EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Energy
Technical and Scientific Support to TACIS and PHARE

TACIS NUCLEAR SAFETY

TACIS PROJECT R8.01/97
TRANSLATION, EDITING AND DIFFUSION OF DOCUMENTS
(Results Dissemination)

TACIS R2.05/93 & R2.05/93BIS PROJECT
NON-DESTRUCTIVE EXAMINATION
IN-SERVICE INSPECTION
EXECUTIVE SUMMARY

TSSTP/DISS97/02 02 008	PETTEN, 2002/03/15

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SUMMARY

Upgrading the quality of the in-service inspections of the main primary components (steam generator, main coolant lines, reactor pressure vessel) of the VVERs was seen as a major contribution for Safety upgrading of these NPPs. This target appeared to be attractive for East European plant operators, who expressed their needs in several occasions in the early 90s.

The main components of the Primary Circuit of the VVER 1000 units were selected for that purpose. The general aim was to ensure the long-term consistency of the in-service inspection policy for these NPPs by defining a framework for the various needs (hardware, software, training, qualification and certification systems, ISI management), based on the available experience and expertise and taking into account the specific requirements. The practical aspects would result in the development of tools (upgraded procedures and instructions, technical specification) for the implementation of the most efficient projects, to be selected among the identified proposals, provisionally considered in the TACIS and PHARE 1993 & 94 budgets.

It was recognised that both the industrial potential provided by the NDT Services Companies as well as the ISI programme consistency guarantied by the Utilities shall be considered. It also appeared that a separate frame for each branch would work the best. Therefore, the optimum chosen by the European Commission was to set up two twin projects (R2.05/93 & R2.05/93bis), having the same aim.

The objectives of the projects have been defined as follows:

- Transfer of scientific-technical information on experience, results, reliability and implementation in the field of NDE in West European NPP,
- Assessment of Russian NDE data available from examination performed during manufacturing, erection and operation,
- Prioritisation of the development actions for the different main primary components,
- Development of a technical specification for the delivery of in-service inspection equipment,
- Elaboration of improved and optimised instructions for in-service inspection,
- Presentation of the results to Gosatomnadsor (GAN).

Four main tasks have been originally identified and worked out:

1. Assess and elaborate improved in-service inspection programme:
2. Assess and define improved technique, operator qualification and training programme:
3. Specify the needs for equipment and services for future projects,
4. Provide assistance to the beneficiary for the implementation of future projects into a long-term perspective and its follow-up.

The objectives set forth in the TOR were properly covered by the deliverables. All tasks have been achieved as per TOR, but deeper and more voluminous than originally foreseen, except task 4, which could not be worked out at the expected level, as far as no projects were launched in time.

Valuable information on the status of the current ISI programmes in Western European and Russian NPPs has been exchanged and discussed. The mutual understanding and appreciation of the respective underlying “philosophy” has been considerably enhanced as a solid basis. The general policy for upgrading the ISI instructions with long-term views was discussed and proposed. This policy was generated in line with the ENDEF strategy for the implementation of effective ISI systems in the East European countries. Some more practical results were achieved like the identification of improved ISI techniques for ISI of primary components, which could be immediately made applicable for VVERs. The ISI handbook, which has been jointly generated, is based on an extensive feasibility study of the possible application of improved and optimised ISI techniques and outlines examples of good practice. Technical specifications for procurement of advanced ISI equipment have been jointly prepared, as well as recommendations for the implementation of advanced training courses.

These achievements form a consistent set appearing as a necessary prerequisite for the implementation of a performance-related code in place of a prescriptive code. Thus, they intend to

create the best conditions for the implementation of the corresponding transition period, currently under consideration in Western countries. Nevertheless, this step forward in terms of performance and Safety needs further implementation of follow-up projects and procurement of equipment, which have been identified.

The co-operative work and the documentation provided had a positive impact by improving the safety culture and building-up a desirable policy for implementing a consistent ISI system, even if no implementation of significant procurement projects has been launched yet in that framework in Russia.

FOREWORD

Two twin projects are of concern, one given to a Consortium of NDT Services Companies (R2.05/93) and one given to a Utility (R2.05/93bis). The corresponding work has been financed by the Directorate General 1A of the Commission of the European Communities under the contracts n° WW.92.04/02.01/B010 and n° WW.92.04/02.01/B011 respectively.

The Contracting Consortium for project R2.05/93 includes Siemens KWU, Intercontrôle and AEA Technology, headed by Siemens KWU. The Contractor for the project R2.05/93bis is Electricité de France, who was requested to give its comments as a utility, involved on a bilateral basis in a project dealing with the implementation of a NDT centre.

A common Project Management Group has been created, involving representatives from each member of the Contracting Consortium for project 2.05/93 and a representative of the Contractor for the project R2.05/93bis. This project management group was headed by a representative from the leader of the Contracting Consortium for project 2.05/93.

For both projects, the Russian beneficiary was Rosenergoatom (REA), acting as the Russian utility.

For both projects, the original Russian subcontractor, MOHT-OTJIG RM, was replaced by DIAPROM for technical reasons, about 8 months after notification of the contracts by Directorate General 1A of the Commission of the European Communities. Within DIAPROM, the main contributors were VNIIAES and NIKIMT. Further specific contributions from design institutions (ZNIITMASH, EDO Gidropress) and Gosatomnadsor (GAN) have been appreciated.

Both projects were supposed to be completed in one year. The global implementation duration of the project was about 2 years. The contract was notified on 15th September 1995. The final seminar took place on 11th September 1997. The final reports are dated December 21st 1998 and October 20th, 1997, respectively.

The work was done according to the requirements specified in the quality assurance program, based on the relevant IAEA standards as well as other international standards, applicable for nuclear facilities.

1 INTRODUCTION

Upgrading the quality of the in-service inspections of the main primary components (steam generator, main coolant lines, reactor pressure vessel) of the VVERs was seen as a major contribution for Safety upgrading of these NPPs. This target appeared to be attractive for East European plant operators, who expressed their needs in several occasions in the early 90s.

