP-spectrometer. The inspection of Er is introduced due to the fact that our enterprise fabricates nuclear fuel with the addition of Er_2O_3 for RBMK reactors. So we have to guarantee that there is no Er in the fuel designed for the VVER. The determination range for Er is 0,3 –10 ppm, the relative error – 0,19.

1.3.2. W

Unfortunately, tungsten (W) is a hard melting material and is badly exited in the arc of the spectral devices. So, to determine the impurity of W chemical method is used. The requirements – W content <110 ppm. Within the range 7 – 130 ppm the relative error of the method is – 0,32.

1.3.3. F and Cl

To determine the content of F and Cl the uranium dioxide powder is positioned into the special reactor and heated up to 1100°C. F and Cl are separated in the form of HCl and HF acids as a result of the pyrohydrolysis. Further the resulting solution is passed through the separation columns of the ion chromatograph. The concentration of F and Cl is detected at the same time at the output of the ion chromatograph.

The operation range of the method – from 5 to 50 ppm, relative error – 30%.

1.3.4. C

Analysis of the carbon content is performed by Coulonometric method. The uranium dioxide powder is burnt at 1100°C in a flow of oxygen. The carbon is separated in the form of CO_2 and absorbed in the solution of the electrolyte. The amount of the electric charge that shall pass through the electrolyte for the pH is recovered is proportional to the carbon content in the sample. The range is 10 – 5000 ppm, relative error in the range of 10 ... 50 ppm – 0,35.

Lately we perform this analysis using the "Leco" analyzer CS-444. In this device another method of the registration of the CO_2 is used – infra-red absorption. The control range 10 – 2000 ppm with the relative error in the range 10 ... 50 ppm – 0,35.

1.3.5. N

Usually the determination of the nitrogen content is performed by the Kjeldahl method. Method range – 20 ... 1000 ppm, relative error – 40% in the range less then 50 ppm.

1.3.6. H₂

Two hydrogen control methods are used in our practice.

The main method – high temperature extraction at T=1800°C. This method is performed on the "Leco" hydrogen analyzer RH – 402. A pellet is positioned into the

furnace and heated in the flow of inert gas. Nitrogen and carbon which extracted from the sample together with hydrogen are removed by special absorbers. Hydrogen is registered at the output by the thermal conductivity detector. Hydrogen which was in pellet in from of moisture is reduced to hydrogen on graphite and is also registered during this analysis. Range of the method 0,2 – 1,5 ppm, relative error – 0,33.

The alternative method is the Coulonometric method. Both methods give close results.

1.4. Density determination

The main control method is γ-absorption. A beam of radiation from a stable γ-source Cs 137 passes through the pellet. The density of the pellet is estimated by the change of the γ-radiation intensity.

The constant raying of the pellet volume (compensation along the chord) is provided for by fact that the distance between two parallel supports on which the pellet is positioned when measured remains stable as well as by the action of the collimating systems of the radiation source and sensor that form a narrow beam of γ-radiation.

Technical parameters are:

- Measurement range – 10,2 $\div$ 10,9 g/cm^3;
- Measurement error – 0,07 g/cm^3;
- Productivity – not less than 150 pellets/hour.

Hydrostatic (or Archimed) method is used for the arbitration pellet density control. First the pellets are weighed in the air – and the value D is determined. Then the pores in the pellet are filled with water, either by boiling during not less than 2 hours or by evacuation of the pellets and pores filling with water under pressure. Further the pellet saturated with water is weighed in the water – S. After this drops from the pellet surface are removed by tamping and the pellet saturated with water is weighed in the air – M. Only after this the pellet density is calculated.

The open porosity of the pellet is calculated as the ratio of the volume of the surface pores to the pellet volume.

Range for density – 10,2 $\div$10,8 g/cm^3.
Error – 0,03 g/cm^3.
Open porosity range 0 – 4%.
Within the range 0 $\div$1% the error is 0,3%.

1.5 Resintering test

The re-sintering test is carried out to determine the thermal stability of the fuel pellets. The sintered pellets are placed to the furnace and held down in the oxidizing medium (Ar + 7% H$_2$) during 24 hours at the temperature of 1700 ± 50°C.

The thermal stability of the fuel pellets is calculated by the change of the average pellet diameter before and after testing – $\dfrac{D_0 - D_1}{D_0} \cdot 100\%$ or by the change of pellets

density – $\dfrac{\rho_0 - \rho_1}{\rho_0} \cdot 100\%$. Methodical error – 0,1%.

1.6. Pellet microstructure

The analysis of the pellet microstructure is carried out to estimate the quality of sintering of pellets. At magnification 100x pores are controlled. The pore diameter is understood as the diameter of the circle equivalent in the area to this particular pore and the maximum pore size is the size of the maximum projection.

Further the cross-section is etched to find the grains. At magnification 400x, by Cutting Lines Method the conventional average grain size is determined which shall be within 8-20 μm.

We perform this analysis on automatic unit where the image of the cross-section is input to PC and the calculation of the microstructure parameters is performed by the program.

1.7 Pellet geometry control

The control of the pellet diameter and height is carried out on a certain sampling by means of a common micrometer.

During the pellet grinding continuous measurements of the diameter is performed by remote laser device "Laser-Mike" that has the error not more 2μm. By the results of the estimation of the average diameter of a sequential group of pellets a feedback signal is transmitted to the grinding machine control.

2. QC METHODS AND MEANS FOR FUEL ROD CONTROL

Technical specification for UO2 fuel rods is given in Table 2.

TABLE II. FUEL ROD CHARACTERISTICS

Parameter:	Value:
Outside diameter - with the exception of the weld zones, mm	$9.10^{+0.10}_{-0.05}$
Total amount of the values of gaps in the fuel column – without accounting for individual gaps less than 1 mm each, not more	6
Outside diameter in the KCC-2 zone, mm	$9.10^{+0.10}_{-0.15}$
KCC-2 weld length (continuity area value), mm, not less	1.5
Coating quality: – fuel rod surface be coated with an oxide film	
Filter-gas characteristics:	
Gas pressure inside the fuel after its sealing, Mpa	0.5...0.7
Volume fraction of the He_2 in the gas mixture under the cladding after sealing %, not less	98
He_2 leakage out of the fuel rod during leakage control, $m^3 \times Pa/s$, not more	$1*10^{-9}$
Contamination of the outside surface of the fuel rod by U-235 g/cm^2, not more	$1*10^{-9}$

2.1 Fuel column quality control

The principle of measurement of inner structure parameters is γ-absorption method. The flow of γ-quanta from the external γ-source passes through the fuel rod during its

motion along longitudinal axis. The γ-quanta passed through the fuel rod are registered by γ-detector.

In case there is a gap between the pellets the number of the γ-quanta registered from the γ-source will be more than for the defectless area of the fuel column. The control of the plenum length and length of the fuel column is performed similarly.

The detection of the presence or absence of the spring is performed by means of the eddy-current method (Fuco currents) when the change of the conductivity of the parts of the cladding without the spring and with the spring is registered.

X-ray control is used as the arbitrary method. In 1996 the automatic X-raying system was implemented – MU115F, created by "Philips Industrial X-Ray (Germany) .The control method is based on the X-raying of a package of 9 fuel rods, transforming the image into light-and-shadow and electronic image and transmitting these images to PC by means of optics and TV-techniques.

The average productivity of the fuel rod control is 250 articles per shift (7 hours).

During the automatic analysis, the system performs the evaluation of the fuel column quality along the following parameters (Table 3):

TABLE III. RANGES AND ERRORS IN MEASUREMENT OF FUEL ROD PARAMETERS

No.	Name, unit	Measurement range	Error
1	Gap between pellets and components of fuel rod, mm	0.5 - 2.3	± 0.3
2.	Sum of gaps in the fuel column, mm	0.5 - 9.9	-
3	Pellet length, mm	8.5 - 12.6	± 0.5
4.	Pellet diameter, mm (measured on the determined base along the axis - 4 mm)	6.7 - 7.3	± 0.3
5.	Fuel crumbs area, mm^2	1.0 - 3.5	35% max..
6	Chip area or sum of chips on one pellet, mm^2	5.0 - 13.0	22% max.
7	Presence of destroyed pellet	yes	-
8	Spring presence	yes	-
9	Rodlet presence	yes	-

2.2 Fuel rod welds control

All the fuel rods undergo the ultrasonic control of the weld continuity. This operation is performed on the unit that is incorporated into the automatic fuel rod production line.

For the ultrasonic inspection of the weld quality the shade method is used. The article is checked by a focused narrow ultrasonic spot ($\varnothing \approx 0{,}4$ mm) with the frequency of 10 MHz. Constructively weld continuity measuring device consists of 2 ultrasonic sensors located in the diameter plane as related to the component checked; one sensor sends the ultrasonic signal and the other receives it. The article checked is rotated and the ultrasonic sensors are moved along it registering the movement value.

In case in the checked section appears a defect in the form of metal non-continuity the amplitude of the received ultrasonic signal decreases on the receiving sensor and a signal that the distance passed is no longer measured is sent to the system. If during the further movement of the ultrasonic sensors a defectless area appears the calculation of the distance passed is renewed. Technical properties of the method are given below:

- Weld scanning range – up to 5 mm;
- Screw line pitch – 0,15 mm;

- Control error – 0,3 mm;
- Productivity (scanning speed) – 0,1 mm/sec.

The metallographic destructive control of the weld quality is performed daily at the beginning and end of shift, after changing the cladding clamping collet in the welding automate and every 100 consecutive welds. The control is performed on 2 witness-samples manufactured together with the fuel rods subjected to control. The samples are cut longitudinally and ground to get the longitudinal and cross-sectional sections. After the chemical etching the sections are sent to analysis. The weld continuity is checked, at 50x magnification, on the longitudinal section and it shall not be less than 1,5 mm. On the cross-section the absence of pores, micro-continuities and inclusions is checked.

The investigation of the sections is performed on the computerized metallographic system. The microscope is connected to the PC via TV-camera. The image of the section is processed mathematically, the processing includes the suppression of the background unevenness, averaging of noises and segregation of the control object by certain criteria. Further the weld parameters are measured.

2.3. Diameter

The fuel rod diameter is checked while the rods are moved through the measuring station of the unit which is a part of the fuel rod production automatic line. The fuel rod passes between the light source and the scale of the photo-receivers to which the shade image is projected. Linear CCD photo-receiver is used. The CCD photo-receiver is a number of photo-sensitive elements, 2048 in total, located with the pitch 12 μm. To increase the accuracy of the diameter measurement the interpolation of the photo-signal is done by means of PC. Here the periodicity of the diameter measurement makes 20msec, and the area width where the single diameter measurement is carried out makes 0,3 mm.

- Measurement range – 3 ± 20 mm;
- Measuring error – 0,01 mm.

2.4. Helium inner pressure control

2.4.1. Non-destructive method

The measurement principle is to agitate the convective gas movement in the control object by means of thermal shock, with further measurement of the cladding temperature increment caused by the convective component of the heat transfer. Technical parameters are given below:

- Pressure measurement range 0,1 ... 0,7 MPa;
- Measuring error – 0,05 MPa;
- Measuring time – not more than 30 sec.
This unit is also certified for the pressure range 1,8 – 2,5 MPa.

2.4.2. Destructive method

The destructive control of the gas pressure and gas impurities content inside the fuel rod is carried out by mechanical puncture of the cladding, measuring the pressure after the puncture in the chamber taking into account the atmospheric pressure.

This system is certified for the range 0,39 – 0,79 MPa and has the error of 0,02 MPa. The system can also be used in the pressure range 1,8 – 2,5 MPa.

After puncturing the fuel rod cladding the portion of gas which escaped form the rod is sent to the gas chromatograph. The chromatograph is calibrated by means of special gas mixtures on He basis with a well-known content of impurities of the checked gases from 0,01 to 1%.

Absence of hydrogen (H_2), oxygen (O_2), nitrogen (N_2) and methane (CH_4) is controlled in the range from 0,01 to 1% with the relative error 0,3.

2.5. Leakage test

The unit is a set of vacuum chambers installed sequentially. The fuel rods are loaded into special pallets. In these chambers, at 0,065 Pa ($5*10^{-4}$ mm Hg column), the fuel rods are heated up to 350 ... 390°C and held at this temperature for about 40 min. Further the articles are fed to the leakage control chamber where at the temperature (350± 50°C), at 0,13 Pa ($1*10^{-3}$ mm Hg column) the leakage test takes place.

It is noteworthy that the fuel rod leakage control is additionally performed in the finish fuel assemblies also that greatly improves the reliability of the control.

2.6. Control of the surface contamination by U-235

The control of the fuel rods surface contamination is performed by scintillation sensors located along fuel rod; the gap between the sensor surface and fuel rods shall not exceed 2 mm. During the exposition time the total α-activity is registered. Further, the corrective factor taking into account the contribution of U^{235} to the total activity is used for further calculations of U^{235} activity.

2.7. Control of enrichment in a fuel rod

2.7.1 Rod scanner (active)

Lately in connection with the increase of types of the pellets fabricated at our factory the pellet enrichment control in the loaded fuel rod was introduced. Our factory uses the unit "Cresus" to check the pellet enrichment in the fuel rods.

The fuel rod is passed at constant speed through the irradiation block with the neutron source of Cf-252. The decay products emit γ- and neutron radiation. In "Cresus" only delayed γ-radiation is registered. The level of γ-activity corresponds to the pellet enrichment.

2.7.2 Rod scanner (passive)

The units of the enrichment inspertion with the neutron activation, in spite of all their merits, have two major drawbacks:

- Necessity of large protective shield of the neutron source Cf-252 and rather frequent change of the source due to its decay;
- High price.
-

So passive γ-scanners having smaller control productivity but more convenient and cheap than the scanners with the neutron activation were developed and manufactured at our enterprise. The metrological properties of the unit are similar to the parameters of the system "Cresus", still, the control productivity is much smaller –25 mm/sec.

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Units for checking the gaps, fuel column length and spring presence are also incorporated in to this system.

3. METROLOGICAL SUPPORT

All the devices – spectrometers, defectoscopes, scales, etc.- shall be metrologically certified and be subjected to periodical verification. A special department, certified by Gosstandart for the verification of measuring devices, exists at the factory.

To calibrate the measuring devices for checking the correctness of the analyses the standard samples of different grades are used – state, branch standard samples or factory check samples. The metrological service of the enterprise accounts for the standard samples and controls the correctness of their use.

The control methods used shall also undergo the metrological certifying. This means that during the methods development a set of research experiments shall be carried out. As a results of these researches the applicability of the methods is determined.

The applicability means the correspondence of the value measured under the methods in question to the specification requirements. For example, to determine O/U we could measure the content of oxygen and divide it by the uranium content. But this is not what is required by the designer because it is needed to determine only the oxygen that is connected to uranium by valence.

When determining the error the following is estimated:

1. random component – this is the well-known standard deviation multiplied by the factor taking into account the sampling limit.
2. systematic error – that is the difference between the average value of many experiments and the real value of the measured parameter.
3. systematic error – not excluded, taking into account the influence of the factors which may not be reflected in these tests (f. i., measuring bulbs and scales error, etc.).

As a result of this work the metrological service issues the certificate of the metrological attesting of the methods.

Naturally, the metrological service itself shall have the certificate of Gosstandart for the right to attest the measuring methods.

I'd like to draw your attention to one peculiarity in the procedure of error estimation while attesting the methods that reflects the difference in the approaches to the determination of the error in Europe and in Russia. You could pay attention to sufficiently large values of the error of our methods. For example, the error of the hydrostatic determination of the pellet density is 0,03 g/cm^3. At the same time the figure 0,005 g/cm^3 is given in the description of similar methods performed at similar equipment in Germany. Does it mean that we in Russia can not work? No. The matter is that during the metrological testing of these methods in Germany the experiment was carried out only on a metal ball. We perform the error estimation on real pellets. In this case only the random component is more than 0,022 g/cm^3.

So, the micro-non-uniformity of the pellet is introduced into the measurement error in our case. Here our technologist, after having received the analysis results from the lab, is sure that the measured value for any pellet from the batch lies within the limits ± the methods error. The technologist in Germany knows that this result refers only to the given

pellet and further he performs a special procedure to estimate the product stability, determining the standard deviation of the control results for a set of pellets.

Which approach is better – it is difficult to decide. Merits and drawbacks exist in both cases.

To conclude the section concerning metrology it is noteworthy to say that the system of checking the correctness of the analysis performance obligatory exists in the lab. For this purpose almost for all analyses two independent measurements are carried out and the result is given only after they are compared to each other. The comparison criterion is – not more than the random component of the error.

Measurements of the standard samples are performed regularly. In this case the result shall not differ from the attested values by more than $\sqrt{\Delta^2_{\text{мет}} + \Delta^2_{SS}}$, where Δ_{SS} – is the error of standard sample.

Besides, the samples are codified. This means that a certain quantity of the samples is divided into two and approximately one month later they are analyzed once again. The difference shall not exceed the sum of the random and non-excluded systematic errors.

In any of the above mentioned cases urgent measures are taken to find out the reasons and to restore the control reliability.

You can see that the system of metrological control valid at our enterprise guarantees the correctness of the measurement results.

THE TECHNOLOGIES OF ZIRCONIUM PRODUCTION FOR NUCLEAR FUEL COMPONENTS IN UKRAINE

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Abstract

Perspectives of development zirconium alloys and VVER-1000 assemble components production in Ukraine are considered. Basic technological production processes of zirconium alloys in conditions of Ukrainian enterprises and modern requirements are analyzed. The critical processes on technical and economic criteria are defined. The main directions of activity and steps on technological processes improvement for production quality providing are offered.

1. INTRODUCTION

Ukraine has the sufficient natural uranium and zirconium resources to provide Ukrainian NPPs with nuclear fuel. The industrial enterprises on processing of uranium and zirconium production can cover the needs of Ukraine in perspective. Ukraine has considerable scientific and technical potential in the field of nuclear technologies. By historical circumstances Russia is the monopoly supplier of nuclear fuel for Ukrainian NPP in the present. Therefore diversification of nuclear fuel supplier is very important issue for energy independent of Ukraine. These factors are the preconditions for the development of the nuclear materials and the nuclear fuel components production.

"The complex program of nuclear-fuel cycle development in Ukraine (Nuclear fuel)" has been worked up and ratified by the decision of the Cabinet of Ministers of Ukraine in April 1995. The basic indexes of this program have been included in "National energy program of Ukraine up to 2010".

Analysis of technical and financial possibilities has been carried out and it has showed the need of attracting of partners in technical and financial fields. Basic cooperation directions are necessary in the field of nuclear fuel technologies improvement, designing and licensing.

The closed international tender "Partner choosing for joint venture foundation in Ukraine on production of nuclear fuel for reactors VVER-1000" has been carried out in 1996. Companies ABB, Westinghouse Electric S.A. and JSC "Concern TVEL" have taken part in the tender. The tender committee has admitted as tender winner the suggestion of Russia JSC "Concern TVEL" under guarantees condition of the Government of Russia on fixed prices on natural uranium and enrichment for the period up to 2010.

2. DEVELOPMENT PROGRAM OF NUCLEAR FUEL CYCLE IN UKRAINE

2.1 Basic activity directions

"The complex program of nuclear-fuel cycle development in Ukraine (Nuclear fuel)" [1] covers all activity directions in the field of production development of nuclear fuel, materials and components, creation of scientific and technical base on planning, licensing, science and technical support of the nuclear fuel activities. The following activity directions are envisaged in the program:

- Development of uranium ore extraction and processing.
- Creation of UF_6 production.
- Development of zirconium alloy production.
- Creation of zirconium rolling production.
- Creation of assemblies and its components fabrication.
- Scientific, design-technological and projecting support of the nuclear fuel cycle.

These directions include, practically, all activity complex connected with production of fresh nuclear fuel. Uranium enrichment production is not included in program in connection with considerable necessary financial expenditures and tendency of world market in this field of services.

The specialists of the following institutions and organizations have being participated in the program realization.

- *The East mine- dressing Combine «VostGOK»* (Zhovty Vody) - the mining and processing of uranium ores.
- *The State Scientific Production Enterprise «Zirconium»* (Dneprodzerzhinsk)- the zirconium alloys and hafnium productions at present; the zirconium rolling is planed;
- *The State Tube Institute* (Dnepropetrovsk) - the scientific, designing and technological support of the zirconium tube production;
- *The Zhovti Vody Scientific and Technical Center* (Zhovty Vody) - the designing works and scientific support of technological processes from mining to fuel fabrication.
- *The Ukrainian Scientific and Designing Center on Industrial Technology* (Zhovty Vody) - the planning support of atomic enterprise production;
- *National Scientific Center "Kharkov Institute of Physics and* Technologies» (Kharkov):
- *Institute of Solid State Physics, Materials and Technologies* - the scientific, technological and analytic support of zirconium alloys production;
- *Scientific and Technical Complex «The Nuclear Fuel Cycle»* - the scientific and technological support on the nuclear fuel and its components designing and technologies;
- *The National Academy of Sciences of Ukraine* (Kyiv) :
- *The Physics and Technological Metals and Alloys Institute* - the electron-beam melting technology and equipment designing;
- *The Electric Welding Institute* - the development of components production technologies; the designing of process control methods and equipment.

Other enterprises and organizations have also being taken part on realization of the program

2.2 Cooperation in nuclear fuel production development .

It is planned to create the joint venture on production of advanced nuclear fuel for VVER-1000 in accordance with the tender offer of the JSC "Concern TVEL". Such distribution of functions are planned:

- Ukrainian shareholder will provide the production of the zirconium alloy and rolling, the zirconium and still assemble components;
- Kazakhstanian shareholder will provide the dioxide uranium pellet production;
- Russian shareholder will provide the rod and fuel assembling and work up the improved VVER-1000 assemblies.

Zirconium claddings of road VVER-1000 have being produced in Russia at present. The Ukrainian specialists have the experience on the tube technology elaboration for the different industry fields. However Russian specialists participation is very important for completion of the technologies elaboration, production certification and fuel licensing with Ukrainian production components.

The zirconium alloys production has well-organized on «Pridneprovsky chemical plant» (Dneprodzerzhinsk) in 70-80ties. A lot of the scientific centers of former USSR have taken part in the technology and production development. However the zirconium alloys production in Ukraine needs reconstruction and increasing of its productivity for cover Ukrainian NPPs in zirconium production at present.