Taking benefit of various high level meetings (USER's GROUP chaired by Lord MARSHALL of GORING, CEU/MINATOM-REA), the Russian Utility has expressed their interest for:

- Transfer of know-how and equipment as well as monitoring systems for advanced non destructive testing,
- Assistance for the implementation of upgraded inspection procedures and instructions, with adequate organisation of the quality control and quality assurance allowing the comparison of the results gained during successive inspections,
- Support for the implementation of well-organised qualification system for equipment and certification system for personnel.

The needs appeared quite well defined, but their scope was too broad to be covered extensively. In order to respond to these requests with the desirable priority and consistency, it was decided to define the scope of the suitable programme to be financed by EC funds, within the TACIS 93 budget.

It was recognised that both the industrial potential provided by the NDT Services Companies as well as the ISI programme consistency guarantied by the Utilities shall be considered. It also appeared that a separate frame for each branch would work the best. Therefore, the optimum chosen by the European Commission was to set up two twin projects (R2.05/93 & R2.05/93bis), having the same aim.

This summary report has the objective to report on the scope and results of the TACIS R2.05/93 & R2.05/93bis projects. These results will be made available to the interested organisations in the Beneficiary country, on an open basis. The final reports of the projects [10, 12] have been extensively used as a basis for this report.

2 OBJECTIVES

The main components of the Primary Circuit of the VVER 1000 units were selected for that purpose. The general aim was to ensure the long-term consistency of the in-service inspection policy for these NPPs by defining a framework for the various needs (hardware, software, training, qualification and certification systems, ISI management), based on the available experience and expertise and taking into account the specific requirements. The practical aspects would result in the development of tools (upgraded procedures and instructions, technical specification) for the implementation of the most efficient projects, to be selected among the identified proposals, provisionally considered in the TACIS and PHARE 1993 & 94 budgets.

The objectives of the projects R2.05/93 and R2.05/93bis have been defined as follows:

- Transfer of scientific-technical information on experience, results, reliability and implementation in the field of NDE in West European NPP,
- Assessment of Russian NDE data available from examination performed during manufacturing, erection and operation,
- Prioritisation of the development actions for the different main primary components,
- Development of technical specification for the delivery of in-service inspection equipment,
- Elaboration of improved and optimised instructions for in-service inspection,
- Presentation of the results to Gosatomnadsor (GAN).

3 IMPLEMENTATION

Four main tasks have been originally identified [1]. In order to help to manage the related broad information, the two first tasks have been sub-divided into individual “technical topics” as shown hereafter:

1. Assess and elaborate improved in-service inspection programme:
    - 1.1. Codes & Standards, Organisation, Experience (status),
    - 1.2. Components,
    - 1.3. ISI methodology & concept,
    - 1.4. ISI instructions (« handbook »),
    - 1.5. Needed inspection equipment,
2. Assess and define improved technique, operator qualification and training programme:
    - 1.6. Reliability (techniques, instruments & human factors),
    - 1.7. Assessment of operators,
    - 1.8. Comprehensive training equipment,
    - 1.9. Simulators and equipment,
3. Specify the needs for equipment and services for future projects,
4. Provide assistance to the beneficiary for the implementation of future projects into a long-term perspective and its follow-up.

To cope with such generic objectives, which are clearly in line with the long-term perspectives, a desirable strategy has been applied, after its elaboration in a broader assembly within ENDEF, the European Non-Destructive Examination Forum.

Consequently the following steps have been implemented for the project management:

- Systematically assembling and documenting the code, the experience and the practice related to in-service inspection of VVER 1000 main primary components on the Russian side (Deliverable 1).
- In parallel, systematically assembling and documenting the codes, the experience and the practices related to in-service inspection of Western PWRs on the Western side (Deliverable 3).
- Establishing a work scheme for the comparison of the two preceding items and especially for the conclusions. The main objective was to assess the need to implement advanced techniques and simultaneously and to investigate the potential benefit of the use of these advanced techniques in terms of achieving the desirable safety level (Deliverable 2). In this context, the foundations for discussing a potential relief with regard to scope and/or intervals of in-service inspection have been laid.
- Performing the actual work as structured in the methodology (Deliverable 2) by generating the foundations for safety-conscious, performance-efficient and timesaving in-service inspection instructions (Deliverable 4).

The other deliverables have been elaborated from the same basis (Deliverables 1 & 3) and are similarly addressing the different areas of work for improvement of in-service inspection:

- Specifying the adequate equipment to be used for the in-service inspection of the main primary components of VVER 1000 units, according to the priorities defined with the Beneficiary (Deliverables 5).
- Investigating on the country-specific criteria of Human Factor considerations and drawing conclusions for the future optimised and adapted personnel training (Deliverables 6).
- Drawing the conclusions of the deliverables 4, 5 and 6 in terms of addressing the need for well-structured projects for the future adaptation, improvement and optimisation of the in-service inspection technology in a comprehensive way (Deliverables 7).

The activities resulted mainly in workshops (2), working sessions (5) and elaboration of common reports. As far as the tasks did not directly correlate to the deliverables, the completion of the project has been checked using a correlation matrix to ensure that the scope of the project has been covered properly.

Despite the difficulties in launching the project and establishing a co-operative frame with the Beneficiary and the Subcontractor, which resulted in a significant delay, the generic objectives were well achieved. The amount of basic information exchanged and discussed within the project is quite impressive. The permanent willingness to prepare a comprehensive framework, addressing all actions necessary for the implementation of adequate, whether updated or advanced, in-service inspection system, has to be underlined. The preparation of the technical specifications for procurement of equipment were prepared according to the priority order given during the project. The baseline for adequate in-service inspection systems for the main primary components has been proposed as well as trend lines for optimal follow-up projects.

4 PRESENTATION AND DISCUSSION OF THE PROJECT RESULTS

4.1 Deliverable 1: Input data on the status of in-service inspection in Russia

This deliverable [2] aggregates the basic documentation on the main primary components of the VVER 1000 units, which is necessary to create a common basis of mutual understanding in NDE techniques and ISI performance for Western and Russian experts involved in the projects. This was seen as a prerequisite for the elaboration of improved solutions.

It refers to two detailed reports including relatively detailed information covering most of the sub-tasks of tasks 1 and 2. It includes the following technical items:

- Codes & standards for NDE techniques used for in-service inspection, including information on their hierarchy and inputs for comparison of various national codes & standards,
- Description of VVER-1000 main primary components (Reactor Pressure Vessel, Main Coolant Lines, Steam Generator, …) with particular emphasis on the conditions for inspection (access, potentials defect location and size), including drawings and information on design options, materials grades, manufacturing processes as well as operating conditions,
- Basic information on the potential and allowable defects, as well as defect sizes to be detected,
- NDE methods in use in Russia and the related Quality rating standards, including the calibration and qualification matters,
- Main aspects on personnel qualification in Russia,
- Existing methodology for ISI and its validity, with emphasis on the Russian position on ISI system performance demonstration as well as on its adequacy for identifying service life limiting defects (impact of flaw detection on reliability),
- Reports on practical experience and results, as well as on their evaluation (comparison of successive results),
- Specific inputs from other disciplines (Fracture mechanics) to be analysed with regards to further ISI methodology improvement and optimisation.

With this information, the Russian basic philosophy, prerequisites, concepts, methodology, equipment, studies on human performance and experience in the entire area of ISI of the main primary components are covered. Mutual and common understanding has been intensified during the seminars and workshops performed in the frame of these projects.

4.2 Deliverable 2: Methodology of improvement and optimisation of instructions for in-service inspection

The methodology [3] for improving and optimising the ISI instructions is shown in figure 1. The methodology has to take into account the specific structure and contents of the interaction of NDE as an integral element of the safety philosophy with the other elements / disciplines and the overall process of safety assessment itself.

The elements of the Methodology are differentiated, whether NDE related or not. There are quite various inputs from technical disciplines not directly related to NDE (material structure characteristics, manufacturing data, potential damaging loads and transients, integrity assessment, operating and ISI experiences), not, which allow defining a defect catalogue and, among these the "essential flaws", which need to be reliably detected and sized. The NDE related elements, additionally needed for optimising the ISI instructions, are the NDE technology, the components description (material grade, geometry, surface finish, accessibility, …), the feedback from capability and reliability tests ("system qualification"), the information on factors influencing the quality (e.g. human factors) and the codes & standards requirements.

The instructions can be improved step-by-step and optimised with regards to required safety margins preventing from unacceptable damage in terms of component integrity. The LBB (Leak Before Break) or the Break Preclusion concept, are examples of integrated assessment methodologies, which are providing safety-related criteria. Obviously, the experience feedback from past ISI campaigns, in terms of performance, will contribute to determine the need and the necessary degree of improvement and optimisation of the NDE system. The ISI instructions should consider the following aspects: scope (inspection locations), frequency, selection of methods and determination of the relevant elements of NDE-methodology, calibration, evaluation and reporting of the results, NDE equipment (hardware and software), personnel training and qualification, ISI-system performance demonstration, schematic of decision process based on NDE results. The type of NDE qualification (specific, general or conventional) depends on whether the occurrence of defects is respectively proven, presumed or not to be expected.
Basically three cases may occur, which require adequate measures:

Requirements < Capability of NDE	Requirements ~ Capability of NDE	Requirements > Capability of NDE
Relieving of the requirements may be considered with respect to earlier conservatism due to NDE uncertainties (flaw assessment or inspection interval)	**Development of improved NDE methodology should be considered (possible future needs)**	**Gap shall be bridged by the development of improved NDE technology**

Successful implementation of the methodology requires system approach-view, iterative process and robust experts' opinion and recommendations. It also required collecting and organising the information made available by the Russian counterpart, addressing the following topics:

1. Data base for VVER-1000 on design options, manufacturing data and operation experience records (including the results of non-destructive examination);

2. Summary of experience and comparative analysis of NDE techniques used for ISI in Western countries and in Russia;

3. Integrated NDE approach relying on:
   - Combination of methods,
   - Selection of inspection parameters,
   - Reduction / minimisation of human factor impact e.g. by increasing the degree of automation or improving the manual inspection process,
   - Determination of the adequate quality of the ISI system and its maintenance (involving feedback process) by NDE personnel training and qualification and performance demonstration of ISI systems (including procedures and equipment).
   - ISI Quality Assurance system,
   - Optimisation of defect acceptance/rejection process for ISI by the use of an overall recording system and the optimisation of the relation between safety and economy,

4. Optimised ISI instructions for inspecting the components,

5. Optimised selection of the scope (location) for each specific purpose like components acceptance, pre-service inspection (PSI), routine ISI, ISI during/after repair/maintenance

6. Optimised ISI intervals.

4.3 Deliverable 3: Western in-service inspection and potential co-operation with Russia

This Deliverable [4] consists of a series of reports containing relatively detailed information on the main West European ISI approaches and NDE technologies in use. This information covers the Western basic philosophy, prerequisites, concepts, methodology, equipment studies on human performance and experience in the entire area of ISI of the main primary components.

In order to improve mutual acquaintance, a comparison of the requirements regarding ISI specified in Russian (PNAEG) and in Western (ASME, RSEM, KTA, UK) codes and standards was performed. Detailed information on Western codes and standards (including bilateral comparisons) were made available for the purpose. The mirror-input information on Russian codes and standards has been detailed in Deliverable 1.

Mutual and common understanding has been intensified during the workshops, which have been performed in the frame of these projects. Two workshops were held to discuss the available information in detail with Russian and Western experts. Visits of the laboratories of the Western companies involved in both projects as well as a Western NPP have been organised. The corresponding proceedings with copies of the handouts given to the participants on these occasions are included in the deliverable.