The Cooperation Program with Russian organizations has worked up and has included the main directions of activity for development of the standard documents, hand over and improvement of the zirconium alloys and components technologies, the planning production, the fuel licensing.

3. ZIRCONIUM ALLOYS AND COMPONENTS PRODUCTION ORGANIZATION.

At present varieties of zirconium alloys for assemblies are produced including Russian alloys E110 and E635 for the VVER-1000 nuclear fuel. Technological production processes of zirconium alloy

alloyed 1% niobium by means of calcium thermal reduction KTZ-110 (analogue E110) were worked up in former USSR in 80ties and were mastered on experienced production «Pridneprovsky chemical plant» (Dneprodzerzhinsk). On first stage by the program decision is accepted to master analogue of Russian alloy E110 as the most studied and mastered in Ukraine on SSPC «Zirconium» which was created on base «Pridneprovsky chemical plant».

Technology elaboration and production of experimental tube parties have being carried out in «The State Tube Institute», which has necessary scientific and production base. The industrial fabrication of zirconium tube is planed on SSPC «Zirconium».

The VVER-1000 assemble component production from zirconium alloy and steel are planed at the expense of reorganization of industrial base of «VostGOK» mechanical plant.

4. TECHNOLOGICAL PROCESSES OF ZIRCONIUM ALLOY AND ROLLING PRODUCTION.

4.1 The ingot fabrication.

Technological production process of zirconium alloy Zr1Nb by means of calcium-thermal-reduction includes the stages of thermochemical conversion of Zr-Ore, separation of hafnium and reduction to metal, alloying [2]schematically presented on FIG. 1.

Zr-Silicate

Thermochemical Conversion   Na-Carbonate; Fusion
of Zr-Ore

Na-Zirconate

H_2O+HNO_3; Leaching

Zr-Nitrate

Separation of Hafnium   Liquid-Liquid Extraction

Zr-Nitrate

HF_3; Precipitation

Zr-Tetrafluoride
(monohydrate)

Reduction to Metal, Alloying   Ca+Nb; Reduction and Alloying
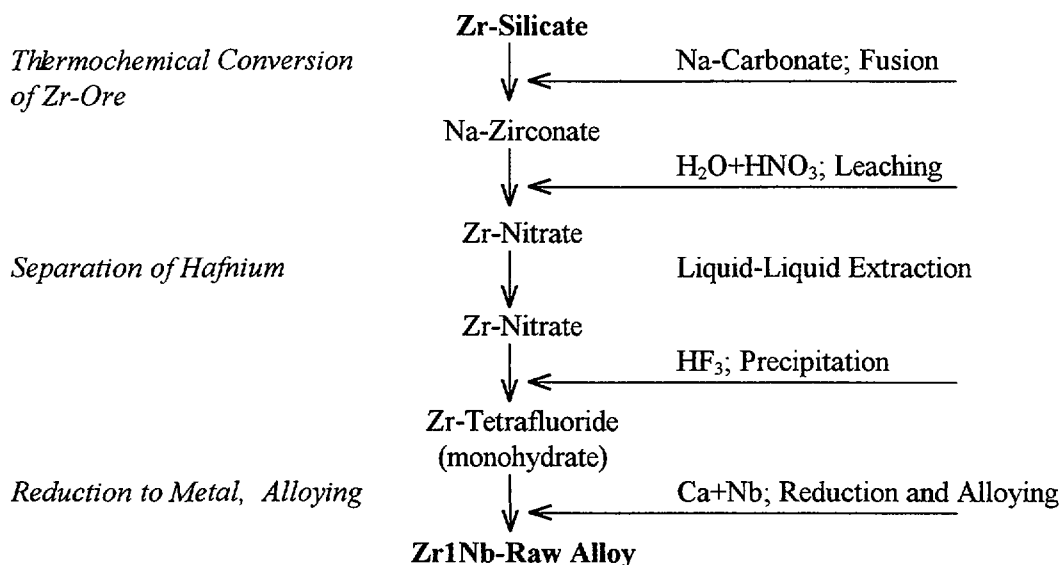
Zr1Nb-Raw Alloy

FIG. 1. Scheme of zirconium alloy production.

The hafnium separation process has the same distinctions using materials and equipment compared Russian and Western technologies.

The Ca-reduction and alloying processes are special one and are not used by Russian and Western zirconium producers.

4.2 Tube billet fabrication.

However, such Ca-reducing zirconium contains nonmetallic inclusions and the most suitable method of its refining is electron-beam melting. The zirconium ingots that may be remelted by the vacuum-arc method and tube billets may be produced by the traditional scheme with the use of hot forging, stripping, hot rolling, beta-quenching, drilling.

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In the recent years at the National Academy of Sciences of Ukraine [3,4,5] an electron-beam casting technology was developed for the manufacture of tube billets by methods of stationary and centrifugal casting Application of the developed technology ensures noticeable reduction of the number of technological stages, which can be seen from the presented scheme (FIG 2) This is resulted in decreasing the amount of waste and impurities in metal, and application of expensive equipment
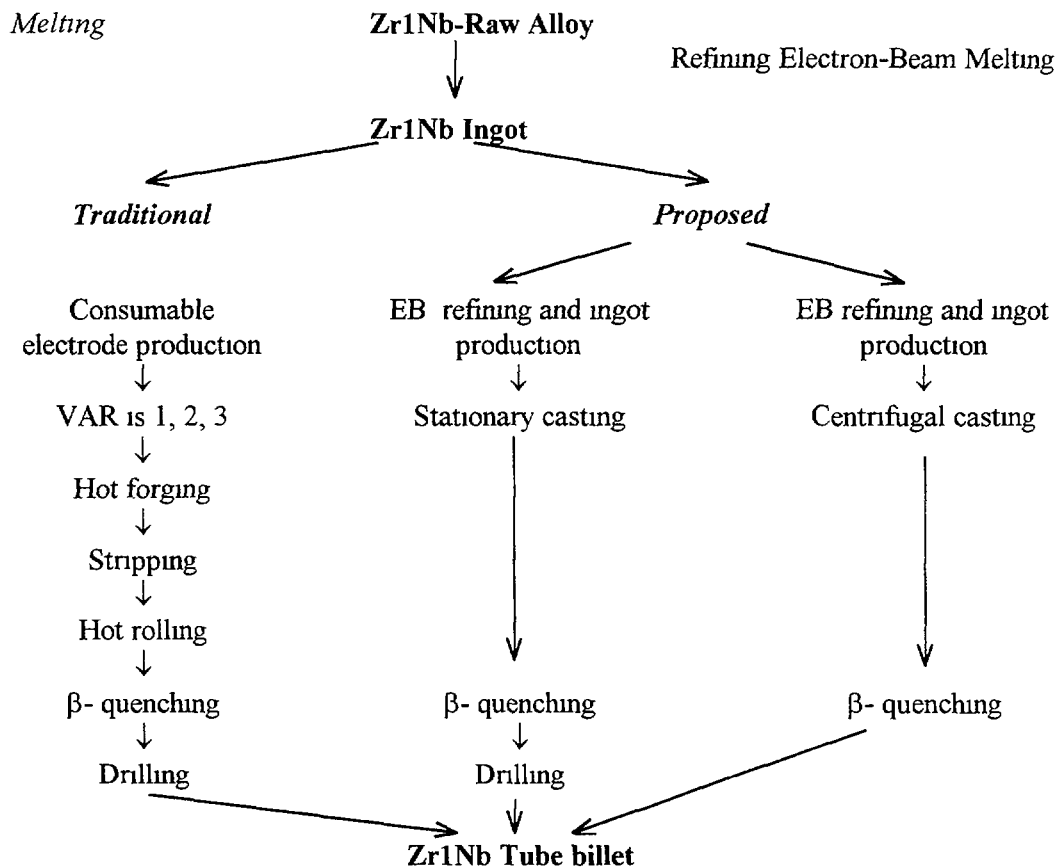

FIG 2   Scheme of tube billet production

Presently the experiment aimed at obtaining cast tube billets and cladding are being conducted Industrial tube rolling technology will be definite only after completion of researches and with consideration of consequent treatment stages

4.3 Tube rolling.

The tube rolling technologies [6] generally do not differ from Western and Russian technologies and represented on scheme (FIG 3) Difference between accepted technologies consists in The State Tube Institute has worked up TREX making method by means of hot extrusion in β-phase with big deformation without ingot forging This method is under approbation for confirmation of its efficiency

5 CRITICAL PROCESSES AND STEPS ABOUT OF PRODUCTION QUALITY

Supposed technologies of the zirconium alloys production are differed from applied on West and in Russia It can reflect on production quality The analysis of supposed technologies [7] has been carried out for technical politics definition in quality providing issues   The basic analysis aims were determination of

    −   critical processes influenced on quality of final production,
    −   development of recommendation for providing of quality and technical efficiency
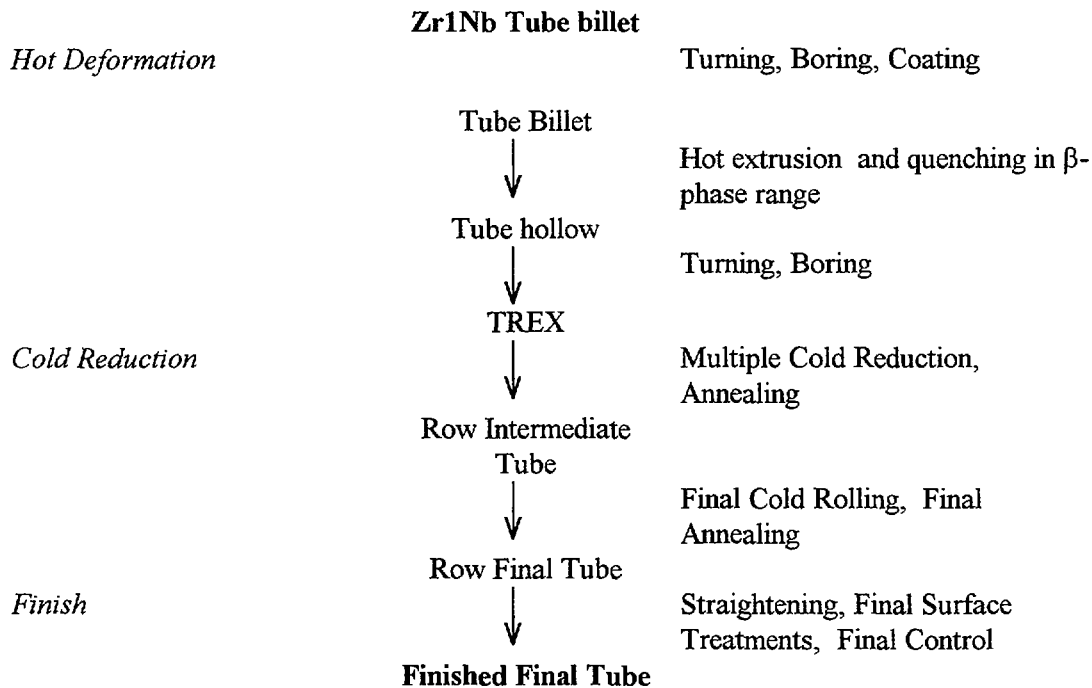   Some results of the analysis are presented below

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ZrlNb Tube billet

Hot Deformation		Turning, Boring, Coating
	Tube Billet	
	↓	Hot extrusion and quenching in β-phase range
	Tube hollow	
	↓	Turning, Boring
	TREX	
Cold Reduction	↓	Multiple Cold Reduction, Annealing
	Row Intermediate Tube	
	↓	Final Cold Rolling, Final Annealing
	Row Final Tube	
Finish	↓	Straightening, Final Surface Treatments, Final Control
	Finished Final Tube	

FIG. 3. Scheme of tube production.

5.1 Critical processes.

The overall result of the performed analysis is that there are two processes that clearly appear to be uneconomic in an international comparison

- The result of the hafnium separation Hf < 100 ppm is technically not satisfactory at present.
- Melting is the result of electron-beam melting have a technical potential for additional purification but does not have the economically superior vacuum-arc process.

Further on the overall analysis shows the process are basically acceptable with respect to economics, but critical to the quality and performance of the final zirconium alloy products and in the present stage are technically risky:

- Ca-reduction,
- Extrusion in the β-phase,
- β-quenching,
- Control of vacuum anneal in α-phase range.

The technologies after melting down to the final zirconium alloy components is basically better comparable to other international practices.

5.2 Steps about of critical processes improvement.

Critical remarks were analyzed by Ukrainian specialists with consideration of having scientific and production experience. It is necessity to complete scientific researches on critical processes for receipt reliable information.

The main direction of activities on development technology and quality assurance are:

- To improve process and to modernize equipment for Hf-separation. In case of unsatisfactory result to define alternative technology.
- To optimize Ca- reduction process for lowering of admixtures maintenance, above a oxygen.
- To compare alternative melting methods on technical and economic criterion.
- To substantiate technology of hot extrusion and quenching of tube billet in β-phase range.
- To perform the analyze of correlation between process parameters and product quality performance.
- To introduce statistically based process control for the process.

6. CONCLUSIONS.

- Development of zirconium alloys and nuclear fuel components production is important for providing of Ukrainian atomic power industry by nuclear fuel.
- The analyze of the technological production processes of zirconium products for nuclear fuel on Ukrainian enterprises showed, that there are the substantial distinctions in Hf-extraction technologies, alloy and tube making.
- There are definite the critical processes, substantially affecting quality of final production.
- There are produced the recommendations and definite to the way of optimization of critical technological processes for providing of production quality.

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PROGRAM OF QUALITY MANAGEMENT WHEN FABRICATING FAST REACTOR VIBROPACK OXIDE FUEL PINS

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Abstract

There are presented main principles of creation and operation of Quality Management Program in fabricating vibropack oxide fuel pins for BOR-60 and BN-600 being in force in SSC RF RIAR. There is given structure of documentation for QS principal elements. Under Quality System there are defined all the procedures, assuring that fuel pin meets the normative requirements. The system model is complied with the standard model IS 9001. There are shown technologic flowchart and check operation, statistic results of pin critical parameter check as well as main results of in-pile tests.

Introduction

For the last few years SSC RF RIAR has developed design and manufacture technology of fast reactor vibropac oxide fuel pins. Results of in-pile tests and postirradiation examinations make it possible to recommend fuel pins of this type for large-scale tests in power reactors. Requirements of supervision body to reactor operation safety being currently in use justify the necessity of creating Quality management system. In order to fulfill the requirements SSC RF RIAR is developing the Quality System, which provides that all the necessary procedures of Quality Management in fabricating vibropac oxide fuel pins and SA for BOR-60 and BN-600 reactor should be implemented.

1.Structure of QS principal elements

In order to assure quality of vibropack oxide fuel pin fabrication in accordance with the requirements of IS (International Standard) 9000 series SSC RF RIAR is developing and introducing Quality System, which is a system of organization, procedures, processes and resources [1]. One of Quality system elements is the Quality guidelines and Quality management programs being developed for every fabricated product. Quality System being currently in use accompanies the product for all the stages of its life-time, beginning with development, through manufacture, in-pile tests and PIE followed by utilization. Under Quality System there are defined all the procedures, assuring that fuel pin meets the normative requirements. The system model is complied with the standard model [2].

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Quality system application is limited by required documentation, structure of which is given in Fig. 1.
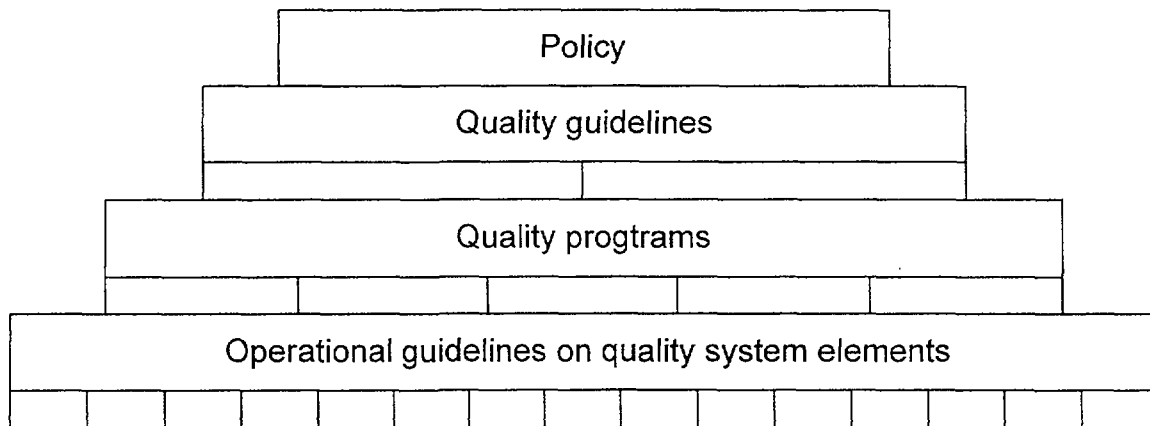

Fig.1. Structure of Quality System documentation

Three upper levels represent organizational-administrative documentation of the system and include:

- policy in quality area, governed by Institute administration;

- quality guidelines, outlining descriptions both of Institute QS and the one when fabricating fuel pin and SA. Guidelines meet the standard requirements [3];

- programs of quality management, incorporating specified steps to assure the quality of each fuel pin and SA kind and flowsheet of their design and manufacture. The programs fulfilled the requirements of International Standard [4].

At present there are in force five QA programs in manufacture, including the ones for different kinds of granulated oxide fuel as well as for BOR-60/BN-600 fuel pin and SA fabrication.

Operational guidelines of bottom level contain design plans and specifications, technologic and technical documentation, which are developed and complied with the requirements of State, Branch and Institute Standards.

2.Quality system operation

There is a special service of quality to check the QS operation efficiency. It is the service that develops the steps of correcting effects if there are found signs of differences.

Management of fabrication process and technical quality administration of initial materials, spare parts and final products (ready fuel pins and SA) are carried out by Inspection

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subdivision. Quality service and Inspection subdivision analyze deviations of initial materials and final products from the set requirements and together with production manufacturer work out measures to correct deviations. Final acceptance of products is implemented by Branch management-acceptance inspection.

For the last 25 years SSC RF RIAR has carried out the integrated investigations to validate the possibility of using vibropack oxide fuel (Fig.2) in fast reactors.
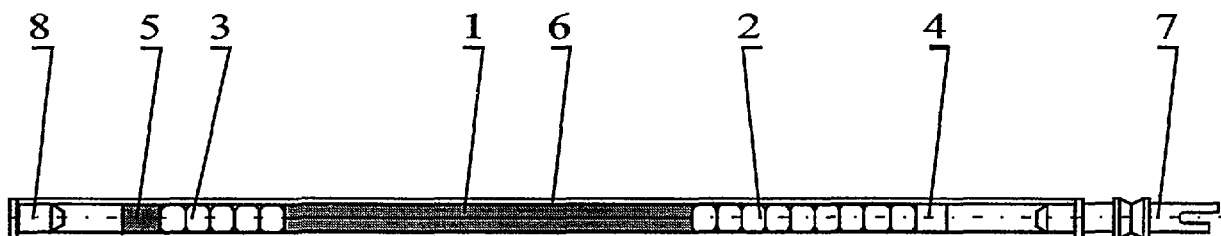
1- Fuel column
2- Bottom blanket zone
3- Upper blanket zone
4- Can
5- Fixing element
6- Cladding
7- Bottom endplug
8- Upper endplug

Fig.2 Design of fast reactor fuel pin

These investigations were aimed at developing reactor advanced fuel cycle, based on a pyroelectrochemical way of irradiated fuel reprocessing, which resulted in high-dense granulate appropriate for vibropack fuel pin fabrication. Particle density was 10,7 - 10,9 g/cm^3 and particle size was in the range of ~10 mcm-1 mm. In the progress of activities a study was made of granulate physical-mechanical and technologic performance, there were carried out radiation tests of experimental and pilot fuel pins in BOR-60, BN-350 and BN-600 reactors and pin material science investigations. Total quantity of fabricated fuel pins amounts to about 30 000 pieces [5].

In BOR-60 reactor maximum burn up attained 30 % h.a. for standard SA and burnup was of 32,3% h.a. for experimental fuel pins of the dismantled SA. In testing UPuO$_2$ vibropack fuel pins in BN-600 reactor there was attained maximum burn up of ~10.8%h.a. Mass tests of UPuO$_2$ vibropack fuel pins in BOR-60 reactor since 1981, irradiation of large-scale experimental SA in BN-350 and BN-600 made it possible to specify and validate statistically initial technologic parameters of fuel column, to confirm concepts underlying fuel pin design as well

as to identify a number of critical design and technology parameters, which are characteristic of vibropack oxide fuel pins and to govern their serviceability. The parameters like these are as follows:

- fuel column smear density;

- uniformity of smear density and FPs distribution along the fuel column length;

- concentration of the major technologic impurities in granulated fuel;

- O/M ratio;

- helium content in fuel.

It is support and check of the parameters that are paid a great attention in fuel pin fabrication and acceptance (Fig 3,4). Besides, while carrying out technologic process of fuel pin fabrication there are checked:

- fuel column and its components mass(Fig.5, Table 1);

- composition of under cladding gas (Fig.6);

- fuel pin integrity and welding seam quality (Fig.7);

- other parameters.

Table 1.