4.4 *Deliverable 4: Improved and optimised in-service inspection instructions*

This deliverable [5] provides the input laying the foundation to elaborate and implement improved / optimised ISI instructions by taking benefit from improved NDE methodology as described in section 4.2.

Thus, interaction of NDE elements with others within an overall risk-based safety philosophy has to be considered as already described before. The available information on the different elements has been discussed in depth (Fracture mechanics, stress calculation and fatigue analysis; consideration of potentially damaging loads e.g. transient-induced loads; technical requirements for manufacturing; operating experience; influence of material structure and characteristics; proposals for defect catalogue development; integrated methodologies of estimation).

Generating improved/optimised ISI instructions is a result of a quite complex integrated process, which includes the following main steps:

- Formulation of the requested target performance level, on the basis of input data from other disciplines, mainly expressed in terms of minimum detectable defect size and sizing accuracy,
- Physical reasoning to assess the performance level of improved NDE/ISI methodology,
- Implementation of the improved ISI methodology for detection and sizing,
- Verification of the performance level by a scrutinising process consisting of technical justification and experimental demonstration of performance according to IAEA guidelines and ENIQ methodology (similarly to the process applied at Balakovo NPP),
- Performance of a complete in-service inspection, using the improved NDE methodology as determined above to ensure its applicability and, subsequently, the component integrity.

After successful completion of the process improvement of ISI instructions should consider modifications of the inspection scope and interval. The optimised ISI instructions has to be risk-based and therefore has to rely on the exclusion of any significant defect by involving well detection and sizing NDE techniques with high performance level. Two examples are given as potential models in figures 2 and 3 for the RPV and the MCL respectively. The diagrams summarise the techniques proposed by the experts involved in the projects (Contracting Consortium, Sub-contractor, Beneficiary, EDF, JRC) for detection and sizing as well as the corresponding tolerance targets. The performance demonstration of the complete ISI system, including procedure qualification is required as prerequisites for the acceptance of the proposed inspection intervals and scopes. The necessary developments for assessing identified deficiencies have been addressed by recommendations (deliverable 7).

Based on the experience and practice made available by the Russian experts, some improvements of the ISI systems have already been proposed in the frame of the projects as a result of the work done by the involved Experts. They can be considered as the first-level inputs into the NDE methodology upgrading process. It was suggested to implement them immediately:

- <u>For the RPV by inspection from the inner diameter:</u>
  - Use of a combination of methods for surface defects: UT sensitive to surface defect (or alternatively low frequency ET) + VT / LPT,
  - Improved ultrasonic inspection parameters: Contact technique required by the Russian code needs adapted frequency (1 to 1,5 MHz) and crystal sizes (6 to 10 times the wavelength for 45, 60 and 70°). Reduced probe arrangements are suggested,
  - Integration of special ultrasonic techniques:
    - Optimisation of the detection capability of all embedded defects in the shells is suggested to be achieved by implementation of LLT (i.e. mode conversion) and TTT techniques (additionally to the pulse-echo technique),
    - Optimisation of the detection capabilities of cladding defects in the nozzle areas is the suggested to be achieved by using small-size probes (within contour adapted shoes) with dual crystal (70°) and focused (focal point within the first layer of the cladding) longitudinal waves,

- Advanced sizing techniques are suggested in order to improve the sizing reliability, e.g. crack tip diffraction or time of flight techniques, lens or phased array focused contact probes with specific delay pattern or specific sector scan software and procedures, reconstruction of echo dynamic curves (amplitude and time of flight).

- For the MCL: Optimisation of the detection capabilities of cladding and sub-cladding defects is suggested to be achieved by using combined (standard angles + special ultrasonic techniques e.g. creeping wave or TTT) UT probes with adapted frequency (1,5 to 2 MHz) and crystal size.

- For the Steam Generators:
  - For the collector welds:
    - Integration of special ultrasonic techniques: Similar to the proposal made for the RPV (LLT and TTT techniques),
    - Improved ultrasonic parameters: The detection capability and reliability shall be enhanced by the use of contact and focused probes with low frequencies (1 to 1,5 MHz),
    - Sizing: Focused ultrasonic probes should be preferred, but procedures will have to be developed and qualified.
  - Tubing (ET is useful for that purpose):
    - Ligaments: Optimisation of the detection sensitivity, defect resolution and sizing capability needs appropriate coil design and frequency as well as the use of mixing algorithms,
    - Lengths of tubes: The defect detection is being enhanced by the use of segmented coil probes with spring loaded coils able to negotiate the bends

- For the Surge Line Piping:
  - Reliable inspection of austenitic pipes needs ultrasonic technique combining adapted wave mode and angle with low detection frequency. Physical focusing techniques by phased array and line focus for different depth are proven to be efficient for reliable detection. Additional enhancement should be considered (special signal processing software / multifrequency technique). For characterisation and sizing the use of the whole range of angles of phased array probes may be considered.

Additionally, examples of ISI-Handbook outlines for RPV inspection have been established and provided in Annex 1 of the deliverable. They can already be implemented as an example of good practice for ISI programme management.

4.5 Deliverable 5: Technical specifications for NDE equipment

During the workshop held in Moscow in April 1997, the Russian party has approved the final list of priorities for the establishment of technical specifications for NDE equipment:

1 Equipment for ISI of the steam generators (tubes & collectors),

2 Equipment for ISI of the MCL piping welds,

3 Equipment for ISI of the RPV from inside (ID) in zones covered by the existing equipment,

4 Upgrading of the existing SK 187 system equipment for ISI of the RPV from the outside (OD),

5 Equipment for ISI of the RPV studs and nuts.

Due to budget constraints, only the two first priorities have been successfully covered in the frame of the contract.

4.5.1 Technical specifications for procurement of equipment for ISI of the steam generators

A complete technical specification for the procurement of NDE equipment, including the necessary manipulators [6] has been established. It covers all damaged zones and those recognised as subjected to potential damaging phenomena:

- ET for inspection of the tubing and the threaded stud-holes in the collector flange,

- VT for inspection of the inner surface of the collector with TV camera,
- UT for inspection of the upper circumferential weld in the collector and the connection weld with the MCL piping from the inner surface as well as the ligaments between the holes.