Masses of fuel components in BN-600 SA

SA number	Fuel mass in SA, g	Plutonium dioxide mass in SA, g
1	28695,90	4967,73
2	28630,01	4953,64
3	28651,05	4995,38
4	28616,46	4998,17
5	28590,99	4993,17
6	28563,99	5003,40
7	28622,84	5041,36
Average value	28649,49	4993,26

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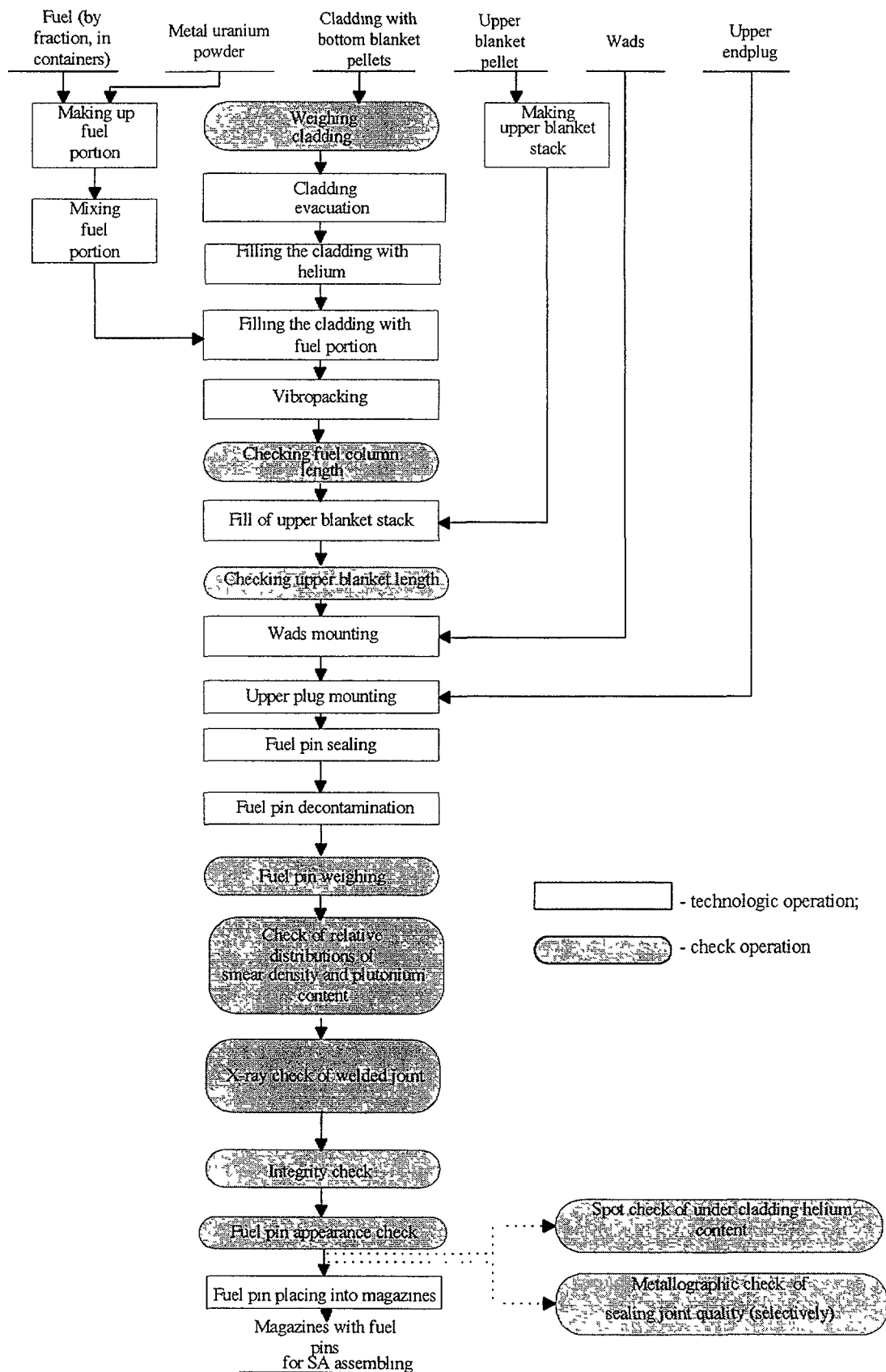
Fig.3 Main technologic and check operations of vibropack oxide fuel pin fabrication

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Fig.4 Flowchart of BN-600 SA manufacture
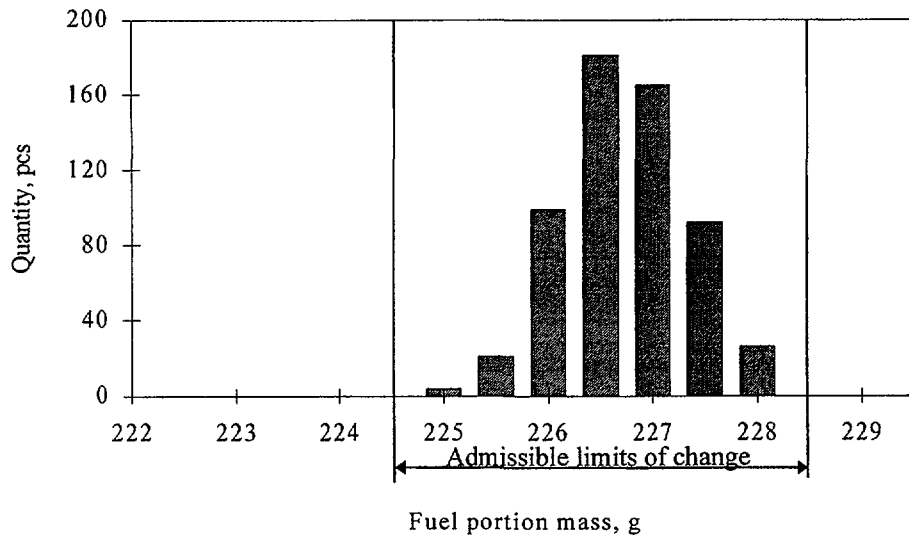
Fig. 5 Histogram of fuel column masses for BN-600 vibropac fuel pins

Both standard and non-standard techniques are used to manage quality.

Standard method of quality management is typical of the plants produced fuel elements. Among non-standard quality management methods there are those of smear density and FPs distributions (Fig.8) uniformity along the fuel column and under cladding helium content, developed in SSC RF RIAR and occupying a particular place.
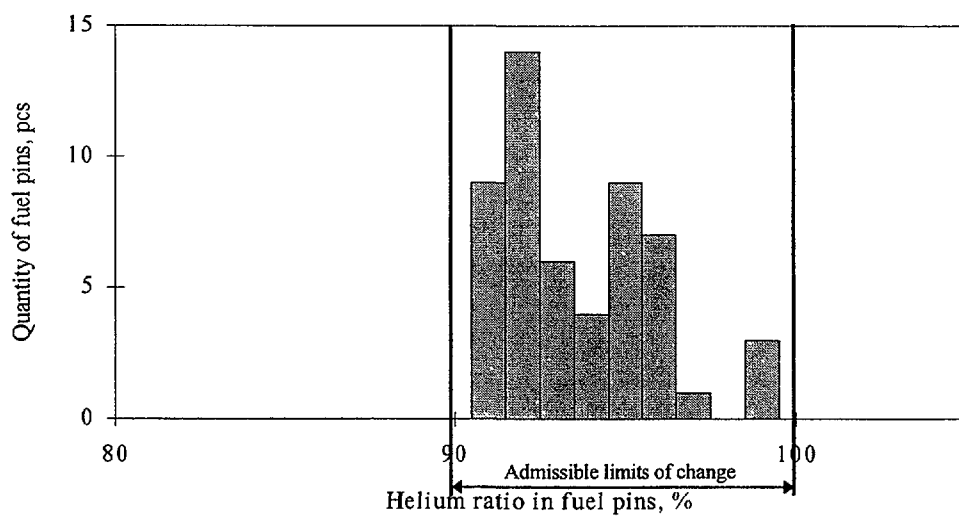
Fig. 6 Histogram of helium ratio in BN-600 fuel pins

a

b
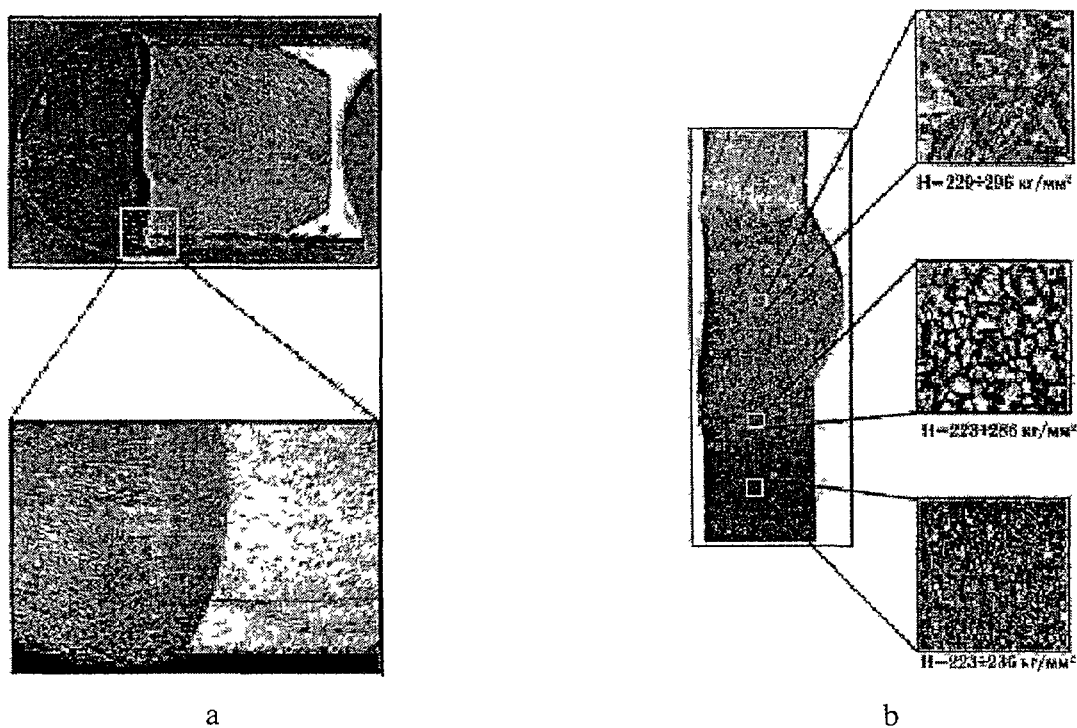
Fig. 7 Multipass weld of fuel pin (a) and SA (b)

a

b
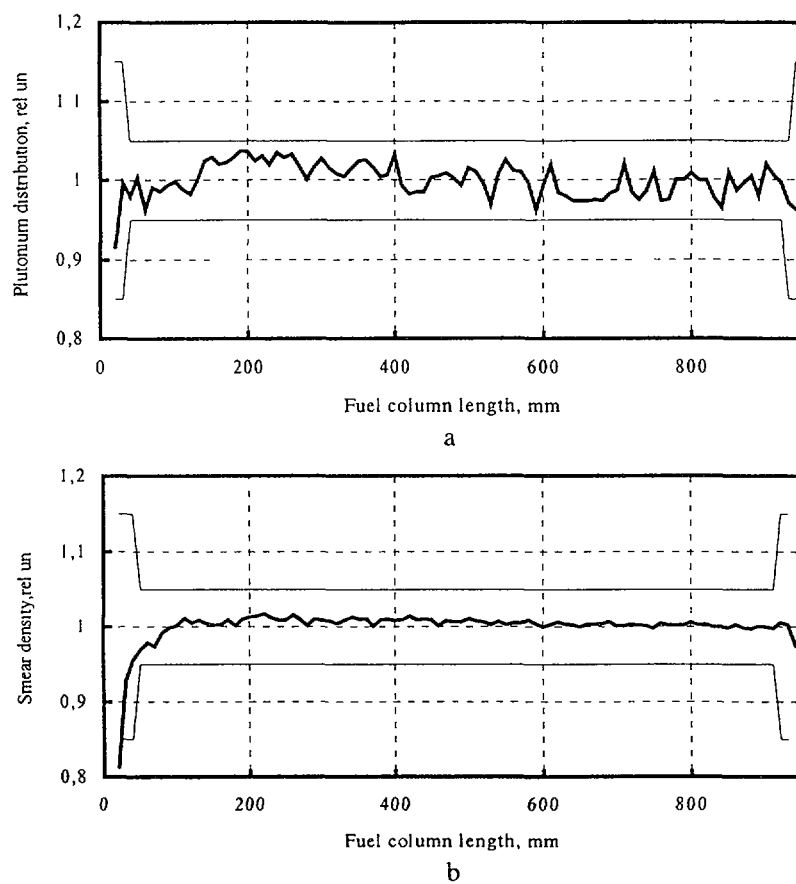
Fig. 8 Distributions of plutonium content (a) and smear density (b) along the fuel
column length

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The methods developed and their equipment support are realized in technologic lines both for hand- (in glove boxes) and automated (in shield cells) manufacture of vibropack fuel pins. Operation of quality management methods for many years exhibited their high authenticity and reliability.

At present annual capacity is:

- up to 2000 BOR-60 fuel pins;
- up to 6500 BN-600 fuel pins.

At that production yield is not less than 98 %, and there are no rejects in separate operations.

3.Conclusions

Statistical analysis of in-pile test results and material science investigations of vibropack oxide fuel pins provides evidence for their high operational reliability and efficiency of QS elements being in use

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STATUS AND RESULTS OF INTRODUCTION OF NEW PROCESS/QUALITY CONTROL METHODS IN NUCLEAR FUEL FABRICATION

(Session IV)

APPLICATION OF SELF-ASSESSMENT IN THE NUCLEAR FUEL SUPPLY ACTIVITIES OF SIEMENS AG

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XA0055761

Abstract

The quality of fuel assemblies supplied to our customers is defined by more than just their expected functionality (performance) during reactor operation and beyond but also by their cost (price) and the timeliness of their supply (including related services). This perspective implies a comprehensive view of the quality of business, - the same focus that the IAEA Code, Basic Requirement 9, addresses regarding management self-assessment. Siemens has adopted a comprehensive management philosophy in the Nuclear Fuels Business in the early Nineties under the header of "TQM" that is similar to the one mentioned above. For this approach we found valuable guidance in the Business Excellence model of the European Foundation for Quality Management (EFQM) which is comparable to the self-assessment criteria listed by IAEA. In this contribution we are presenting examples and experiences of how such system of self-assessment and continuous improvement was implemented by senior management. Our experience of more than 6 years of TQM and 4 years of self-assessment yielded an increasing alignment and focus of our organization and all its members on the continuous improvement of our processes (business, management and support) - on the way to a learning organization.

1. INTRODUCTION

Quality is a word and a term with many facets. Probably everyone has his or her own picture of it, even though the Definition of ISO Standard 8402 : 1994 seems clear:

"Totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs".

Obviously, in a contractual environment of technical products and especially in a regulated environment such as the nuclear safety field, many needs can be readily identified between customer and supplier using standards and specifications. The second element of the definition, though, referring to implied needs, can be regarded open to interpretation. What are these "implied needs"?

It appears that they refer largely to features beyond the technical characteristics; - implied needs can be circumstantial aspects and services related to the purchase, supply, after-sale service (and disposal/recycling) of the technical product and even inter-personal relations in daily interactions with the customer. Usually there are no standards available for this. Here, the implied need can be very customer-specific as well as product-specific, - and it can change over time.

This explains why customer satisfaction surveys are popular these days, - surveys that bring out, how satisfied the customer is with the product and surrounding services and how much relative weight he places on the various aspects of the product supplied. His answers reflect, how much his stated and implied needs are met. Examples of critical topics can be taken from Customer Opinion Surveys in the nuclear fuels business: On-time-delivery, reliability, quality of documentation, support in problem situations, handling of complaints and suggestions, reachability of experts etc.

Therefore *the whole business*, - every member of the organization, is challenged to contribute to the quality of supply and service surrounding the product.

The IAEA as well expressed that there is more than just *product quality* to be taken into focus (Fig. 1): The IAEA Safety Series, Code and Safety Guides Q1-Q14 (1996), "QA for Safety in Nuclear Power Plants and other Nuclear Installations" [1] asks among others that "Management at all levels shall regularly assess the processes for which it is responsible" (401) and "Managers should assess and analyze performance. They should ...use performance indicators" (411) And it lists an exemplary set of criteria applicable for performance of such *management self-assessment*: Leadership, Information and Analysis, Strategic Planning, Human Resources, Process Management, Measuring Results, External Focus.

Just like we have had standards and procedures to check the quality of products, these criteria here provide a means to check the quality of an organization. While the criteria quoted above are close to the business excellence model of the U.S. Malcolm Baldrige National Quality Award, here in Europe the European Foundation for Quality Management (EFQM) has similarly developed criteria and a model aimed at supporting management in evaluating the effectiveness of performance in *all* areas of their responsibility, - a model for management self-assessment. [2]

2. THE EFQM MODEL FOR BUSINESS EXCELLENCE

The EFQM Model for Business Excellence provides the structure to assess the quality of a business organization by identifying,

- what the criteria are that matter in today's business world and
- what the measuring scale is, by which you evaluate the observations.

This process yields not only a number between 0 and 1000, as a measure for the quality of the organization (and it tells you if you have improved or not), but - most importantly - self-assessment produces insights in the strengths of an organization *and* its areas where improvements can be made.

Why self-assessment can be so effective is simple: People from the organization itself know best what the reality is and therefore can better assess against the criteria and the measurement scale. And: Because "self-realization is the first step to improvement" (German saying), i.e. if you recognize the deficiency yourself, you will be better motivated to do something about it than if you are just told to.

Code:	401 Management at all levels shall regularly assess the processes for which it is responsible.	507 Examples of criteria
		• Leadership
SG Q1:	411 Managers should assess and analyse performance. They should (use) performance indicators..	• Information and analysis • Strategic planning
		• Human resources development and management
SG Q5:	501 The purpose of management self-assessment should be to evaluate known performance issues, identify contributing management aspects and make improvements.	• Process management • Measuring results • External focus
	503 Management at all levels ... perform these self-assessments with an emphasis on the allocation of human and financial resources to achieve organizational goals and objectives.	

FIG. 1. IAEA Basic Requirement 9: Management Self-Assessment [1]

Actually, according to the model, there are *two groups of criteria* that tell the quality of an organization: The *enablers* and the *result criteria*. And in such a self-assessment you look at the organization from two perspectives (Fig. 2), each worth 500 Points:

- Five *enabler criteria* ask "how good are the management tools (processes) and their application?" i.e. Leadership, Policy and Strategy, People Management and Management of Resources and of Processes.

- Four *result criteria* ask for the organization's achievements and their significance, i.e. in Customer Satisfaction, Employee Satisfaction, Impact on Society and Business Results.

Both groups of criteria are given equal weight, which expresses that the quality of an organization is seen made up by the management tools *and* the results. At the same time it is understood that improvements in the area of the enablers may take a while to show in terms of the business results. Any improvements on behalf of the enablers, however, are recognized as an important step towards an excellent organization and therefore reflected in the scoring.

The 9 criteria are defined by 32 sub-criteria which in turn are detailed by several (recommended) "areas to address".

The measuring scale is of course different for enablers and results:
Enablers are judged for the degree of excellence of your approach (systematic? prevention-based? regularly reviewed? integrated into daily operation? etc.) and its degree of application (applied in all relevant areas and activities?).
Results are assessed in these terms: Are there positive trends over time? How do they compare with external organizations and with own goals?, are the results caused by approach?, and how representative are the results for the organization?.
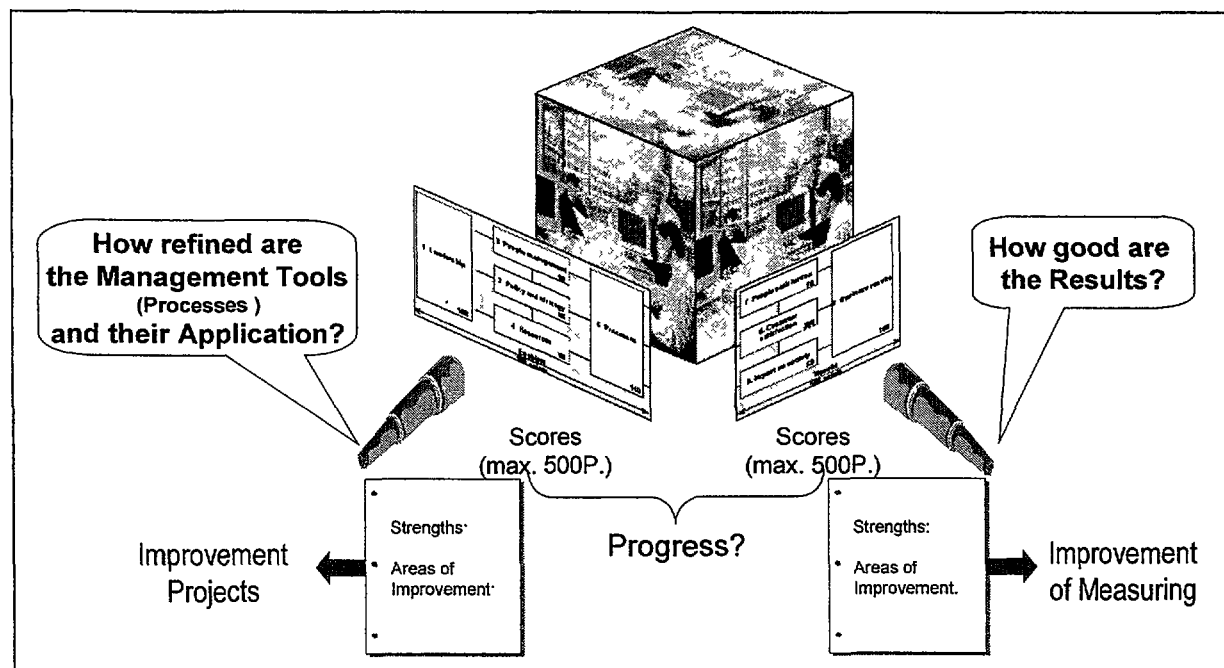

FIG. 2. Self-Assessment according to the EFQM-Model

3. THE PROCESS-ORIENTED MANAGEMENT STRUCTURE

Application of such a model very quickly asks for a process-oriented structure on the part of the organisation. Looking at our organization in more detail, we realized that a successful business organization is not an agglomerate of departments but a well tuned grid of processes (Fig. 3): At the core of it is the Business Process that generates a product (or service), based upon input from the customer and aimed at meeting the customer's expectations (in our case: the supply, upgrading and servicing of Nuclear Power Plants and Fuel Assemblies). And if this goal is met, our organization can claim success.
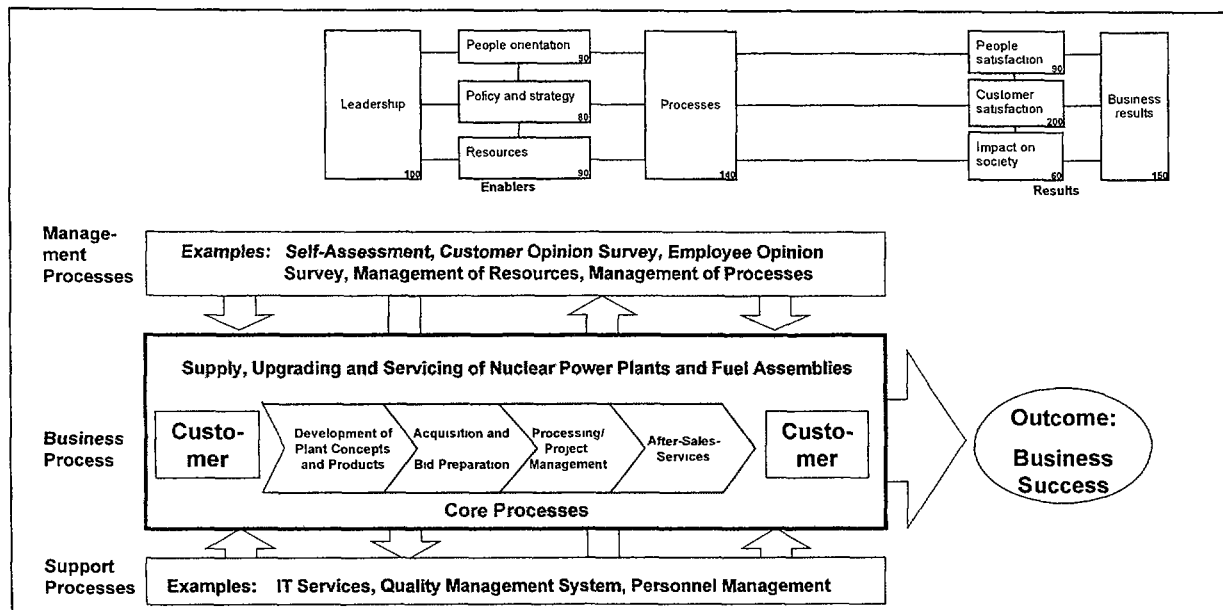
FIG. 3. Integrating the Model for Business Excellence with our Process Model

This business process is *supported* by support processes that provide various resources and services (i.e. information technology, QM system or Personnel Management).
Significant influence over the business process, however, comes from the so-called management processes that are crucial for the functioning of the organization and ultimately its success (e.g. Recognition, Business Planning, Qualification Planning, IT Strategies, Continuous Improvement of Processes).