All necessary equipment for remote control of all inspections, including the data acquisition and storage system is specified.

4.5.2 Technical specifications for procurement of equipment for ISI of the main circulation line piping

A complete technical specification for the procurement of NDE equipment, including the necessary manipulators [7] has been established. It covers all welds junction of MCL piping sections one to each other and junctions with other main components (RPV, MCP, SG, Surge line).

Only UT inspection from the outer surface is specified, with particular attention to zones where potential manufacturing defects could grow significantly due to operational loads or defects could be initiated by specific operating conditions (cladding, sub-cladding, external surface).

All necessary equipment for remote control of all inspections, including the data acquisition and storage system is specified.

4.6 Deliverable 6: Technical documentation: Reliability and Human Factors

This report [8] reviews the methods for demonstrating and achieving reliability in the area of ISI through the training and qualification of operators, both in Russia and Western Europe. Based on this review, recommendations have been made for operator training equipment:

- Simulators are desirable, mostly for manual inspection training, for providing help for in-depth understanding and evaluation of consequences of human factors,
- Specific human factor effects shall be addressed by training on automated inspection systems,
- Suitable test blocks and appropriate mock-ups of the zone to be inspected shall be made available (mock-ups are especially necessary for automated inspections),
- The training and qualification system for operators should be upgraded (specific nuclear scheme / EN 479),
- Consideration to specific training shall be given for particular ISI systems involving specific procedures.

4.7 Deliverable 7: Financial and technical documentation: Implementation of improvement and optimisation of in-service inspection instructions

This report [9] includes proposals for future TACIS/PHARE projects in the area of NDE/ISI, which are consistent with the long-term strategy developed within ENDEF. Due to the above-mentioned delay in the implementation of the projects, immediate feedback on the proposed projects in the TACIS programme for 1993 and 94 could not be implemented.

The following technical information has been presented and discussed:

- A comprehensive overview of the integral methodology and the performance concept for ISI, with consideration of all factors influencing the reliability and validity of results (with emphasis to mechanised and modular inspection approach),
- The consequences of the introduction of the optimisation concept and of improved instructions into the actual plant operation strategy (impact on outage planning including specific preparation works with regards to ALARA considerations),
- The necessity to have a new step for programming the activity in the ISI area taking into account the available proposals (as attached to the TOR), the needs as identified by the ENDEF

global approach (matrix concept) and the equipment priorities for safety and availability enhancement (Steam Generator and Main Coolant Lines are the most urgently needed),

- A review of the deliverable results,
- The financial aspects (provisional budget evaluation) of implementation of future projects,
- The final conclusions and the documents to be submitted to GAN and REA (Final presentation meeting: September 11th, 1997).

5 OVERVIEW OF THE PROJECT RESULTS

5.1 Fulfilled scope

Table 1 summarises the work done in the frame of the projects. The matrix is showing how extensive the tasks have been covered by the deliverables. Except the task 4, which could not be covered at the expected level all tasks have been achieved as per TOR, but deeper and more voluminous than originally foreseen.

The Consortium, acting as Consultant, was able to provide valuable information on the status of the current ISI programmes in Western European NPPs through the direct involvement in the ISI business on national and international level of each partner. They also have been active in ISI activities through bilateral assistance and commercial projects on VVER reactors and therefore are quite experienced in that area. This finally resulted in an active co-operation with the subcontractor, after serious difficulties during the implementation phase.

Additionally, due to their involvement in the international co-operation in the field of validation of ISI systems (PISC, ENIQ) they were also able to take over the general policy by implementing the ENDEF strategy into the project management.

Some more practical results were achieved like the identification of immediate improved ISI techniques for ISI of primary component, ISI handbook outlines to be used as examples of good practice, Technical specifications for procurement of ISI equipment, as well as recommendations for the implementation of advanced training courses.

From the very beginning, EDF, as contractor of the twin project R2.05/93bis, was fully integrated in the project as a member of the project management group. This integration provided for direct input from the utility's perspective as well as from the on-going bilateral project regarding the preparation of Russian ISI-NDE centre.

A final presentation of the results gathered in the frame of the projects during a 2 years co-operative work between West European and Russian experts was organised in order to introduce the results to GAN, who delegated the appropriate technical staff. The lack of attendance of the managerial level of GAN as well as REA was considered as a sign of limited interest in the results and further activities.

5.2 Discussion

Figure 4 shows the flowchart of the work organisation chosen according to the strategy, developed within ENDEF and applied for the twin projects. The corresponding main steps can be summarised as follows:

1. A comparison of codes and standards, which basically cover the relevant regulatory requirements, has been completed, using the collected information on the state of the art in East and West European countries.
2. Information on Russian and on Western state of the art practices for ISI of the main Primary Components have been concentrating on requirements; design features; manufacturing technologies; specific operating conditions; NDE techniques, tool and methods; ISI results and their evaluation. With regards to the requests expressed by the "USERS GROUP", a set of basic technical requirements for adequate ISI systems was derived as well as baselines for a NDE concept, inspection methodology and monitoring the results. Furthermore, the necessary equipment specifications for the procurement of the desirable equipment and services have been prepared according to a priority list.

3. Based on a comparison of the impact of human factors on NDE results in Eastern and Western Europe, recommendations have been made for an advanced training system, which would require an adequate centralised organisation, including an NDT centre.
4. The benefit from the implementation of the proposed NDE concept, inspection methodology and results monitoring system may be expected sooner or later depending on the availability of the corresponding hard and software:
   - If such equipment is already available, its qualification for the assigned purpose has to be performed according to the relevant requirements for improved in-service inspection instructions are proposed accordingly, with regards to the component integrity assessment results;
   - If not, the advanced equipment needs to be developed and qualified for the assigned purpose according to the relevant requirements and the operators trained accurately and extensively. The specific maintenance needs must also be considered. An NDT centre would offer a common platform for all these required services. Improved in-service inspection instructions can only be proposed accordingly afterwards, with regards to the component integrity assessment results.