The Business process often includes special technologies and know-how which are the unique reason for the organization to exist. The management processes, however, are non-specific to the business and can therefore much more readily be available for analysis, learning and exchange by many organizations.

In this context the EFQM Model serves as a filter for the analysis and improvement of the management processes by which we control our precious Business Process. The second part of the model then assesses the overall success of the organization as defined by its prime stakeholders: Customers, employees, society and shareholders. (Customer Satisfaction, People Satisfaction, Impact on Society and Business Results).

4. IMPLEMENTATION OF SELF-ASSESSMENT

How do you get this philosophy into an organization?
In the early Nineties, the Siemens Nuclear Fuels Business had already undertaken a special Quality Campaign in which many facets of a total quality concept were energetically addressed and businesswide promoted: quality is more than just the quality of the product!
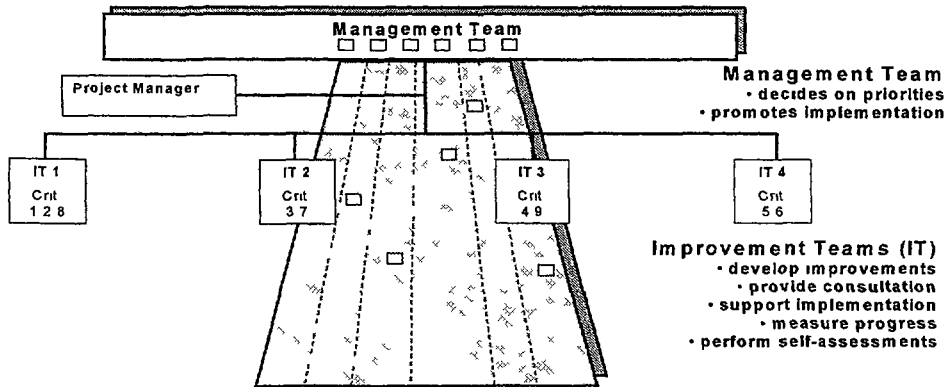
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FIG 4 The Management Team and four Improvement Teams across the Organization drive Continuous Improvement

New momentum, however, came from a TQM-Workshop with Senior Management of the Siemens KWU Divisions in 1994, in which an inspiring example was presented of a company that managed its turn-around, guided by the European Business Excellence Model. Our management recognized its benefits and decided to use this model as a tool for improvement of our business in periodic self-assessments.

Training sessions of various depth were carried out by licensed trainers for managers and employees, using case study material of EFQM. A special project structure was developed to ensure representation of all major organizational units and of all levels of responsibility in the business, while distributing the actual self-assessment activity into teams that were focused on specific criteria of the EFQM Model. This approach has since been refined, and is reflected in Fig. 4.: Four "Improvement Teams" are working now, each one led by a member of the Senior Management Team (or two) who is - with his team - "in charge" of certain criteria of the Model. Jointly with the Senior Management Team the Improvement Teams drive the improvement process across the organization. They develop improvement projects relevant for the whole organization, provide consultation in matters of their criteria They support implementation and measure progress. One of their prime activities, however, is the annual self-assessment.

In short, the self-assessment process (Fig. 5) consists of a structured process in which defined management processes and defined result categories are systematically and regularly analyzed and assessed according to the EFQM measuring scale. Based on improvement areas recognized, projects and actions are developed.
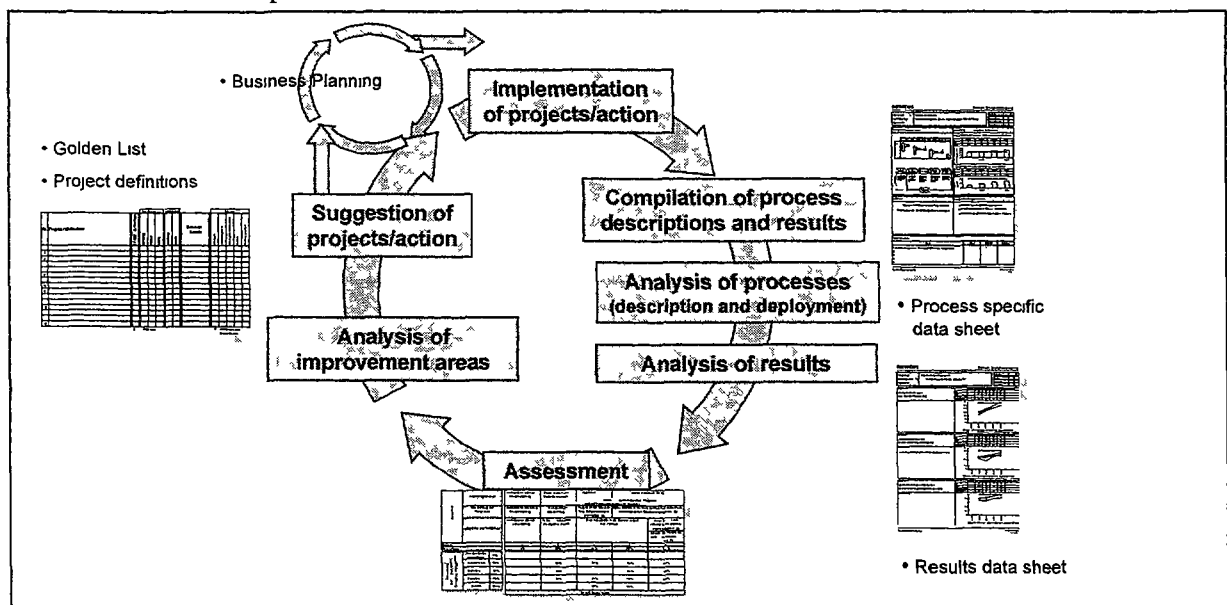

FIG. 5. Our Self-Assessment Process

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These proposals are usually entered into the Business Planning process along with other relevant parameters to allow a comprehensive evaluation of priorities before decision and implementation. The project definition sheets and the summarizing "Golden List" hereby serve as a basis for communication and project controlling. This process is subject to periodic process reviews and has been continuously improved over the last six assessments.

One important rule is that you can only assess what has been documented. Therefore it is necessary - in preparation of the self-assessment - to have available the description of the process (possibly in the structure of Plan-Do-Check-Act) and the evidence of data describing the results (preferably with data reflecting trends, goals and external comparisons). To support this approach, we have been using forms that facilitate such documentation, updating and scoring for the Enabler criteria and the Results criteria of the EFQM Model.

5 OUR BUSINESS EXCELLENCE PROCESS

As mentioned above, self-assessment results are an important piece of input into Strategic Business Planning which is a key element of our Business Excellence Process (Fig. 6). This is the process by which we *orient* our whole organization toward running our business in the optimal way. It is aimed at assuring *business success* according to the mission of the organization, and this graph identifies the main steps, inputs and tools: It covers the whole business year and is repeated annually. Strategic Planning brings all relevant elements of information together and evaluates them.

As shown on the left, self-assessment results constitute only one of several input elements, however they are very significant, since all aspects of management processes are addressed. The Strategic Planning step ultimately decides on priorities and balances the interests of the stakeholders. The *Business Field Meetings* finally provide the stage for discussing and finalizing the strategy of the business, clarifying the strategy drivers. And in the *Policy Deployment* step that we call Agreement of Objectives, the strategy and goals of the business are broken down into goals and objectives for the individual organizations through all levels of the hierarchy, down to the individual employee. Ultimately, every member of the organization, manager and staffer alike, holds a compilation of goals and objectives ("Kursbuch") for himself, his organization and all his superior organizational levels. Larger business organizations monitor their status with respect to their strategic goals using a set of financial and non-financial indicators that are based on their strategic drivers and that aim at providing early warning signals At other levels, the *Status of Objectives* is checked periodically, in order to clarify needs for support or counteraction. Finally, Self-Assessment, Customer Opinion Survey and Employee Opinion Survey stand for steps that yield data and information, based on which we try to continually improve our business and the way we are running it.
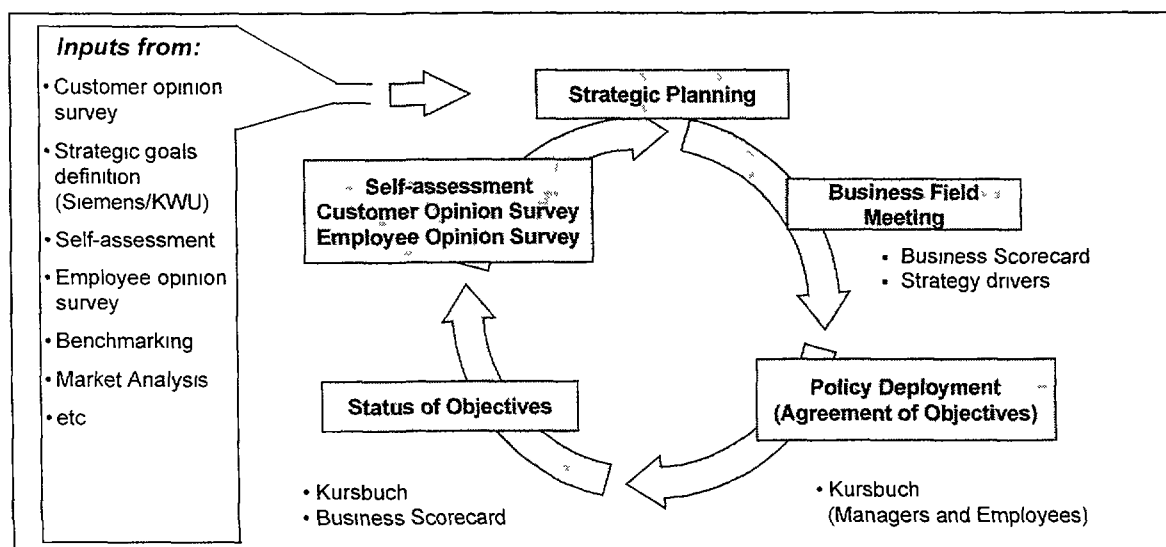

FIG. 6. Our Business Excellence Process (simplified)

6. CUSTOMER OPINION SURVEY; EMPLOYEE OPINION SURVEY

Let us briefly address the Customer Opinion Survey and the Employee Opinion Survey, both of which are structured similarly and are supported by external consultants and have been refined from year to year:

Our *Customer Opinion Survey* (Fig. 7) supplements our system of continuous customer project feedback evaluation; it is taken in regular intervals in order to identify and understand better his satisfaction with our products and services, his priorities and areas of improvement relative to competitors. The survey is based on structured interviews by independent personnel, the responses of which are discussed within our organization as well as with our customers. Action for improvement is derived in the units as well as at higher management levels and conclusions are entered into the Strategic Planning step of our Business Excellence Process, as shown above.
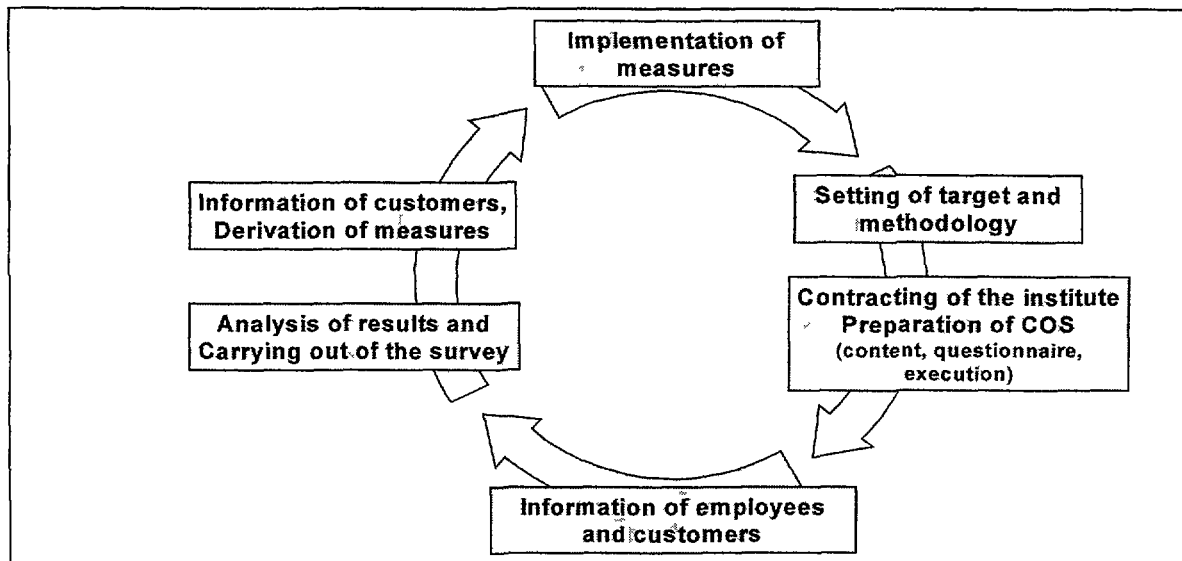

FIG. 7. Customer Opinion Survey (COS) as a Closed-loop Process

Our *Employee Opinion Survey's* essential steps (Fig. 8) include an anonymous questionnaire, discussion of results between employees and managers, agreement on measures of improvement at the local level, implementation of measures and a review of achieved success. All managers receive a detailed report on the results of their unit which are then evaluated. Jointly agreed actions of improvement are recorded with the goals of the local unit in the "Kursbuch", while more general conclusions enter in the process of strategic planning and policy deployment. This year's EOS has for the first time been carried out on an international level, including the U.S. part of the Siemens Nuclear Fuel Activities.

7. RESULTS

What have we achieved through self-assessment using the EFQM Model?
In most general terms we can say that we have achieved an increase in corporate quality as evidenced in the plot of assessment scores (Fig. 9). We will not claim any scientific precision for this record of data, however, it gives an indication of an effort that can hardly be argued with:

On the *Enabler side* we own now a "state-of-the-art tool box of Management Processes" that could help us master better the challenges in our everchanging business environment. I mentioned just a few examples above (EOS, COS, Policy Deployment, ...). Another example from our organization is being described in detail in a separate paper (Mr. Osseforth/Mr. Engel, ANF GmbH, on improvement work by employees in the fuel fabrication area). It is up to us to keep learning with these processes and to develop them further.
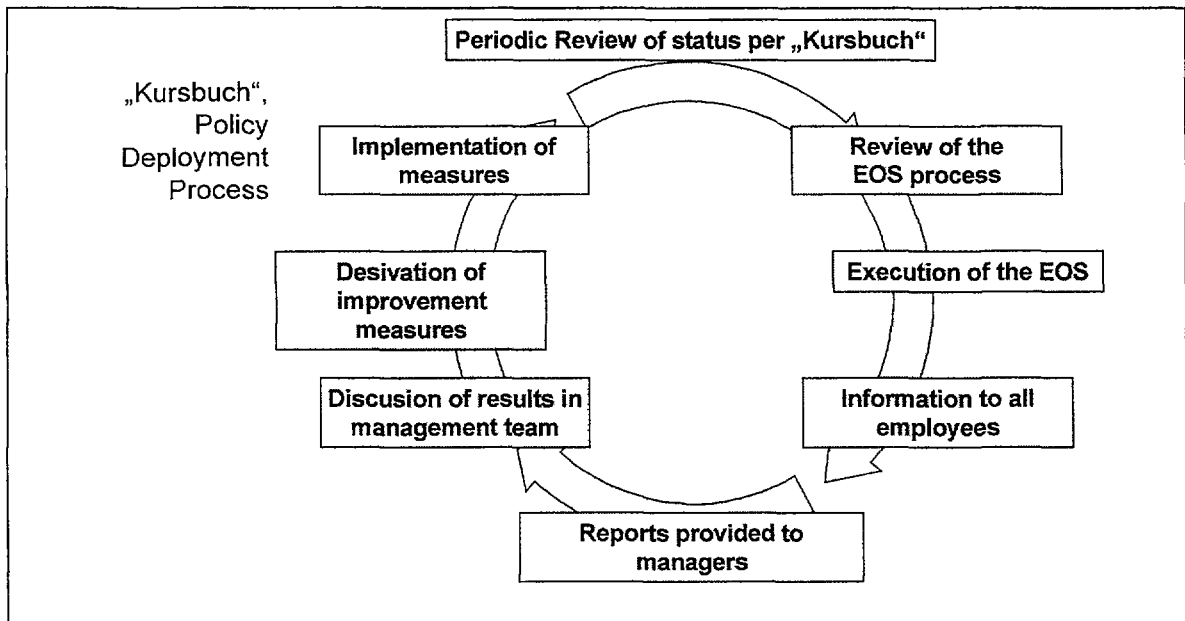
FIG. 8. Employee Opinion Survey (EOS) as a Closed-loop Process
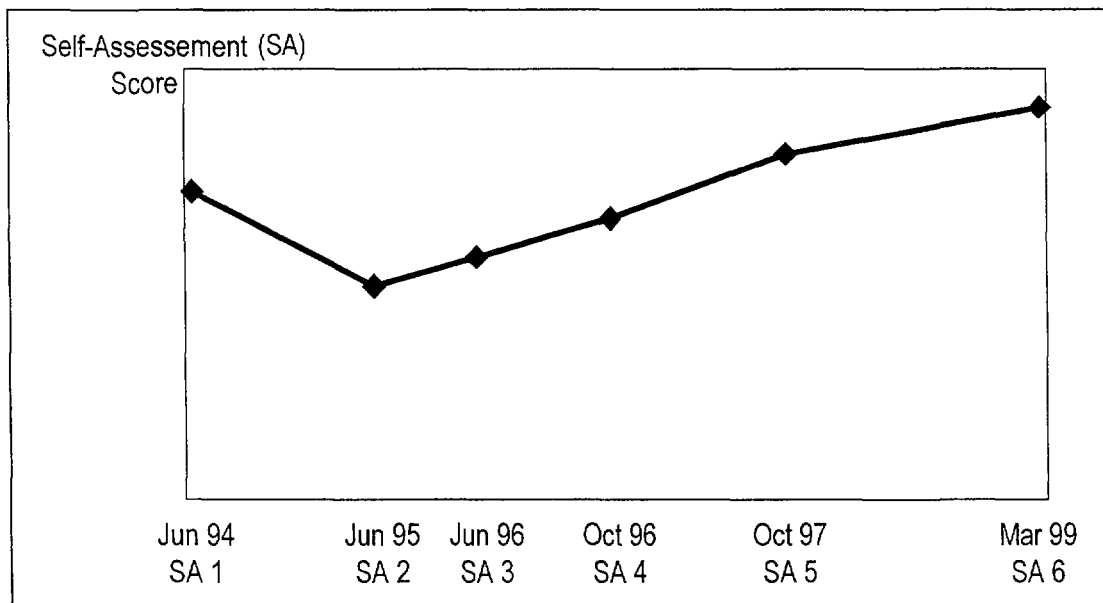

FIG. 9. Self-Assessment Scores of the Siemens Nuclear Fuels Business (Europe)

Just a few examples on the *Results side* (Fig. 10): Customer satisfaction is evidenced by positive data from the Customer Opinion Survey.