This strategy is consistent with the general policy in the area of development in the field of ISI. It is a step towards the global risk-based concept, which is recognised as the main target for the future.

Close co-operation between both twin projects has been organised from the very beginning, but the implementation of the subcontract with DIAPROM was not effective during 8 months, reflecting the difficulties between both parties regarding the implementation of the technical requirements of the project. Due to the corresponding delay, it was necessary to fix the scope of the foreseen TACIS projects for 1994, without outcome of the project. Therefore, the ISI purposes were deleted from the scope of the project R2.01/94 (Safety related modernisation of Novovoronezh NPP) and the project R2.10/94 (NDT & ISI – Specific project implementation establishing a NDT centre at ELEKTROGORSK) was cancelled. At the same time, the priority list for the development of the equipment specifications for the procurement of the desirable equipment and services has been reconsidered. The inspection of steam generator tubes became first priority. As a consequence, Steam generator and main circulation lines only were considered, as they were of highest priority.

It should be noted that the expected impact on the overall TACIS programme management for ISI improvement was certainly overestimated at the stage of the specification of the project. On the other hand, it has to be pointed out that the co-operative work and the documentation provided has had a positive impact by improving the safety culture and building-up a desirable policy for implementing a consistent ISI system, even if no implementation of significant procurement projects has been yet launched in that framework in Russia.

Further discussions and meetings took place within the frame of ENDEF, which resulted in the publication of a proposal for further activities [13] as well as guidelines [14] for the improvement of the ISI systems in East European NPP type.

According to these recommendations, follow-up projects are under implementation or consideration in the frame of the TACIS On-Site Assistance activities in Armenia (A1.01/96H on improvement of ISI quality and effectiveness of primary components at Medzamor NPP) and Ukraine (U1.01/97D on optimisation of SG tube ISI at Rovno NPP; U1.02/94H on modernisation of the SK 187 manipulator and immersion tank at South Ukraine NPP; U1.04/97B on development and implementation of ET for inspection of threaded holes on vessel flanges at Khmelnitsky NPP; U1.04/97C on retrofitting of the RPV SK-187 surveillance system at Khmelnitsky NPP; U2.02/93 on training of specialists on methodology, organisation and execution of VVER primary system ISI; U2.01/97 for establishing a Center for training, qualification and certification of personel of the Ukrainian nuclear power industry).

Follow-up projects have also been defined in Russia for supplying equipment for NDE systems for MCL in-service inspection in Russia (R2.05/93) in order to meet advanced technical requirements, as well as for the upgrading of a Maintenance Center for Diagnostic Systems (R2.02/93). The corresponding technical specifications have been prepared recently.

6 RECOMMENDATIONS

The project did not succeed in generating on-line project implementation as foreseen in the TOR, mostly due to delay in implementation, but also because the objective was to build first a consistent frame for the long term. As indicated above, this situation was not really anticipated and needed additional accompanying measures in order to cope with the implementation of the suggested automated ISI systems.

However proposals were made in order to help to select and prioritise smaller follow-up projects on-line with the conclusions of the project in order to take benefit of its positive effect and transfer a large amount of the good ideas into reality. Basically, consideration was given for:

- The implementation of the equipment supply on the basis of the developed technical specifications,
- Further selected design projects in strong co-ordination with ENDEF in order to avoid any duplication with already on-going projects. The following projects are suggested:
    - To transfer of the results to the VVER 440 reactors,
    - To implement a consistent technology development programme for VVER reactor application, with regards to adaptation of existing techniques and production of prototypes,
    - To generate adequate test blocks,
    - To study factors with negative influence on ISI effectiveness,
    - To study the limits of the systems capabilities,
    - To establish the NDE-related inputs for review and adaptation of ISI codes and standards,
    - To establish a qualification, training and maintenance centre (improve safety culture and avoid duplication of equipment).

Whereas the EC is concerned with this challenge in terms of programming further TACIS projects according needs and funds, REA is concerned about the optimal implementation of these projects with regards to their integration into a solid strategy. Basic questions like efficient management of ISI experience feedback for validation of optimised ISI instructions and the creation of a NDT Center for co-ordinated training, qualification and maintenance should further be considered.