Employee satisfaction is showing positive trends of accepting the management style.
Critical indicators for business results - like on-time-delivery - are showing favourable trends.
And with respect to the bottom line of business results we can say that our Total Quality efforts gave us valuable orientation after passing through restructuring.
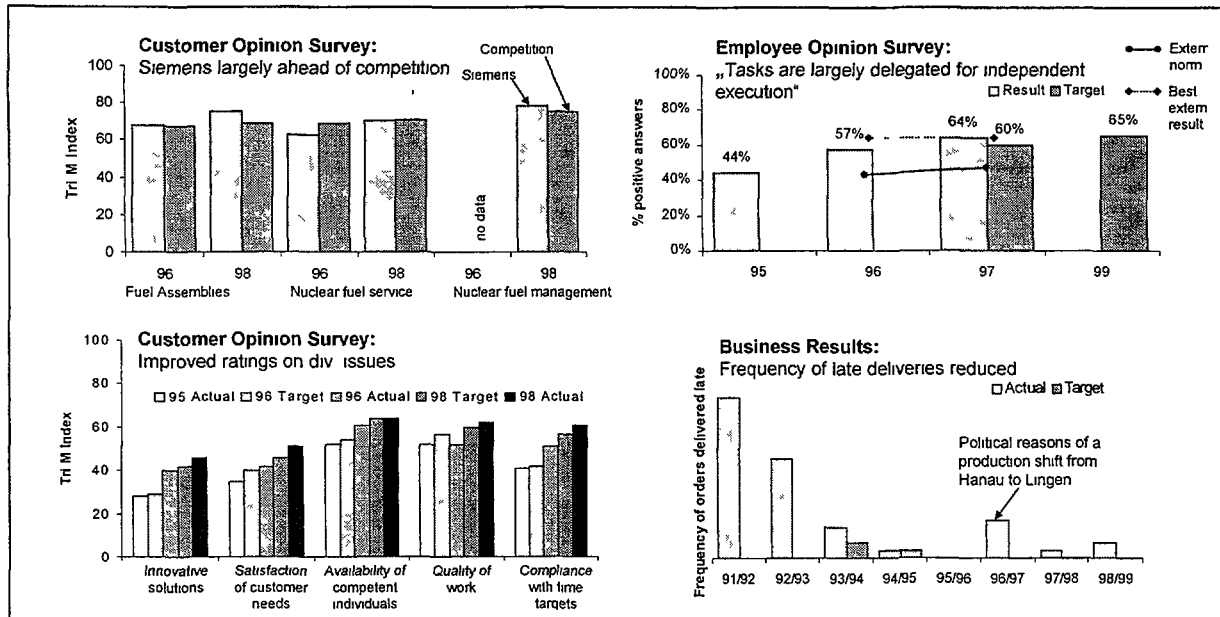
FIG. 10. Some Results of Self-Assessment Work: Customer Satisfaction, People Satisfaction, Business Results

8. OUTLOOK

In using the EFQM Model we have realized, that the recommendations for self-assessment in the IAEA Standard are well suited to improve our business for the benefit of all our stakeholders: Customers, Employees, Shareholders and Society.

Looking at the current development of international standards, we seem to be heading in the right direction, since the new ISO 9000-series (draft: 2000) has already integrated relevant elements of Business Excellence. Furthermore, the improved EFQM Excellence Model, issued 1999, even more stresses customer orientation and partnerships. A culture of learning is identified as a basis for Business Excellence and all activities must be oriented - through policy deployment - towards the attempted business results.

These changes in the field of general standards and management concepts fit in with new approaches of the IAEA Codes in the *nuclear field*. For us in the nuclear industry, improvement of Corporate Quality *is* important, - not only in order to make out in the face of competition with fossile and other energy sources. Especially with the power market being deregulated in Europe and cost pressures increasing further, attention on *product quality* must be maintained, but also enhanced by well structured consideration of the Corporate Quality issues including safety, environment, economics, risk management and society.

It was said: The quest for quality is like going for the end of the rainbow: We have to keep trying, - the path is the goal.

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EXPERIENCE OF THE IMPLEMENTATION OF QUALITY MANAGEMENT SYSTEM AT THE JOINT STOCK COMPANY "MASHINOSTROITELNY ZAVOD", ELECTROSTAL

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Abstract

The paper describes major steps of development and implementation of Quality Management System (QMS) in nuclear fuel fabrication at Joint Stock Company "Mashinostroitelny zavod", Electrostal, Russian Federation. Special emphasis is paid to the estimation of QMS effectiveness, current impact of QMS implementation on nuclear fuel quality, sales market and directions for further QMS development.

1. Introduction.

JSC "Mashinostroitelny zavod" (JSC "MSZ") is one of the major enterprises in the world manufacturing nuclear fuel for nuclear power plants.

The enterprise was set up in 1917 as a factory for the ammunition production and aviation bombs of different caliber. Fabrication of the products for nuclear industry with the use of different chemical-metallurgical processes started in 1945. From 1953, the enterprise started fabrication of fuel rods and fuel assemblies for the nuclear industry.

The list of current products fabricated by the JSC "MSZ" includes:

-Fuel assemblies for different nuclear reactor types including WWER-440, WWER-1000, RBMK-1000, RBMK-1500, EGP-6 (for Bilibino NPP), BN-600, PWR and fleet reactors;
-Metal distilled calcium;
-Anisotropic ceramic barium and high-power magnets;
-Hard alloy tools for metal treatment and rock-cutting machines;
-Tubular heaters for air, water and oil;
-Air conditioners and other domestic appliances.

2. General characteristic of the market and requirements to quality of the products manufactures

The present report contains the review of the market of fuel assemblies because the fuel assemblies contribute mainly to the economics of JSC "MSZ". JSC "MSZ" delivers the nuclear fuel to 50 power units of NPPs in Russia, Armenia, Kazakhstan, Lithuania, Ukraine, Bulgaria, Hungary, Germany, Slovakia, Finland, Czech Republic.

At present, there is a strong competition on fuel assembly's market. LWR fuel fabrication capacities are much higher than the annual current demand wordwide. Only in Far East countries, the demand for the fuel fabrication services exceeds the available production capacities. On this basis the fuel manufacturers have to take measures to increase the fuel fabrication effectiveness.

The market dictates the necessity of constant fuel optimization, improvement of commercial terms and conditions, increase of the reliability of the supplied fuel ensuring, at the same time, necessary fuel safety margins for the high burnup operation.

The approach to settling these problems acknowledged worldwide is the set up and optimization of the Quality Management System (QMS). The basis of the QMS most widely used now is the series of the international standards (IS) ISO 9000.

The functioning of the QMS of the nuclear fuel suppliers plays an important role for successful licensing. This has led to the establishment of the requirements on the presence and functioning the QMS in the contracts signed with foreign and Russian customers. Besides, such requirements are put forward by the regulatory bodies of Russia, in particular, by GOSATOMNADZOR of the Russian Federation.

3. History of the QMS

The history of setting up the QMS at JSC "MSZ" includes several stages. They are overviewed below.

3.1. Pre-history (up to the mid-50s)

During this period the basis for the responsible attitude to the quality of the work fulfilled and products manufactured was created. The nature of the products manufactured – ammunition and bombs – required high accuracy and responsibility (in the modern quality terms) during the loading process.

3.2. Stage 1 (end of 50s- beginning of 70s) – creation of quality control system

At this stage fabrication of new products – fuel assemblies was started, as well as development and implementation of specific inspection methods. The structural formation of the services and departments of JSC "MSZ" took place at this period. Mainly, the formation of the departments included into the quality service was completed during this time period.

3.3. Stage 2 (end of 70s – end of 80s) – complex (factory) Quality Management System

At this stage the complete **product** QMS was developed and implemented. The complete product QMS of the JSC "MSZ" was one of the first in the USSR and it was registered in the Moscow Centre of Standardization and Metrology.

The implementation of the complex product quality management system allowed to optimize the technology and inspection techniques and methodologies, and to improve the quality of the technical documentation.

3.4. Stage 3 (from the beginning of 90s) – Quality Management System

Step 1 – is setting up, implementation and certification of the QMS on the basis of IS ISO 9000.

The setting up of the QMS was performed in accordance with the requirements of the IS ISO 9000 using to the maximum the elements of the valid complex product QMS. First, it was decided to spread the QMS for the fuel assemblies production. Within a year, work related to the perfection of QMS was performed, it was documented and the needed arrangement changes were introduced. In November 1995, the QMS was introduced.

Taking into account the opinion of the customers, TUV CERT, an independent German company, was chosen as the certification body. The certification according to model ISO 9002 successfully passed the certification in March 1996 and a certificate for QS was issued. From 1999, the quality system that meets the requirements of the international standard ISO 9001 has been valid.

Step 2 – is QMS re-working, QMS estimating under the **criteria of the Award of the Russian Government**, participation in the competition and obtaining this Award. The second step

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became the natural result of the realization of the fact that the existence of QMS meeting the requirements of ISO 9002 confirmed by the certificate for QMS is currently the necessary but not sufficient condition for the effective production.

At present the quality award models become more and more popular. In 1996 the Government of the Russian Federation set up a Quality Award (further- Russian Quality Award).

The structure of this award mainly meets the European Quality Award. The analysis of the award conditions and self-assessment of QMS demonstrated that it is reasonable for JSC "MSZ" to participate in the first competition for this award. During 1997, great work was carried out as to be prepared for the participation in the competition. Upon the results of the first competition, in November 1997, the Quality Award of the Russian Federation was granted to JSC "MSZ". This confirmed the correctness of the way chosen for the QMS optimization.

Step 3 – is QMS development with the purpose to create TQM (Total Quality Management).

4. Estimation of QMS effectiveness

After the enterprise has reached the formal goal – QMS certification, the QMS effectiveness becomes the priority and, consequently, the QMS estimation becomes one of the most important issues. At present, this estimation is carried out by 2 different means that are almost independent of each other. Our purpose is to synthesize them, create one powerful and effective tool for the QMS functioning estimation completely oriented to TQM.

Let's consider these estimation methods in more detail. One of the methods is the fulfilment of the new matters that were introduced in QMS by the IS requirements of ISO 9000. The QMS effectiveness estimation is made at the meeting of the Coordination Board according to the "Methods of the QMS effectiveness estimation" developed on the basis of the quality policy. One of the main constituents of the estimation are the results of the internal QMS – internal audits. Here, the criterion is the conformity of the activity with the normative documentation for QMS and requirements of IS ISO 9000. The departments, on the basis of the estimation results, develop together with the auditors and, under their control, perform corrective and preventive actions in QMS. The other method is the estimation by the criteria of one of the quality awards, foe example, Russian. At present such estimation is performed as follows:

- departments of JSC "MSZ" responsible for a certain type of activity estimate this activity ("self-assessment") by the criteria of the Award and they choose the items and procedures that demonstrate the fulfilment of the criteria;
- a final report is prepared on the basis of the estimation results of the departments;
- a group of experts performs the scoring of the QMS effectiveness on the basis of the report.

Both methods have their merits. The task is to use these merits.

On the basis of the experience gained in the "self-assessment", a sufficiently representative and effective set of items and procedures, according to the criteria of the Russian Quality Award, is developed and included in the valid QS normative documentation. The estimation under the award criteria can be carried out by the results of the internal audit – a valid effective tool of direct and objective checking in departments and JSC "MSZ" in general. The expert group can be combined with the group of auditors (really, now it mostly comprises auditors). A representative scoring (1000 - point) methods, oriented to TQM, will be used for the QMS estimation. Here, the almost non-limited possibilities to optimize the methods shall be noted.

5. QMS implementation results

In this section, individual, the most representative results of the QMS implementation are presented.

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5.1. Preservation of sales markets

This activity aspect is especially important for us as in the situation of general recession, destruction of contacts and removal of Russian goods form the sales markets the preservation of the sales markets, especially foreign, is doubtlessly a real achievement.

Only lately we can note the victory in the bid for the fuel supply to Czech Republic (NPP "Dukovany") and Slovakia (NPP "Bohunice", NPP "Mohovce"). During the bid the major world nuclear fuel suppliers –"Westinghouse" (USA) and EVF (Germany – France) were our competitors.

5.2. Coming into new markets

Here, the strong competition in the market between the leading companies-manufacturers, already mentioned before, shall be noted again. In such situation, some leading foreign companies, acknowledging the reputation of JSC "MSZ" often prefer the mutually profitable cooperation to competition. For example, German company "Siemens" became our major partner. The fuel assemblies fabricated at the enterprise operated successfully during the third campaign at NPP "Obrigheim". New contracts with "Siemens" are signed for the supply of fuel assemblies for 4 NPPs of Germany and Switzerland. Preliminary negotiations concerning signing contracts for the fuel delivery to other NPPs in Sweden, Holland and Belgium are under way.

Also, successful release of the fuel for WWER-1000 can also be noted for Kalinin NPP.

Active work is performed with a number of foreign companies in other directions as well.

5.3. Changing the psychology of the management in the system of staff training

One of the main results of the QMS implementation we consider to be the change of the psychology of the management regarding the staff training approaches.

First, all the staff was trained. More than 100 people underwent training in quality according to European programs for the high and middle level management, promoters, auditors, with the assistance of consulting companies RW TUV and "Intercertifica". 9 people were trained under the 160 quality management hours course in Germany and Bulgaria. The rest of the staff was trained under the programs developed by JSC "MSZ" for different categories in the Staff training department.

Second, as a result of the direct development, implementation and estimation of QS functioning a group of specialists of all the levels of JSC "MSZ" got the practical experience and improved its qualification in the field of quality management. At present, JSC "MSZ" has the specialists in the field of the quality management possessing the unique, for Russia, experience in the QMS setting up and functioning. Just for the sake of confirmation:

1. JSC "MSZ" has developed and implemented QMS for the magnet production and in April, 1998 TUV CERT has performed its successful certification audit, as well as the certification in accordance with ISO 9001 in June 1999.

2. The self-assessment results according to the Russian quality award almost completely coincided with the conclusion of the experts of this award.

3. The high level of the arrangement and performance of internal audits and audits of the quality system of the sub-contractors, noted during the supervisory audit of TUV CERT in April 1998 and during the qualification audit of "Siemens" company in March 1998.

The availability of such a potential allows us to look into the future without fear.

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6. Main directions of the QMS development

As it was noted earlier, now we are developing QMS based on TQM principles. We have already paid certain attention to some work, in particular, we have noted the optimization of procedures of the policy development in the field of quality and QMS effectiveness estimation. Let's briefly consider the most important directions of QMS perfecting.

6.1. Covering all the products manufactured

At present, the work related to the spreading of QMS to all the consumer goods production and fabrication of the equipment for the internal use is under the supervision of GAN. Certain work is planned in relation to spreading QMS to calcium production.

6.2. Involving all the structural departments.

In 1997 the validity of QMS covered the fabrication of thin-walled tubes. The financial department was included into QMS. It is planned to include other workshops and services in it.

6.3. Development and implementation of new QS elements optimization of the procedures under the existing QS elements.

Such work is carried out continuously, in particular, in relation to the estimation of the expenses for quality, design management, etc. At present preparation work for certification in accordance with ISO 14000 "Management for Environment Protection" is underway.

6.4. Annual self-assessment according to the models of national and international quality awards.

To perform the QMS effectiveness estimation the criteria of the Russian quality award can be now used.

6.5. Participation in the European Quality Award

For us it is important to participate in this Award as this will allow to have a look at our QMS with the eyes of the leading European QS experts, find out the weak points and plan further ways of optimization. Having considered the results of the self-assessment and those of the competition within the Governmental Award of the Russian Federation, the Coordination Board of the factory decided to participate in the European Quality Award.

7. Conclusion

As a conclusion, we would like to stress once again that the quality issues related to the products fabricated, that can be settled with the help of QMS, always have been and remain the first priority for the management of JSC "MSZ". We understand that, in the market conditions, this is the basis of our prosperity now and in future.

INTRODUCTION OF THE NEW PROCESS AND QUALITY CONTROL METHODS IN FUEL FABRICATION AT SIEMENS/ANF

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Abstract

The central point of ANFs quality philosophy is the process of continuous improvements. With respect to the causes of defects and the efforts needed for elimination, the importance of continuous impovements is evident. In most of the cases, defects are caused in the initial stages of a product but the majority of the problems will be only detected during fabrication and inspection and in the worst case when the product is already in use. Goal of the improvement process is to assure a high product quality. Therefore, the efforts are focused on robust and centered processes. A reasonable quality planning is the basis for achieving and maintaining the quality targets. Quality planning includes prefabrication studies, inprocess inspections and final inspections. The inspections provide a large amount of various quality data, process parameters as well as product properties. Key data will be defined and subjected to a statistical analysis. In view of the effectiveness of the analysis, it is important, that the process parameters which influence the characteristics of the product are well known and that appropriate methods for data evaluation and visualization will be used. Main approach of the data visualization is to obtain a tighter control of the product properties and to improve the process robustness by implementation of defined improvements. With respect to the fuel safety and fuel performance, the presentation shows for typical product quality characteristics some examples of visualized quality data. The examples includes the integrity of the pellet column (rod scanner results), the spring force of PWR spacers (critical characteristic with regard to rod fretting) and the spacer intersection weld size (thermo-hydraulical fuel bundle behaviour). The presentation also includes an example for the statistical process control, the in-line surveillance of the fuel rod weld parameters which assures the integrity of the welds within tight tolerance ranges. The quality system and efforts assure products of high quality and contribute herewith to the safe and economical performance of the fuel supplied by Siemens/ANF.

1. INTRODUCTION

The presentation provides an introduction of the new process and quality control methods which are applied in the fuel fabrication at Siemens/ANF to assure a high product quality.

With respect to the main objectives of the meeting, that is the improvement of the fuel safety and fuel reliability, the presentation is focused on the principle and the goals of the continuous improvement process.

The presentation provides useful information to the content and structure of a reasonable quality planning which can be considered as the driving force for continuous improvements.

The presentation explains the importance and the purpose of the analysis of quality data. The visualization of quality data will be illustrated by practical examples.

2. THE CONTINUOUS IMPROVEMENT PROCESS

The continuous improvement process is the central point of ANF's quality philosophy.

A continuous control and a monitoring of processes will initiate preventive actions which finally will result in further product improvements or process modifications. Any design or process changes require a qualification. Based on the qualification, the changes will be introduced in the fuel
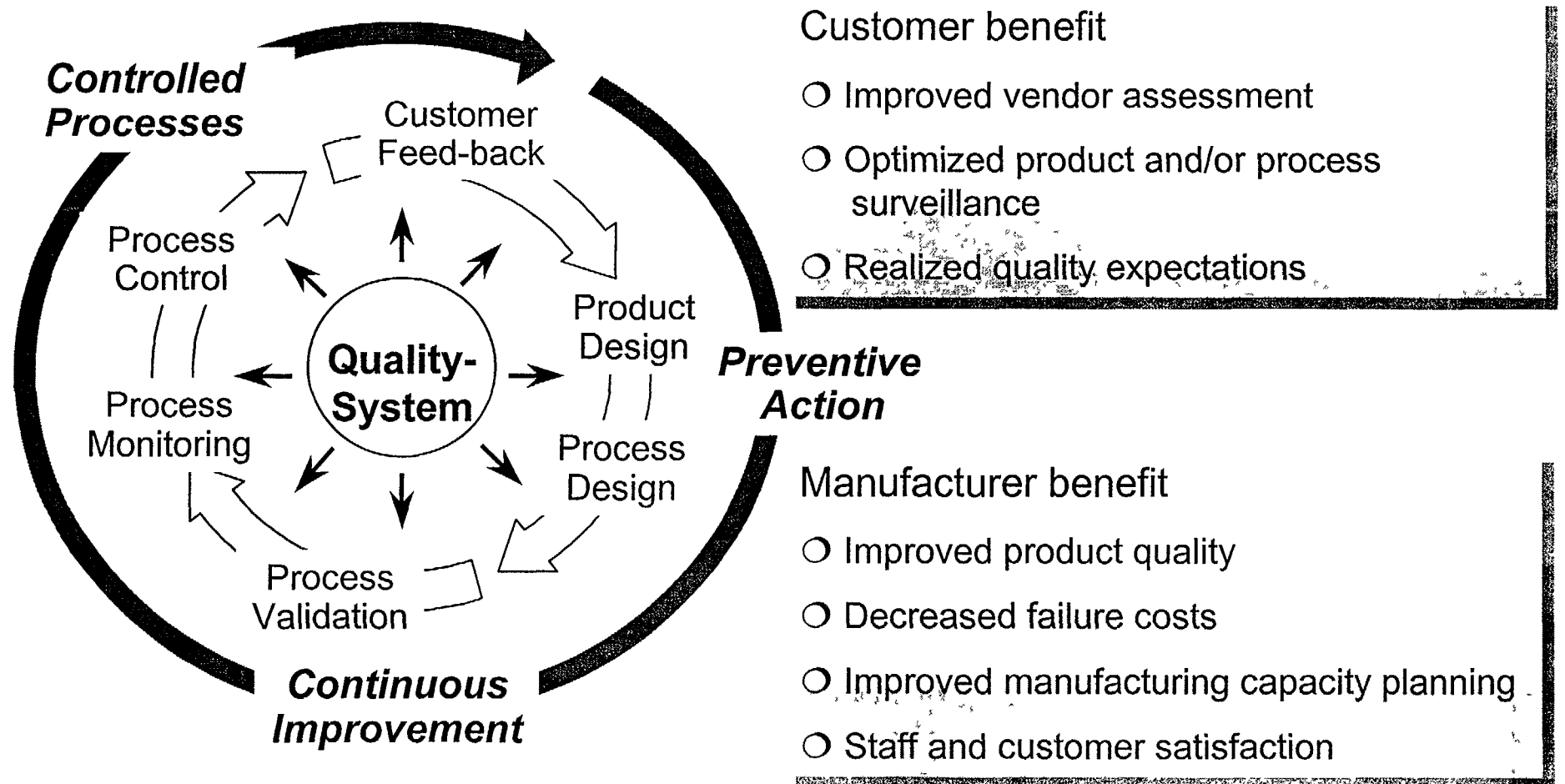
Controlled Processes

Customer Feed-back

Process Control

Process Monitoring

Quality-System

Product Design

Process Design

Process Validation

Continuous Improvement

Preventive Action

Customer benefit

O Improved vendor assessment

O Optimized product and/or process surveillance

O Realized quality expectations

Manufacturer benefit

O Improved product quality

O Decreased failure costs

O Improved manufacturing capacity planning

O Staff and customer satisfaction

FIG 1 Principles of continuous process improvement

fabrication and the controlled process continues. The sketch (Fig. 1) clarifies the principle of the entire process.

The quality system provides the basis for the continuous improvement process, e.g. by appropriate requirements with respect to the product and process qualifications and by a management system for preventive actions. In addition to the QM system, there are also other factors contributing to the efficiency of the continuous improvement process, especially the feedback of the customers.

Besides the fulfillment of quality expectations, the continuous improvement process provides additional benefits to the customer such as an improved vendor assessment and an optimization of product and process surveillances. Improved product quality, a decrease of failure costs and achieving staff and customer satisfaction are the main benefits for the manufacturer.

The diagram (Fig. 2) explains the importance of improvements by showing the dependence on the cause of defects and their elimination. In most of the cases, defects will be caused already in the initial stages of the product research and development but the majority of the defects will be detected much later, in most of the cases during inspection. In the worst case, defects which are already latent during the product and process development will be detcted only during the performance of the product. The costs to eliminate a defect depend on the phase of detection. Defects which appear during final inspection or in the use of a product cause significantly higher costs than defects which can be already settled during planning.

To meet a high product quality Siemens/ANF relies on robust and centered processes. The diagrams shown in Fig. 3 illustrate the benefits of robust and centered processes. A process can be considered as robust when relatively large variations of process parameters will have no significant influence on the product properties. The centered process (Taguchi philosophy) can be evaluated by means of the cpk-values. In order to achieve a robust and centered process it is necessarry to have an adequate knowledge of the entire process.
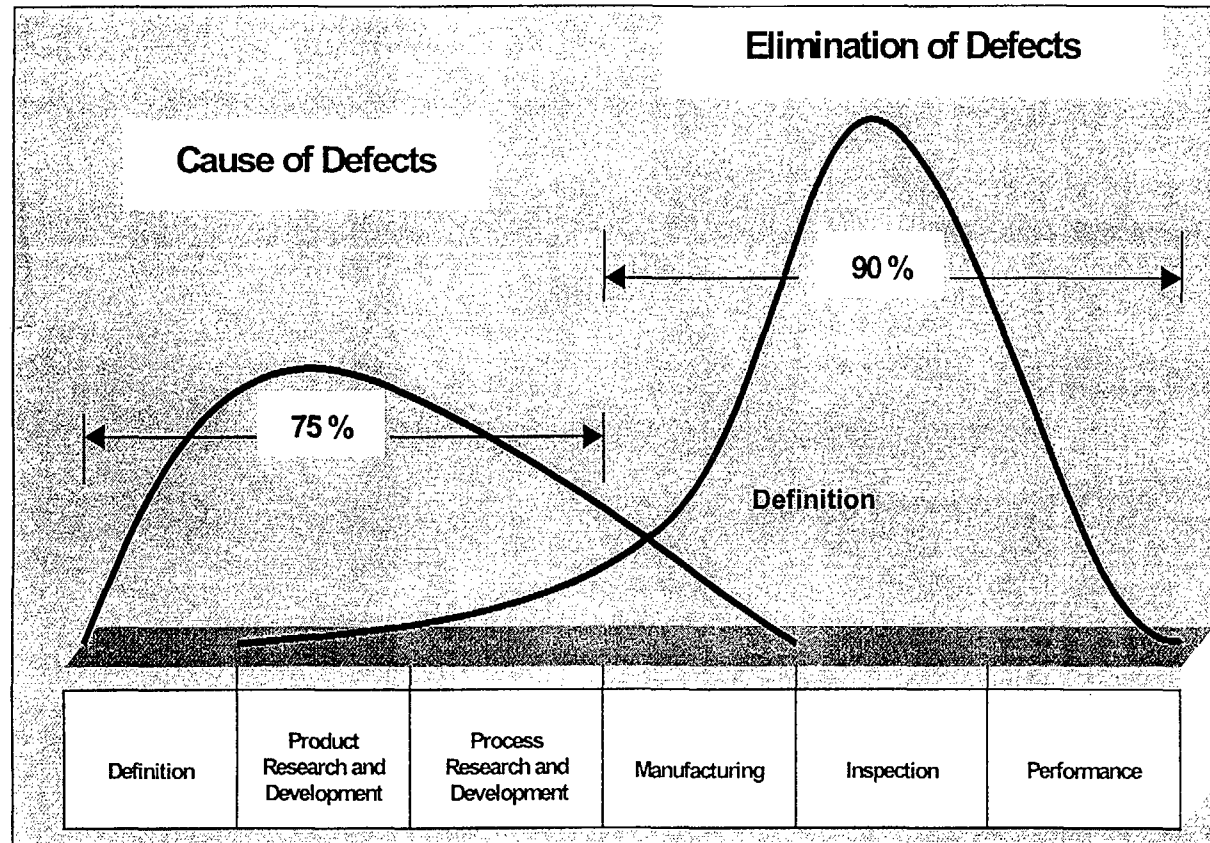
3.   QUALITY PLANNING

A systematic quality planning is the driving force for continuous improvements. Quality planning includes:

- Prefabrication studies with review of the design package,
- Fabrication and inspection planning with review of qualifications,
- Determination of key quality data for statistical evaluation,
- Analysis and visualization of quality data,
- Quality improvements (In view of the results of the statistical analysis).

Prefabrication studies are especially required in case of a new product design and or manufacturing processes. The studies are mainly focused on:

- Review of the suitability of the existing production and inspection equipment, including the intended methods and techniques,
- Review of the applicability and validity of present process and product qualifications,
- Review of the process flow (sequence of operations, e.g. cleaning steps),
- Review of the sufficiency of personnel qualification,
- Review of the design package. Prior to the issue of a parts list, the specifications and drawings will be reviewed by ANF key functions to verify the fabricabiltiy of the product on the basis of the specified requirements. The design documents have to be agreed between the design department and the manufacturer site. This procedure presents an important part of the installed QM system and assures, that the design requirements and the production experiences are brought together on the basis of a systematic process.

Elimination of Defects

Cause of Defects

90 %

75 %

Definition

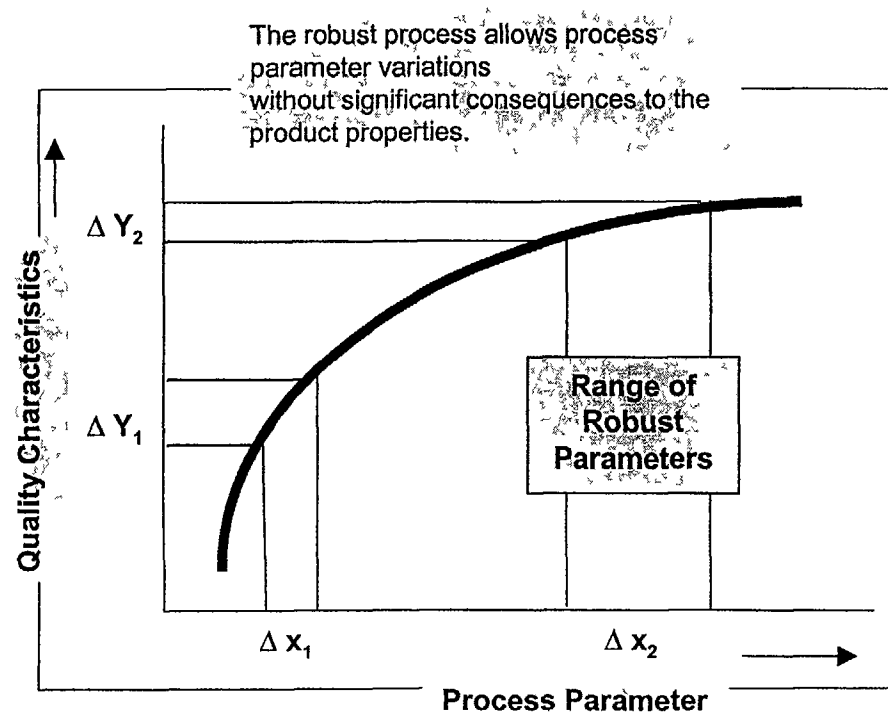| Definition	Product Research and Development	Process Research and Development	Manufacturing	Inspection	Performance

In most of the cases, defects are caused in the initial stages of a product. A large amount of problems is already latent during the product and process development phases.

The majority of defects and problems will be only detected during the fabrication and inspection of the product or later when the product is in use.

The costs to eliminate a defect depend on the phase of detection. Defects which appear during fabrication or in the use, cause significant higher costs than defects seen already during planning.

FIG. 2. The diagram of continuous process improvement - cause of defects and their elimination

Goal of Continuous Improvements is to Assure a High Product Quality

The robust process allows process parameter variations without significant consequences to the product properties.

Quality Characteristics (y-axis)

ΔY_2

ΔY_1

Range of Robust Parameters

Δx_1 Δx_2

Process Parameter

ANFs approach:
Achieving high product quality via controlled and robust processes!

lower limit   upper limit

Losses

Target

Taguchi philosophy:
Process control
shall assure
a centered process
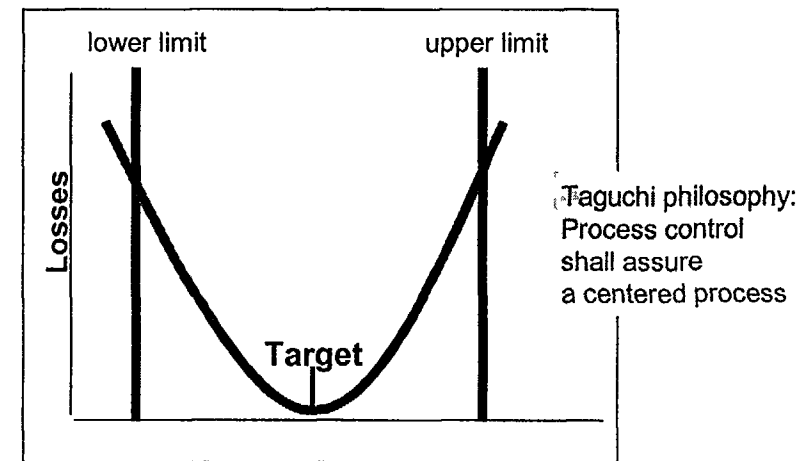
FIG 3   The benefits of robust and centered processes

The issue of inspection plans, including the determination of the inspections to be carried out, the applicable sample sizes, as well as the selection of the methods to be used and the definition of hold points is also part of the inspection planning. The quality data which have an important influence on the reliability of the process and on the product properties will be determined and the statistical methods to be used to analyze the data will be decided. The preparation of the inspection plan and the selection of the key data, require a fundamental knowledge of the entire processes.

An additional part of the inspection planning concerns the preparation of working documents.Typical documents are manufacturing and examination sequence plans, shop traveller cards and inspection certificates. Those documents are issued on the basis of the specifications, drawings and applicable procedures.

In order to assure product quality from the beginning up to the end of the process, the overall inspection plan requires besides the final inspection also preproduction tests and inprocess inspection.

Pre-production tests are used to verify the process parameters and to estimate the product behaviour in the process. A typical preproduction test is, for example, the characterization of uranium powder to verify its fabricabiltiy and sinterability.

In-process inspections are performed to monitor product properties during the process. The tests and inspections will be performed either on samples or in-line on the product. Typical in-line inspections are the control of the green pellet density as an intermediate product characteristic and the measuring of the weld nugget size during spacer welding which is a final product characteristic but is measured directly after fabrication. Typical in-process tests on samples are the frequent metallographical examinations or the corrosion tests on weld samples of rod end welds.

The final inspection of finished products is mainly performed to proof that the products fulfill the specified requirements in the as-delivered-condition. The results of the final inspection are documented in appropriate certificates.

The tests and inspections shown above provide a lot of data (product properties and process parameters). Important quality data will be subjected to statistical evaluations.

4. ANALYSIS AND VISUALIZATION OF QUALITY DATA

The important quality data will be analyzed and visualized for the following reasons:

• To define the need of quality improvements by obtaining knowledge about reject rates and failure costs. These will be achieved by the comparison of actual data against target values. Typically by the evaluation of FPA values and failure costs.

• To clearly visualize quality trends. This is an important instrument to obtain an appropriate management response and support concerning the initiation of quality initiatives and the realisation of requested preventive actions. (Trend analysis of product properties or FPA values and failure costs).

As shown in Fig. 4, typical diagrams for the visualization of quality data are, for example, the Pareto analysis or histograms.

Important Quality Data will be Analyzed and Visualized

➢ To define the potential for improvements
(Comparison of actual data with target values and trend analysis)

➢ To have knowledge about reject rates and failure costs

➢ To make quality trends clearly visible, especially as an instrument
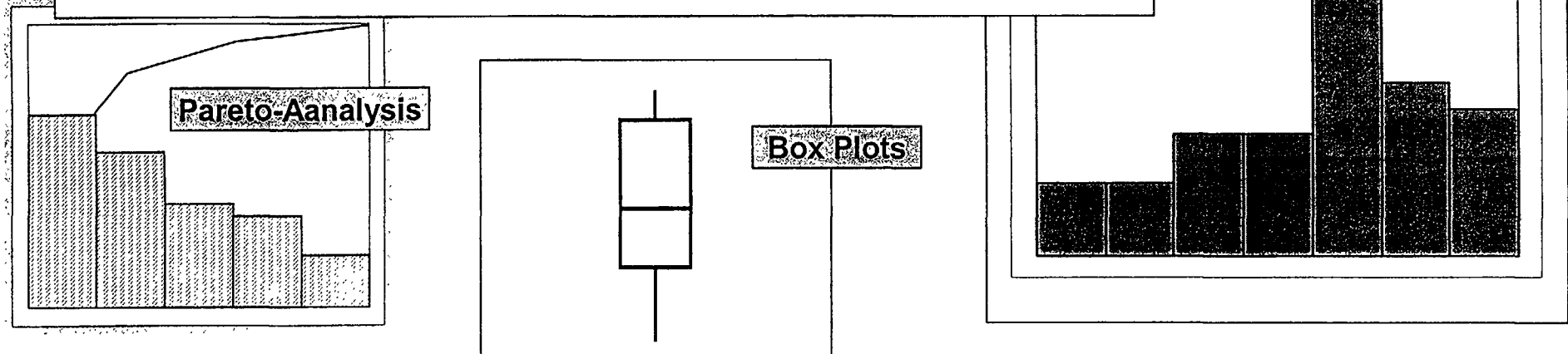for management information

Histograms

Pareto-Aanalysis

Box Plots

FIG. 4. Typical diagrams for the analysis and visualization of quality data

5.   EXAMPLES FOR VISUALIZED QUALITY DATA

Fig. 5 shows a simple but typical example of a Pareto analysis for fuel rod rejects. The diagram shows the different reject causes just in the order of the number of rejects.

Fig. 6 provides a trend analysis of fuel rod FPA values. (FPA: First Pass Acceptance). This trend analysis provides an excellent example for the efficiency of the continuous improvement process and especially for the benefits gained by the introduction of a new technique. Up to the middle of the nineties the main reasons for rod rejects were weld problems. The target for the FPA value was set at that time to 99%. The introduction of the upset shape welding technique caused initially even higher weld reject rates in the following years.

Since ANF became during this phase more familiar with the process by the solution of problems, the reject rate was clearly reduced. The process can be considered now as stable for already several years. The achieved weld reject rate is significantly smaller than it was the case with the weld technique used before. The FPA target was elevated from 99% to 99.5%. As shown in the diagram, the new target will be fairly met.

Fig. 7 shows the trend of the rod scanner rejects over the last years. As it can be seen, the reject rate decreases continuously from year to year with only some exceptions. In about seven years the total reject rate was reduced by 90%. This is a further example for the effectiveness of continuous improvements in the ANF fuel fabrication. A slight peak in the eddy current rejects in 1996 can be explained by the introduction of a new equipment. Due to lack of experience with the new equipment, very conservative accept limits were set at that time.

Fig. 8 shows a typical box plot diagram. The box plot visualizes the statistic of spacer spring force values of some PWR spacers. The spacer spring force is measured on the finished spacer in the frame of the final inspection.

Fig. 9 provides an example for an inline inspection control chart. The diagram shows the weld nugget size of the intersection welds of a PWR spacer. The size of the intersections weld is measured directly after welding the individual weld point. Thus, the data can be used to control the weld parameters during welding one spacer to assure optimum weld geometrys for each spacer.

6.   EXAMPLE FOR THE STATISTICAL PROCESS CONTROL

Fig. 10 shows as an example for the statistical process control at a new upset shape weld machine. The chart shows the typical windows of the fully automated statistical process control of rod end welding. The important process parameters, like the welding current, the force to be applied to press the end plug to the tube and the position of the tube end prior to welding, relative to the upset after welding, will be measured and recorded during welding. Directly after welding, the width and the height of the weld is measured. The data will be visualized for the personnel at the station and also stored in a database to enable effective process and parameter studies.
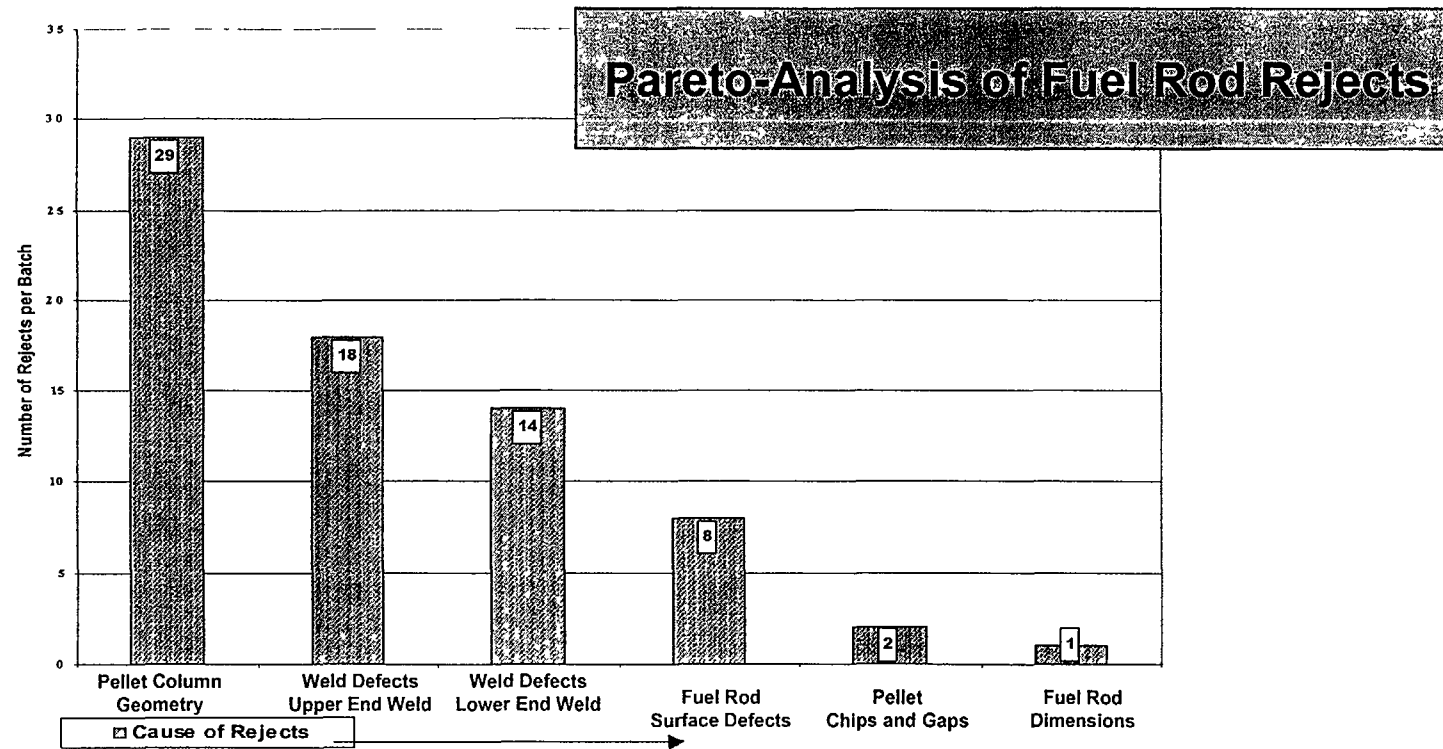
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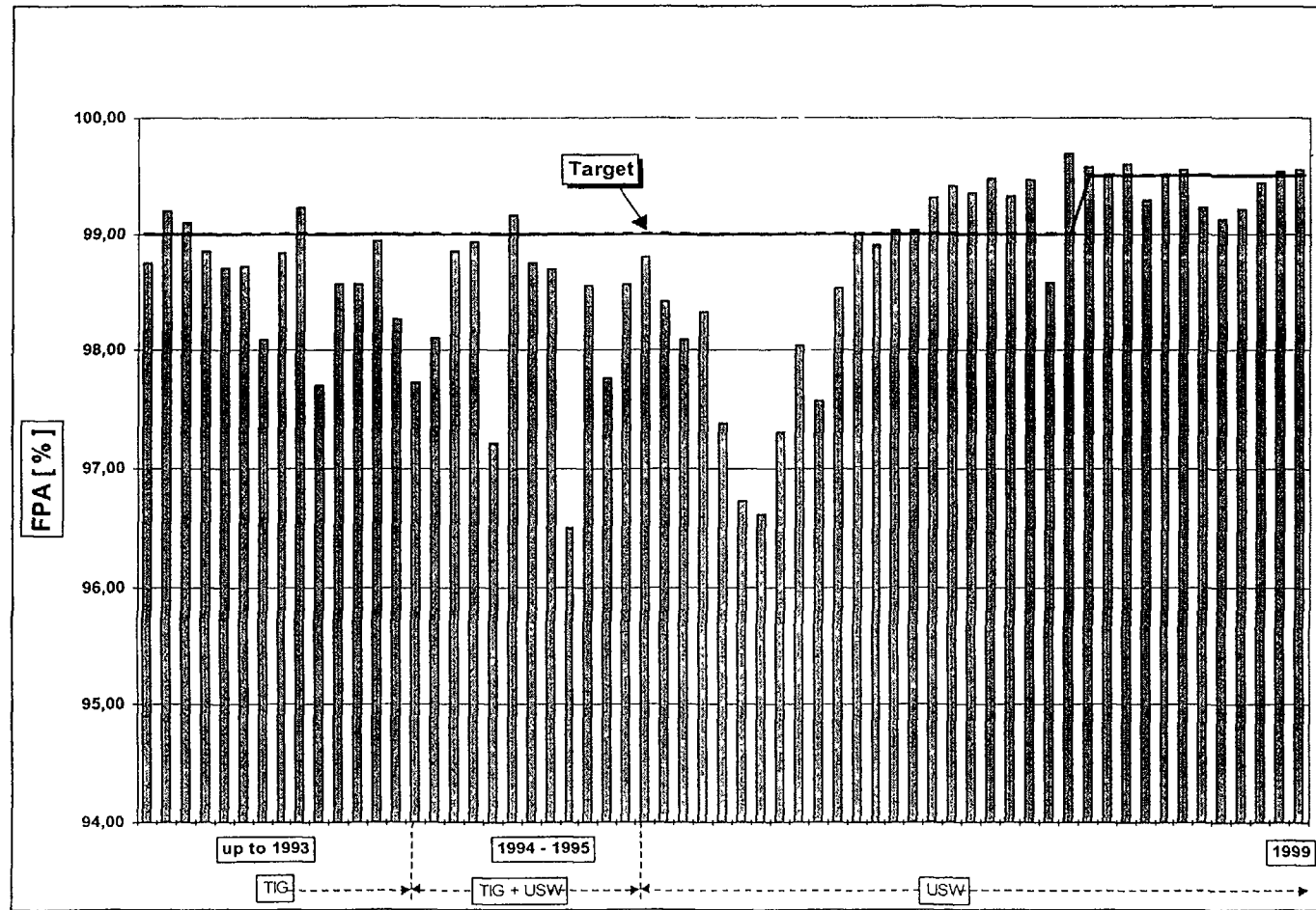*FIG. 5. Example of a Pareto analysis for fuel rod rejects*

FIG. 6. Trend analysis of fuel rod - First Pass Acceptance values
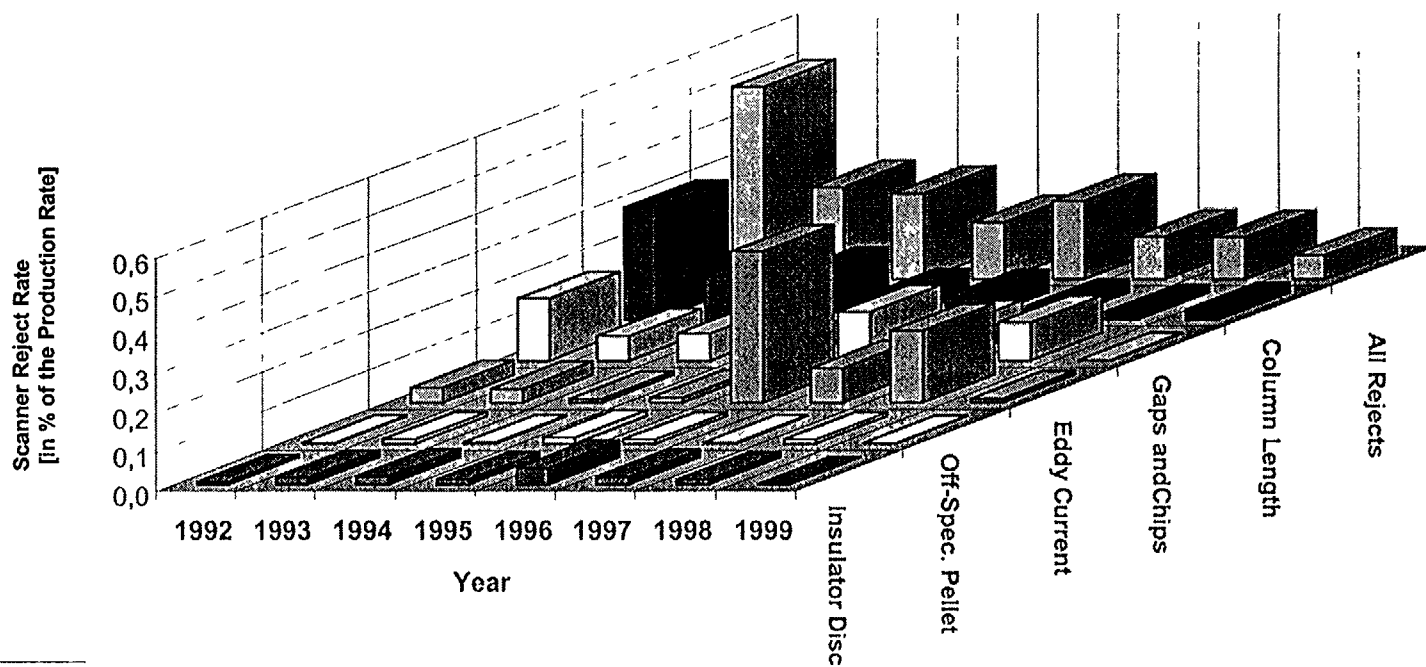
FIG. 7. Trend of the rod scanner rejects over the last years
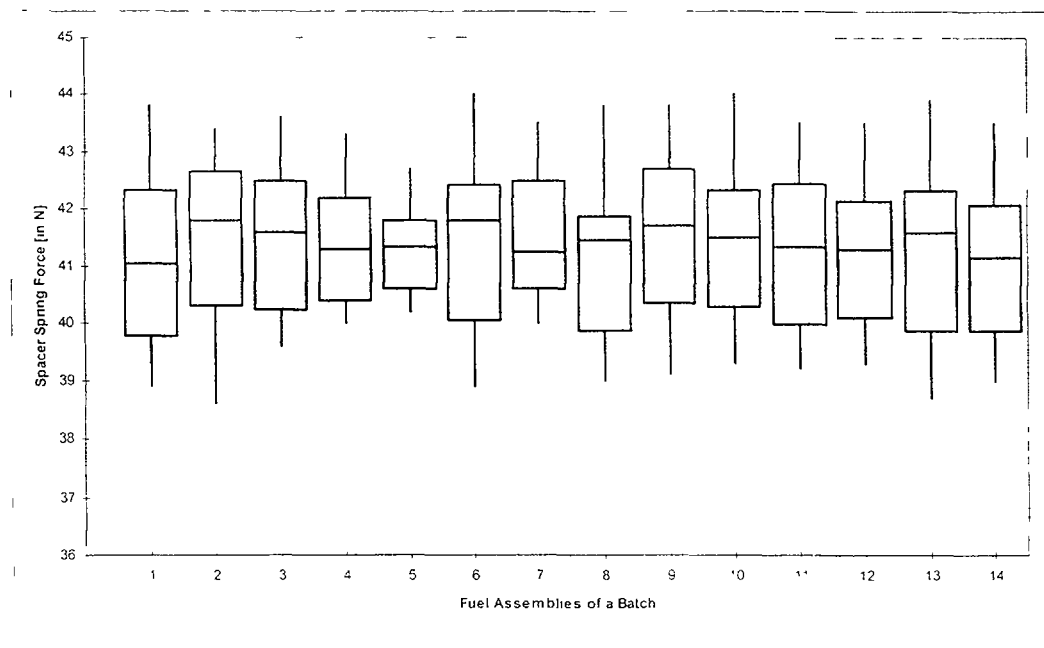
FIG. 8 Typical box plot diagram
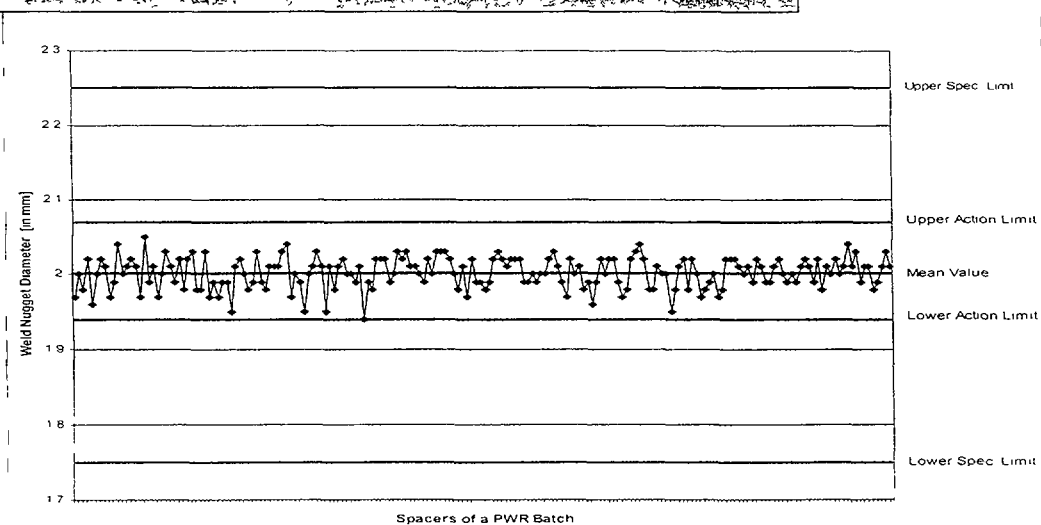
FIG. 9. Example of an in-line inspection control chart

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Control of
Important
Process and
Product
Parameters
at a New UPS-
Weld Machine

FIG 10 Example of the statistical process control at a new upset shape weld machine

7. VISION AND OUTLOOK

The installed quality system guarantees already products of high quality. With the following visions Siemens/ANF will assure that the product quality will be further improved to contribute herewith to the safe and economical performance of the supplied fuel:

- We rely on robust products and processes,
- We will use modern equipment designed for continuous process control,
- We will use state-of-the-art methods, such as FMEAs and Ishikawa diagrams, for process and equipment qualifications,
- We will use process control with closed loop techniques,
- We will continue to improve the qualification and motivation of the personnel,
- Together with the customers, we have the approach to achieve a reasonble pro-cess control and to have only a minimum of product inspections,
- We will assure high quality products with uniform characteristics.

REDUCTION OF COST OF POOR QUALITY IN NUCLEAR FUEL MANUFACTURING

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Abstract

Within ABB reduction of Cost of Poor Quality (COPQ) has become an important process to focus quality improvement initiatives on bottom-line results. The process leads to improved bottom-line results, through cost savings, but it also leads to quality improvements in our processes, products and services.

The traditional way of measuring and controlling COPQ in the production workshops is not enough. It is of vital importance to include other non-value creating costs as well, both internally, e.g. in the engineering work, and externally, in delivered products and purchased goods.

ABB Atom has since a number of years used the COPQ process in the various steps of nuclear fuel manufacturing. The definition has been expanded to cover, for instance
- Scrap, rework and deviations
- Margin slippage
- Warranty costs
- Lack of supplier performance
- Excess and obsolete inventory

Each of the COPQ elements has a responsible "owner" within the management of the Nuclear Fuel Division. The owners form a COPQ task force, which is responsible for analyzing results, setting goals and initiating improvement actions. The COPQ result is updated each month and is presented to all employees in several ways, such as Intranet.

For the various COPQ elements improvement initiatives have been implemented. The presentation will describe some of them, such as reduction of

➤ Scrap, rework and deviations through
  ⟹ a process with zero defect meetings
  ⟹ high level of process automation
  ⟹ statistical methods

➤ Margin slippage through
  ⟹ business process re-engineering

➤ Warranty costs through
  ⟹ an improved design review process and expanded testing of new products

➤ Costs for lack in supplier performance through
  ⟹ a new concept for supplier QA/QC

It is our strong belief that both ABB Atom and our Customers will benefit from the COPQ process since it leads to a higher quality for nuclear fuel and control rods and facilitates lower product prices.

1. INTRODUCTION

ABB Atom is part of the ABB Nuclear Power Organization, which also includes ABB Combustion Engineering Nuclear Power (ABB CENP) in USA, ABB Reaktor in Germany and ABB Barras Provence in France. ABB Atom's Nuclear Fuel Division works closely with ABB CENP to promote the ABB nuclear fuel business worldwide.

The ABB Atom Nuclear Fuel fabrication plant is located in Västerås, Sweden. The factory has facilities for manufacturing of BWR and PWR fuel assemblies as well as BWR Control Rods and Fuel Channels (Figure 1). UO_2-powder/pellets and Burnable Absorber pellets are manufactured both for ABB needs and for other fuel vendors as separate products.

The plant license allows ABB Atom to manufacture 600 t UO_2 per year.
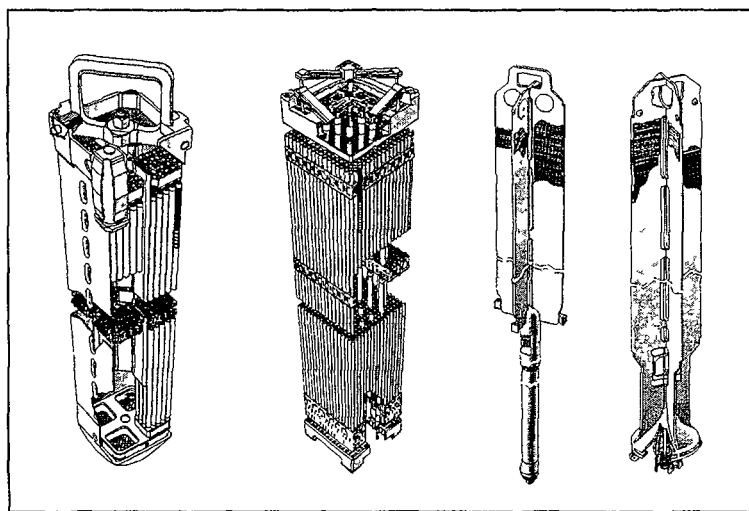

FIG. 1 Nuclear fuel and control rods

Customer requirements for high quality fuel (and control rods) and lower prices drive an improvement process to reduce non-value creating costs, i.e. Cost of Poor Quality (COPQ). The COPQ process is not only applied for ABB Nuclear. It is extensively used among the different ABB business areas worldwide as an important tool for improvements.

2. THE COPQ PROCESS MANAGEMENT WITHIN ABB ATOM NUCLEAR FUEL

Quality expert J.M. Juran states that "In most companies COPQ runs at about 20 to 40 percent of sales". Reduction of COPQ has a direct positive influence on the income of a company or, alternatively, it can be used to lower the product prices, hence increasing the competitiveness of a company. These positive aspects alone make the effort to reduce COPQ worthwhile. However, another equally, or even more, important aspect is the fact that the process to reduce COPQ also will have *a substantial positive impact on the quality level* of both products and processes.

The definition of COPQ used by ABB Atom is "All costs caused by quality deficiencies in processes, products and services, that is non-value creating costs". To make it more concrete we have chosen to divide COPQ into the following basic elements:
* Scrap, rework and deviations

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- Margin slippage
- Warranty costs
- Lack of supplier performance
- Excess and obsolete inventory

This definition has been used for a number of years and although we realize that it does not cover all possible non-value creating costs it is adequate to our needs and most importantly, it is possible to measure in practice! The trend so far is quite encouraging. COPQ has dropped from a level of close to eight per cent to about four per cent of the revenues.
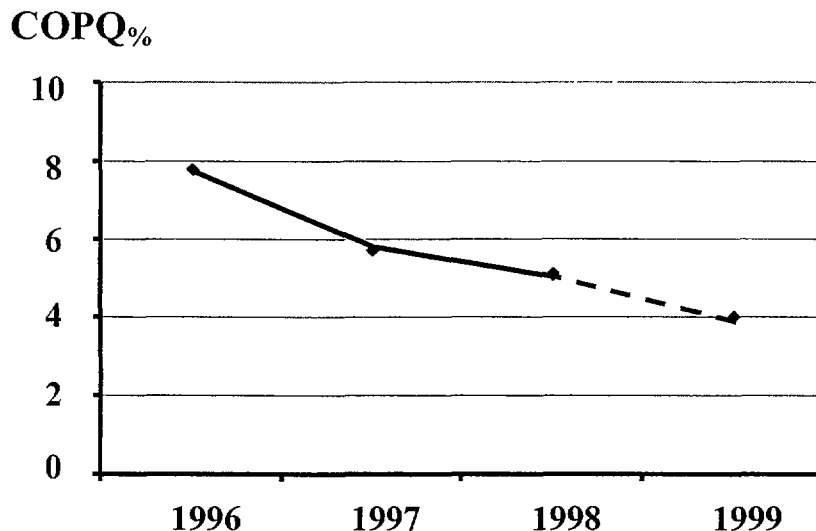
COPQ%

FIG. 2. COPQ in percentage of revenues

COPQ is measured in the various departments and workshops by personnel directly involved in activities which have impact on COPQ. Input of COPQ data is done each month locally. The data is entered in Excel files showing the result for the particular department or workshop. All local COPQ metrics are then automatically linked and summarized and then presented on the ABB Atom Intranet which is available for all employees. COPQ is part of the top level metrics, '6-ups!', i.e. the six most important metrics for the Nuclear Fuel Division.

A special Task Force is responsible for the COPQ Process Management. The Task Force is responsible for analyzing COPQ data and decides on improvement actions. It is also responsible for the deployment of goals and actions in the organization. Each basic COPQ element has an appointed owner within the group.

Improvement initiatives have been implemented for the various COPQ areas. Below some of them are described.

3. REDUCTION OF SCRAP, REWORK AND DEVIATIONS

During the budget preparation the workshop managers analyze the COPQ status of their respective workshop areas and manufactured components. The managers are responsible for setting challenging budget goals and for implementing improvements to reach the goals. One of the main tools to reduce COPQ and improve the products is a process with zero defect meetings and corrective action meetings. This process leads to elimination of deficiencies at

an early stage. Rejects are traditionally measured in %, kg, 'number of' etc but it is also psychologically important to measure it in money. This increases the understanding among employees about the values of the goods that they handle and results in higher awareness and focussing during manufacturing and inspection

ABB Atom is traditionally continuously improving and upgrading production and quality inspection processes. Large investments during previous years include e g. new automated process control system in the conversion workshop (Figure 3), a new automated rod manufacturing line with integrated automated visual inspection of welds, UT of welds, rod scanning etc. Also major investments in the Burnable Absorber pelletizing shop have been done. These modern, highly automated and capable processes ensure repeatable manufacturing with high product quality level and low scrap rates

FIG. 3 Conversion workshop control room

Statistical methods and Design For Manufacturability are becoming increasingly important in striving to reduce production rejects to a minimum. Manufacturing experience and capability studies provide important input to the design process. Through close cooperation between personnel from design, qualification, production and quality departments it is possible to continuously improve the production yield and quality, either through design modifications or by improving production methods (Figure 4).

Two examples:

1 Experience and production statistics provided essential input to design modification of the BWR pellet design. The new design led to a substantial reduction of scrap rate from the visual inspection.

2. A process capability study of the manufacturing of bottom tie plate indicated deficiencies in one process step. An altered production method resulted in 50% lower scrap rate.
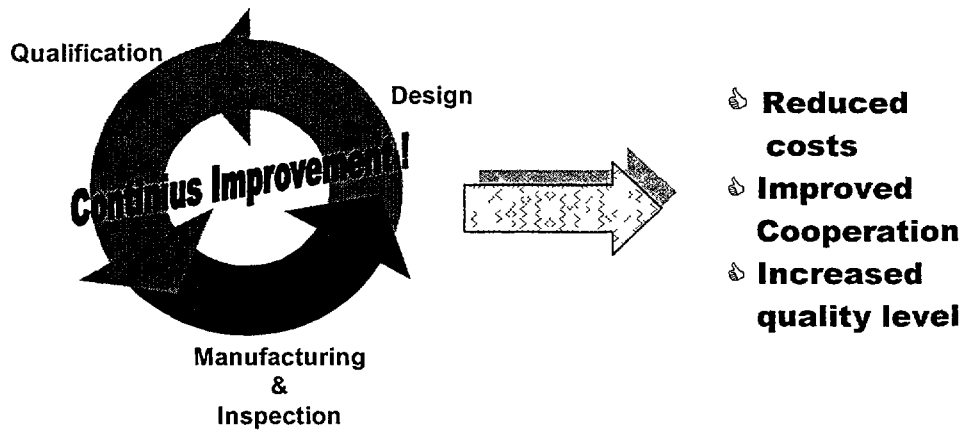
FIG 4 *Continuous improvements in design, qualifications and manufacturing*

4 REDUCTION OF MARGIN SLIPPAGE

Margin slippage is defined as the difference between 'as sold' and actual costs in delivery projects. Also, no netting with orders with a positive margin variance is allowed.

Hence, deficiencies in the Project Execution Process are identified and measured In order to remove these deficiencies in the process, the Project Execution Process has been re-engineered.
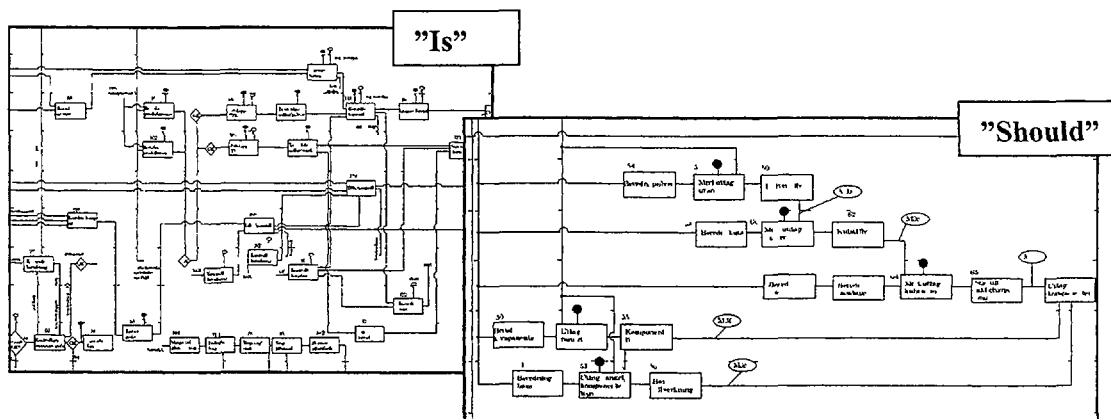

Figure 5. "Is" and "Should" maps (example)

The re-engineering started with the development of an "Is" map of the process (Figure 5). At this stage also "disconnections", i.e. deficiencies, were identified. A "Should" map was then developed to reduce the number of "disconnections" and to get a better, more streamlined flow of activities in the process. Recommended improvements were established and decided. Many of the improvements lead to reduction of margin slippage and at the same time improve the quality in the engineering work

A Process Team has been appointed and is responsible for implementation of improvements and then to continuously improve the Project Execution Process

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5. REDUCTION OF WARRANTY COSTS

Deficiencies in delivered nuclear fuel assemblies or control rods can result in costs for the supplier, i.e. warranty costs. Of course, the customer is often also seriously affected by this, both from an economical point of view but also through various disturbances. Hence, there are several reasons to really make sure that the delivered products are without deficiencies. Deficiencies can be related to manufacturing flaws, which are extremely unusual, or related to the design.

In order to eliminate and avoid design related deficiencies ABB Atom has introduced an improved design review process for new or modified products. The new process is called the Integrated Design Review process. The Integrated Design Review is performed *in addition* to the normal review of drawings, specifications and various design reports within the project. The Integrated Design Review is done by experts in a detailed and systematic way.

Several competence areas and their interrelation are covered, such as:
• Prerequisites
• Function and reactor safety
• Manufacturing and quality
• Environmental aspects

The process comprises of a number of steps, such as: Planning ⇒ initiation ⇒ preparations ⇒ initial presentation of documentation ⇒ review meeting and decision on required actions ⇒ documentation of actions ⇒ follow up of implementation.
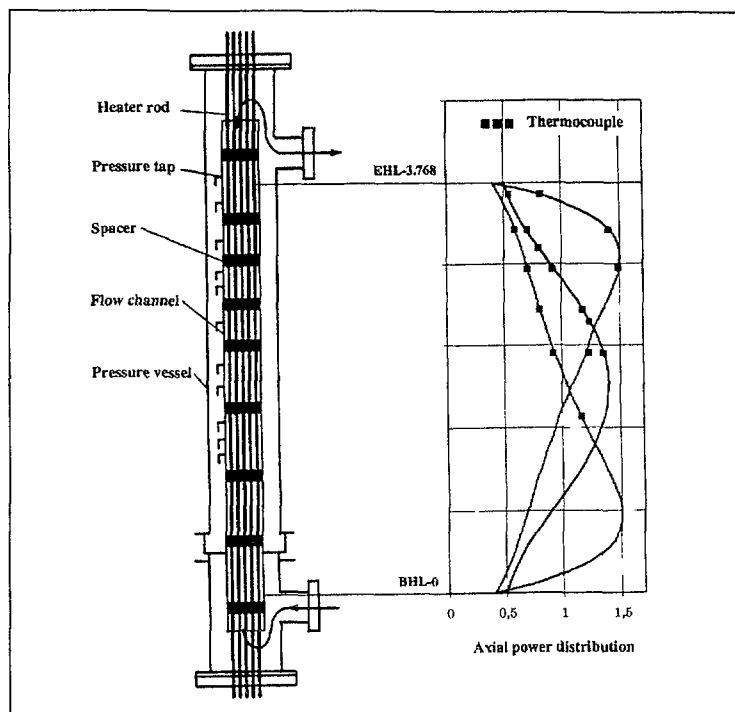

FIG. 6. FRIGG loop for BWR thermal-hydraulic testing

Besides theoretical considerations, calculations and judgments of new products also validation through testing has been expanded and become more thorough. ABB has in its FRIGG loop access to a world class fuel testing facility for BWR fuel (Figure 6). FRIGG has recently been upgraded for thermal-hydraulic testing of full bundle and void measurement. The heating power is now 15 MW.

For PWR fuel the ABB TF-2 test loop is used to qualify new fuel designs. The capacity of the TF-2 loop to operate up to 320 °C and 17 MPa assures that endurance testing can be conducted at simulated reactor conditions, thereby requiring no extrapolation of test results to in-core performance.

6. REDUCTION OF SUPPLIER RELATED COPQ

A fairly large portion of the delivered nuclear fuel and control rods comprises of components and material delivered by sub-suppliers to ABB Atom. Therefore, it is of utmost importance to work closely with the sub-suppliers to make sure that non-value creating costs are avoided and ensure a high quality level of goods delivered to ABB Atom.

Tools have been developed in order to be able to control and reduce the supplier related COPQ (Figure 7). The costs are measured for each supplier and the responsible supply manager requests improvement actions. These are often established in cooperation between ABB Atom and the supplier.
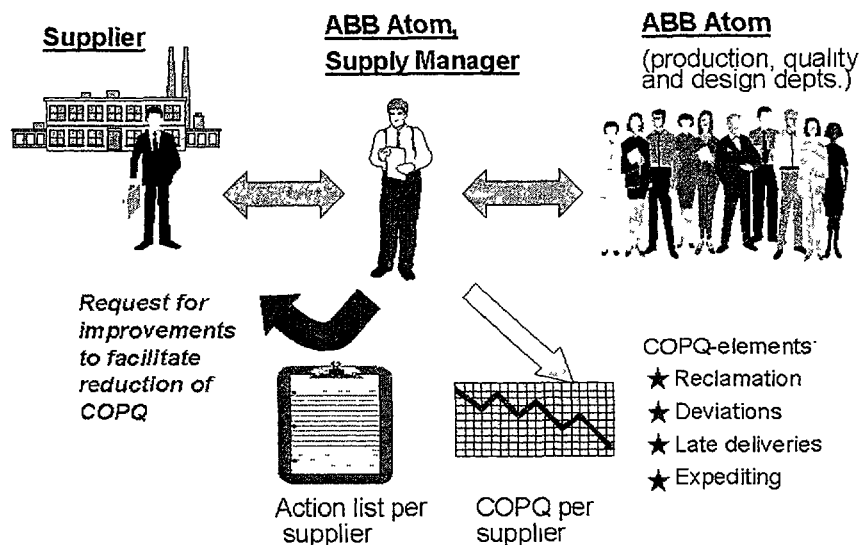

FIG. 7. Reduction of supplier related COPQ

7. EMPLOYEE MOTIVATION

An important part in improvement programs is the participation of all employees in the efforts leading to fulfilling the objectives. Participation requires understanding, competence and motivation. During 1998 ABB Atom Nuclear Fuel Division launched an Employeeship Program (Figure 8) for all employees.
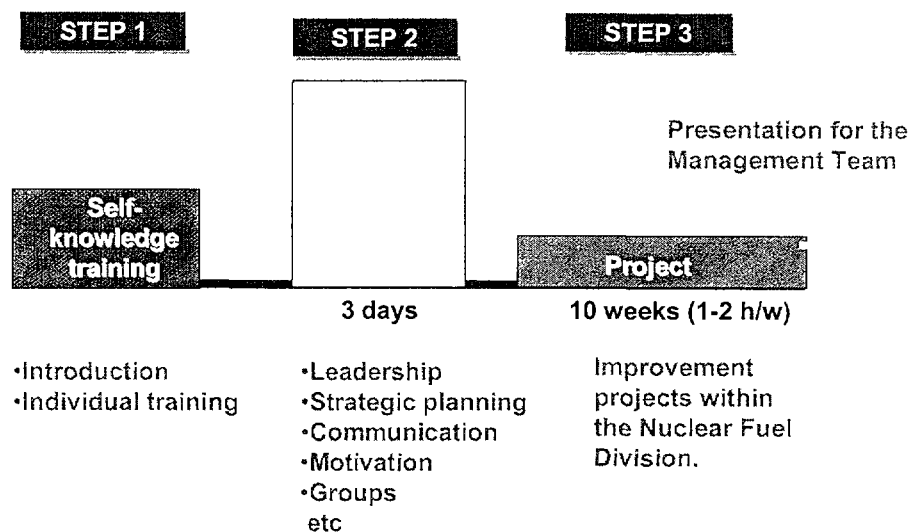
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STEP 1              STEP 2              STEP 3

                                        Presentation for the
          Self-                         Management Team
       knowledge
        training                           Project

                    3 days          10 weeks (1-2 h/w)

•Introduction      •Leadership       Improvement
•Individual training •Strategic planning projects within
                   •Communication    the Nuclear Fuel
                   •Motivation       Division.
                   •Groups
                   etc
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FIG. 8. Employeeship Program

The Employeeship Program was successful and resulted in increased understanding, competence and motivation, i.e. the main components to achieve employee participation in improvement programs, such as reduction of COPQ. The final part of the Employeeship Program was in fact to run an improvement project. Totally 74 improvement projects were started! Several of these projects led to reduced COPQ and increased quality level.

8. CONCLUSION

It is our strong belief that both customers and ABB Atom will benefit from the COPQ process. Motivated employees will use the COPQ process as a powerful tool and driving force to

- further increase the quality level for nuclear fuel and control rods
- facilitate lower product prices

Furthermore, the COPQ process supports continuous improvement initiatives for business processes as well as production processes.

IMPROVEMENTS BY EMPLOYEE MOTIVATION IN THE MANUFACTURE OF NUCLEAR FUEL ASSEMBLIES FOR LWRs

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Abstract

Nuclear fuel assemblies are manufactured on a very high technical level and automation. However there is still a need for more improvement. One of the most important ways is employees motivation, because improvements lives of the ideas, impulses, initiatives and commitments of its employees. It can be realized by the emploee himself or a group.

Three ways of improvement by employees are mainly implemented at ANF :

> **ANF's 3i - program**, based on the standard implementation within Siemens, is the first and an important strategy to improve processes, products and costs. It is to involve all employees and make use of the full potential for improvement .The individual employee or a group make a suggestion and receive a commendation depending on the benefits .

> **Work groups** with a high level of responsibility are the second part. The groups mainly organize their work , working time and improvements by themselves . They help eachother in job training, are very flexible and able to do also most of the maintenance work.

> **CIP – groups** (Continous Improvement Process), based on the philosophy of KAIZEN is the third strategy. These groups come together to improve all processes in the manufacturing area, also the administration or logistical processes at ANF. CIP – groups are implemented as so called long-term groups, the members are from different levels and departments.

By comparing the different ways in order to achieve manufacturing improvements, employees motivation is one of the most important and cheapest part and will increase in significance in future.

1. INTRODUCTION

A company lives on the ideas, the impulses, the initiative and the commitment of its employees. Nuclear fuel assemblies are manufactured on a very high technical level and automation. However, there is still a need for more improvement.

One of the most important ways is employees motivation, because improvements lives of the ideas, impulses, initiatives and commitments of its employees.The managers are the most important partners of the employees in the improvement process. The participance of the groups is spontaneous and voluntarily. Participants who want <u>not</u> to work with a group may not have disadvantages!

2. DESCRIPTION OF SCENARIO SELECTION PROCEDURES

2.1 Employees initiatives

For a more effective and sensitive way to motivate employees for making improvements, ANF introduce in 1995 the 3i-program based on the standard implementation within Siemens. The 3I-program is made of Ideas+Impulses+Initiatives.
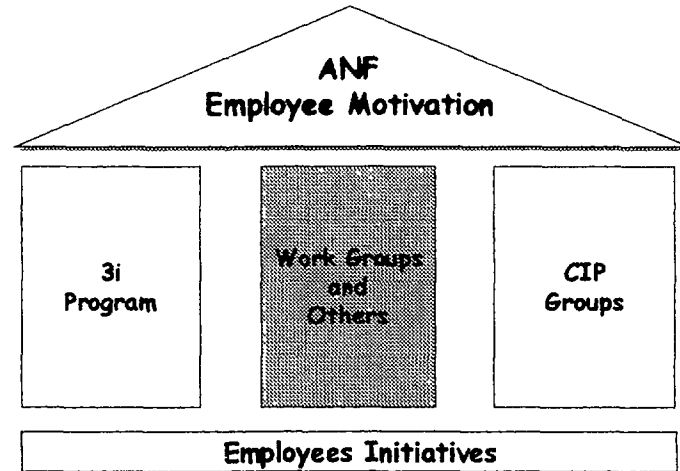
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Fig. 1 shows what Empoyees initiatives are.

FIG. 1. ANF employee motivation

2.1.1. 3i-program

Based on the standard implementation within Siemens, the 3i-program at ANF is the most important part to improve processes, products and costs by the ideas of its employees. It is to involve all employees and make use of the full potential for improvement .The individual employee make a suggestion and receive a commendation depending on the benefits. The managers are the most important partners of the employees in the 3i-process, the essential features of successful management are shown in Fig. 2.
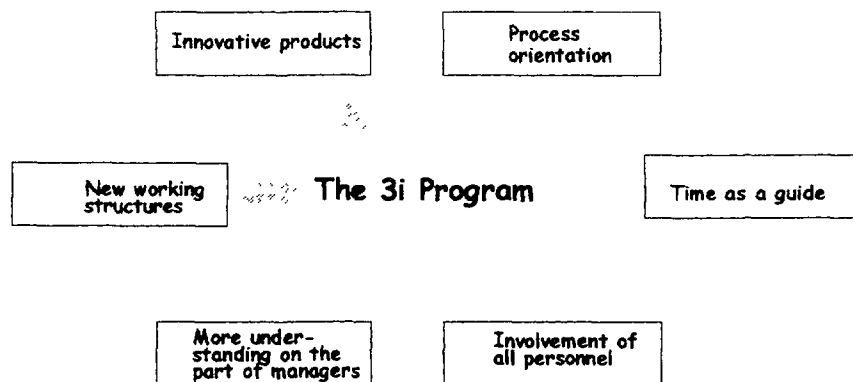

FIG. 2. The 3i-program implements the essential features of successful management

2.1.1.1.   Roles in the 3I-program

Not only the employees of ANF are playing an important role in the 3i-program, also the role of management is important. The management and the manager themselves will be responsible for the success of the program as a partner and a coach of the employees to realize the ideas of improvement.

Employees: The employees have (Fig. 3):
- to bring in engagement for the improvement of products, processes and status as well as for innovations,
- to be creative for solving customer and internal problems,
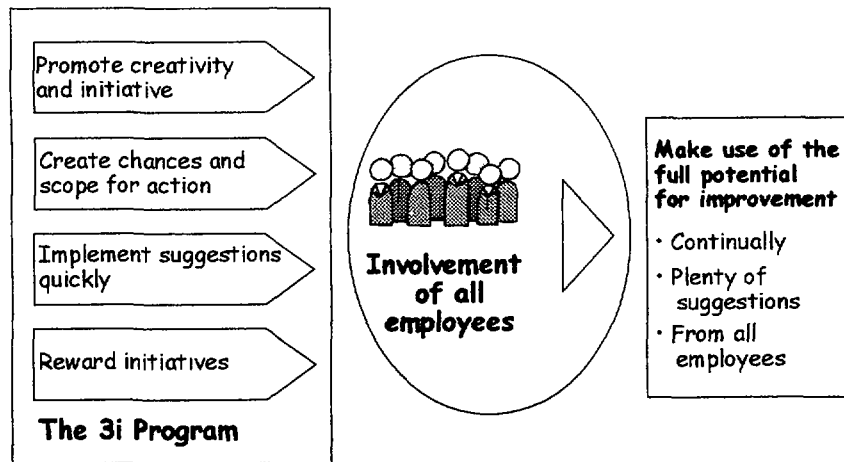- to bring in informations and specific competence.

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Promote creativity
and initiative

Create chances and
scope for action

Implement suggestions
quickly

Reward initiatives

The 3i Program

Involvement
of all
employees

**Make use of the
full potential
for improvement**

· Continually
· Plenty of
  suggestions
· From all
  employees

FIG. 3. The new 3I-program is counting on all empoyees

Management, managers:

The management and the managers have to speed up the improvement process at ANF (Fig. 4).

The Management has:

- to give promotion for the employees
- to supply them with necessary ressources
- to control the success
- to reward the suggestion by single employee or groups

The Manager has:

- to make active promotion
- to give the employees or groups
  - free space (time, money...)
  - active support
  - awards (3i-program)
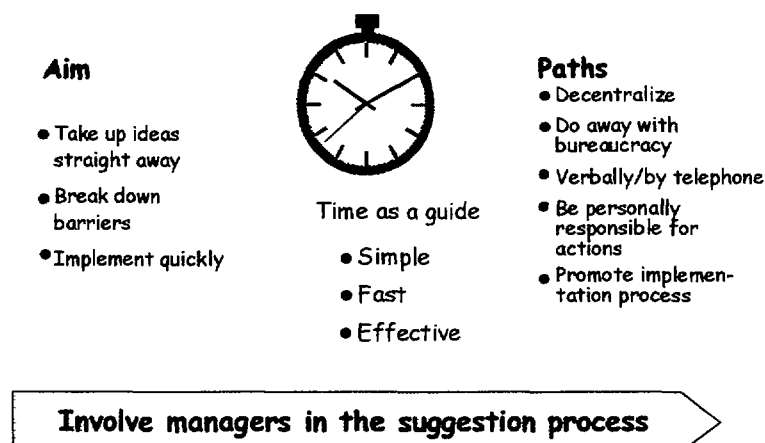 - to cowork with the group
  - to control the realization

Aim

· Take up ideas
  straight away
· Break down
  barriers
· Implement quickly

Time as a guide

· Simple
· Fast
· Effective

Paths
· Decentralize
· Do away with
  bureaucracy
· Verbally/by telephone
· Be personally
  responsible for
  actions
· Promote implemen-
  tation process

Involve managers in the suggestion process

FIG. 4. The imrovement process is speeded up

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2.1.1.2. Improvement by suggestion

Especially the improvement by suggestion is an important part of the 3i-program. An impovement by suggestion showing

- ◆ „what" should be improved,
- ◆ „how" it should be improved
  and
- ◆ that the realization could be an improvement
  - ➢ for our customers,
  - ➢ for the company,
  - ➢ for our employees or
  - ➢ the company's influence on environmental protection.

At last the 3i -program leads to qick decisions for improvements by suggestions, if management take over their role (Fig. 5)

- • as partners for every person who makes suggestions especially in :

  - • being open for discussions
  - • Offering advice
  - • Helping to implement
  - • Assessing
  - • Rewarding

- • and as coaches for :

  - • Creating freedom of action
  - • Informing
  - • Prompting
  - • Supporting
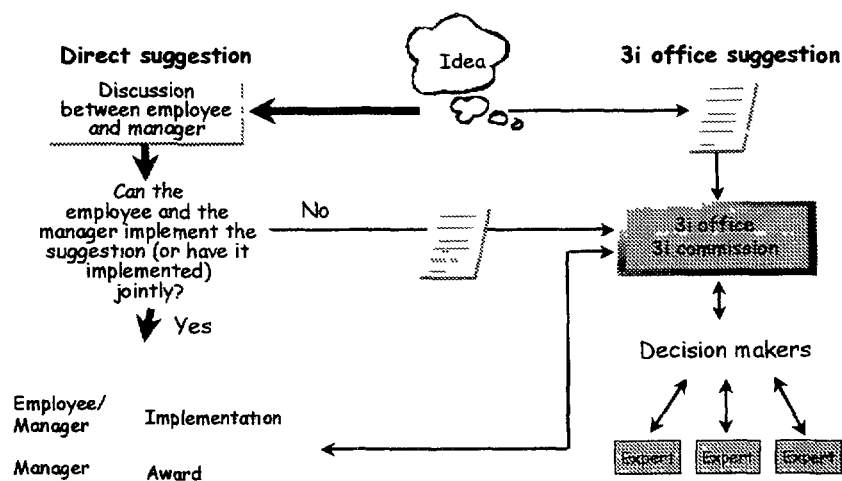 - • "Publishing"
  - • Spreading good ideas

FIG. 5. 3I-program stimulates quick decisions

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2.1.2. Work groups

Work groups with a high level of responsibility are the second part. The groups mainly organize their work , working time and improvements by themselves . They help eachother in job training, are very flexible and able to do also most of the maintenance work.

Basic features of a Work group are:

- A Work group is a team of 3 to 10 persons
- The group has a common task
- The group organizes a lot of work and working time by themselves
- The members of the group train each other

Benefits of the Work groups are:

- Employee identification with process/machine
- Less work for management
- Less work for service groups
- Increase of emploee flexibility
- People are well informed about the company goals

The specific features of the Work group at ANF are:

- About 90% of the production empoyees are organized in Work groups
- The groups know their goals on a weekly/monthly/yearly basis
- The groups also know the goals of others
- The groups organize their working and machine running time
- The most groups are able to do the maintanance
- The group members have a strong identification with the equipment.

2.1.3. CIP – groups

CIP – groups (**C**ontinous **I**mprovement **P**rocess), based on the philosophy of KAIZEN is the third part. These groups come together to improve all processes in the manufacturing area, also the administration or logistical processes at ANF. CIP – groups are implemented as so called long-term groups, the members are from different levels and departments.

Working in a CIP- group:

❖ **Working time ?**

- within the normal work time without hierarchical structure, in several hours or in days

❖ **Written things?**

- The problem has to be written in   certain protocols during all the time, to determine the procedure and control the costs

❖ **Support?**

- The group can have support by the coordinator of the initiative groups

❖ **Costs?**

- If the costs of the group are higher than the costs they have planned, the responsible manager has to be informed

❖ **Finish the work**

- The group will be finished by a presentation to the management where they will show the solution of the improvement. This will also contain a plan for realization as well as for the expected costs.

❖ **Awards?**

- After the group has presented the solution of the problem to the management, they should handle it as a 3i-improvement idea and give an award to the group

We need CIP Groups because of:

- Thinking/talking of the process brigs ideas
- We have a lot of meetings, but the wrong people talk to each other
- The operator gets a tool to optimize his process
- Enable the empoyees to quickly influence their process (e.g. administration, production, inspection,...)

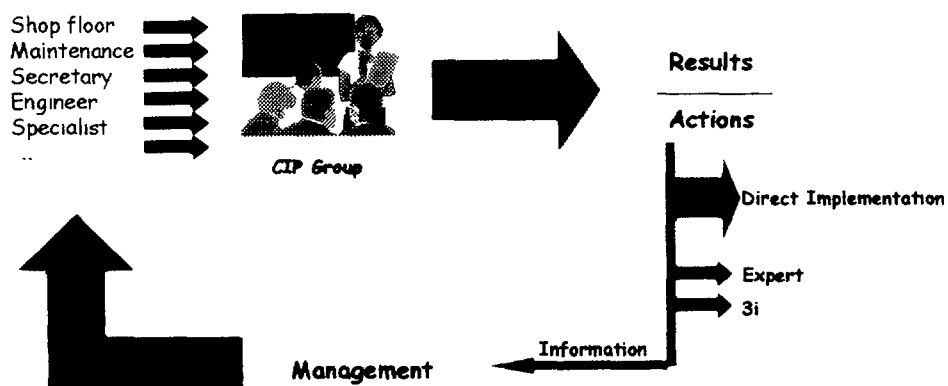Fig. 6 shows basic principles of work of CIP Groups at ANF.

FIG. 6. Basic principles of work of CIP Groups at ANF

The improvements by suggestions, work groups and CIP-groups at ANF leads to cost savings of approximately 1.8 Mio DM in FY 98/99. Some examples for that successful employee motivation at ANF in FY 98/99 are shown below:

- ANF had 1.4 ideas per empoyee and savings of 1.18 Mio. DM
- Just by empoyee motivation the cost for protecting clothes have been reduced by more than 10%
- The yields increased significantly
- Production cost decreased by about 10% (about 3% because of employee motivation).

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