7 LIST OF ABBREVIATIONS

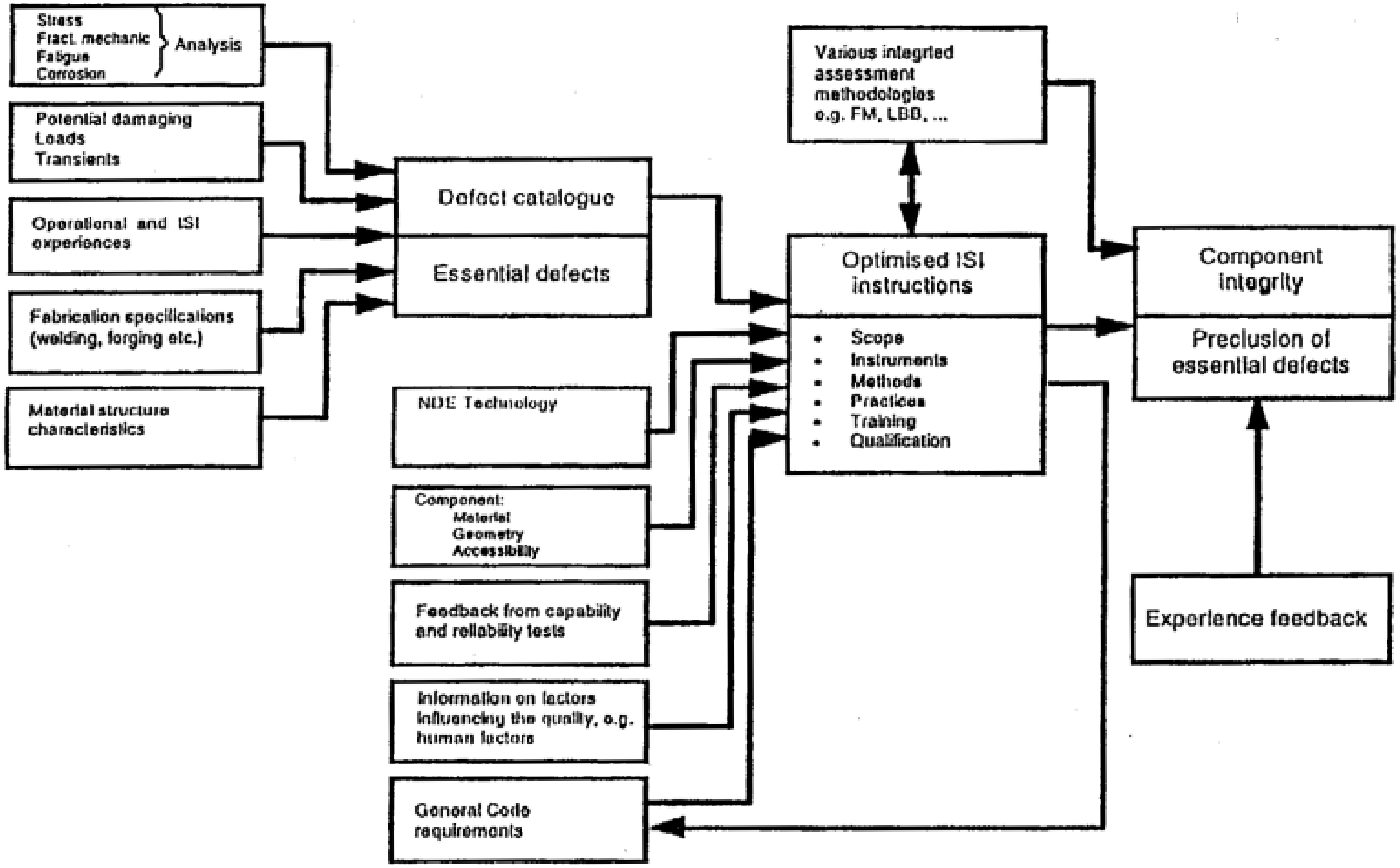
BM	Base Metal
WM	Weld Metal
HAZ	Heat Affected Zone
NPP	Nuclear Power Plant
VVER	Russian type Pressurised Water Reactor type
PWR	Pressurised Water Reactor
RPV	Reactor Pressure Vessel
MCL	Main Coolant Lines
MCP	Main Coolant Pumps
SG	Steam Generator
LBB	Leak Before Break (Concept for Safety assessment of piping systems)
ALARA	As Low As Reasonably Achievable (Concept for reducing the Personnel doses)
PSI	Pre-Service Inspection
ISI	In-Service Inspection
NDE	Non-Destructive Examination
NDT	Non-Destructive Testing
ID	Internal Diameter (Internal surface of the pipe or component wall)
ED	External Diameter (External surface of the pipe or component wall)
VT	Visual Testing
TV	Television

LPT	Liquid (Dye) Penetrant Testing
ET	Eddy-current Testing
RT	Radiographic Testing
UT	Ultrasonic testing
LLT	Transverse wave to Longitudinal wave and reflection of Longitudinal wave
TTT	Transverse-Transverse-Transverse Wave
TOFD	Time of Flight Diffraction
PISC	Programme for the Inspection of Steel Components
ENIQ	European Network for Inspection Qualification
ENDEF	European Non-Destructive Examination Forum
TOR	Terms of Reference
PNAE-G	Rules and Norms for Nuclear Energy (Russian Design Code)
ASME	American Society of Mechanical Engineers
KTA	Kerntechmischer Auschuss (German Rules issued by KTA)
RSEM	Regles de Surveillance en Exploitation des Materiels Mecaniques
U.K.	United Kingdom Safety cases
Siemens KWU	Siemens Kraftwerkunion
Intercontrole	French In-Service Inspection Company (Nowadays subsidiary from Framatome ANP)
AEA Technology	A unit of the British Atomic Energy Agency
EDF	Electricite de France
MINATOM	Russian Ministry of Atomic Energy
REA	Rosenergoatom (Russian Utility)
MOHT-OTJIG RM	Russian economical corporate company for the development and application of annealing technology, backfitting and modernization of NPPs
DIAPROM	Russian company for diagnostic and monitoring of NPP components
VNIIAES	All-Russian Research Institute for Nuclear Power Plant Operation
NIKIMT	Research Institute for Construction Materials and Technologies
ZNIITMASH	Scientific and Production Corporation for Machine-Building Technology
EDO Gidropress	Experimental and Design Organisation “Gidropress”
GAN	Gosatomnadsor (Russian Regulatory Body)
IAEA	International Atomic Energy Agency
CEC	Commission of the European Communities
EC/JRC	Joint Research Centre of the European Commission
TACIS	Technical Assistance to the Commonwealth of Independent States
PHARE	Poland Hungary Assistance in Reconstruction of the Economy
WANO	World Association of Nuclear Operators

8 References

1. Technical Terms of Reference – TACIS 93 – Nuclear Safety – Russian Federation – Non-destructive Examination / In-service inspection – Project Number 2.05 – PR - 93/267 Rev. 6, 02 August 1994
2. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 1: Input data on the status of in-service inspection in Russia – DIAPROM (Iantchenko) – DIAPR41200811-1, dated May 17, 1997
3. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 2: Methodology of improvement and optimisation of instructions for in-service inspection – DIAPROM (Iantchenko) – DIAPR41200812-0, dated February 24, 1997

4. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 3: Western in-service inspection and potential co-operation with Russia – DIAPROM (Iantchenko) – DIAPR41200813-3, dated September 29, 1997
5. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 4: Improved and optimised in-service inspection instructions – DIAPROM (Iantchenko) – DIAPR41200814-1, dated September 15, 1997
6. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 5.1: Technical specifications of the NDE equipment for the steam generator inspection – DIAPROM (Iantchenko) – DIAPR41212815-5, dated April 16, 1997
7. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 5.2: Technical specifications of the NDE equipment and manipulator main circulation piping inspection – DIAPROM (Iantchenko) – DIAPR41212825-2, dated September 15, 1997
8. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 6: Technical documentation: Reliability and Human Factors – DIAPROM (Iantchenko) – DIAPR41200816-1, dated September 15, 1997
9. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Deliverable 7: Financial and technical documentation: Implementation of improvement and optimisation of in-service inspection instructions – DIAPROM (Iantchenko) – DIAPR41200817-2, dated September 15, 1997
10. TACIS 93 – Project R2.05/93 – VVER 1000 In-service inspection – Final Report – Siemens KWU/Intercontrôle/AEA Technology (Bakirov, Grigoriev, Iantchenko [DIAPROM], Engl & Heumüller [Siemens KWU], Morisseau [Intercontrôle], Sephton & Worall [AEA Technology], Tillet [EDF]), dated December 21, 1998
11. Technical Terms of Reference – TACIS 93 – Nuclear Safety – Russian Federation – VVER ISI Methodology – Non-destructive Examination / In-service inspection (NDE/ISI) – Project Number 2.05bis – 95.001 Rev. 4, April 1995
12. TACIS 93 – Project R2.05/93bis – VVER 1000 In-service inspection – Final Report – EDF (F. Champigny) – EDFFR81200706-1, dated October 20, 1997
13. EUR 18067 EN – Proposals for future activities in the filed of NDE in CEEC's Russia and Ukraine – Version 7 – May 1998
14. EUR 18752 EN – ENDEF guidelines for detailed proposals to improve in-service inspection in VVER and RBMK reactors – June 1999



<u>Figure 1</u>: METHODOLOGY FOR ISI IMPROVEMENTS

IMPROVED ISI INSTRUCTIONS - RPV

PREREQUISITES:

"AVAILABLE" IMPROVED NDE METHODOLOGY

- **DETECTION CONTACT TECHNIQUE**

REQUIREMENT (From recent Russian calculations):

Surface / subsurface	8 x 24 mm^2
Embedded: examination from OD	8 x 24 mm^2

MINIMUM DETECTABLE DEFECT:

	EXAMINATION FROM ID (For Western equipment applied to VVER)	EXAMINATION FROM THE OD SURFACE Contact technique using phased array	
SHELL surface/ subsurface embedded	4 x 12 mm^2 } ID and OD 4 x 12 mm^2 } surface 5 x 15 mm^2	6 x 18 mm^2 } ID 5 x 15 mm^2 } surface 5 x 15 mm^2	3 x 10 mm^2 } OD 3 x 10 mm^2 } surface
INNER RADIUS surface/subsurface	4 x 12 mm^2	6 x 18 mm^2 (limited scope)	
NOZZLE TO PIPE WELD surface/subsurface embedded	3.5 x 11 mm^2 4 x 12 mm^2	4 x 12 mm^2 4 x 12 mm^2	

- **SIZING / DETECTION OVERCHECK**

Sizing technique: { Sizing tolerance: { {	Focussed technique /TOFD/SAFT $+\Delta$ = max.(2.0, 0.1z) mm $-\Delta$ = max.(1.0, 0.1z) mm [z = dimension being measured]	Phased array /TOFD/SAFT. $+\Delta$ = max.(2.0, 0.1z) mm $-\Delta$ = max.(1.0, 0.1z) mm [z = dimension being measured]

- **MANIPULATOR ACCURACY:** Relative ± 1 mm; Absolute ± 3 mm
- **QUALIFICATION (ISI SYSTEM & PROCEDURE)**
- **ISI (FROM ID & OD SURFACES)**

CONSEQUENCES:

- HYDROTEST 8 YEARS
- ID ISI (After hydrotest) 8 YEARS
  (EXTENDED SCOPE:
  Surface / subsurface 0 ÷ 40 mm in core region)
- OD ISI 4 YEARS (in 4 phases)

Figure 2: IMPROVED ISI INSTRUCTIONS FOR THE RPV

IMPROVED ISI INSTRUCTIONS - MAIN CIRCULATION PIPING

PREREQUISITES:

"AVAILABLE" IMPROVED NDE METHODOLOGY

- **DETECTION CONTACT TECHNIQUE**

  REQUIREMENT (From recent Russian calculations):

ID Surface	4 x 20 mm^2
ID Subsurface	5 x 20 mm^2
OD Surface	4 x 20 mm^2
Embedded	5 x 20 mm^2

  MINIMUM DETECTABLE DEFECT (For Western equipment applied to VVER):

ID Surface	4 x 12 mm^2
ID Subsurface	5 x 15 mm^2
OD Surface	2 x 10 mm^2
Embedded	5 x 15 mm^2

- **SIZING**

Technique	Phased array /TOFD/SAFT
Sizing tolerance	$+\Delta = \max(2.0, 0.1z)$ mm $-\Delta = \max(1.0, 0.1z)$ mm [z = dimension being measured]

- **MANIPULATOR ACCURACY:** Relative ± 1 mm; Absolute ± 3 mm
- **QUALIFICATION (ISI SYSTEM & PROCEDURE)**
- **PERFORMANCE OF IMPROVED AND QUALIFIED ISI OF PIPING WELDS**
- **X-RAY TESTING FROM 3 DIRECTIONS**

CONSEQUENCES:

- HYDROTEST 8 YEARS
- BUTT WELD (Pipe to pipe) 8 YEARS
- BUTT WELD (Pipe to component) 4 YEARS
- BUTT WELD (Pipe to elbows) 4 YEARS
- DISSIMILAR METAL WELDS 8 YEARS UT } 4 years
  8 YEARS RT } apart

Figure 3: IMPROVED ISI INSTRUCTIONS FOR MAIN COOLANT LINES

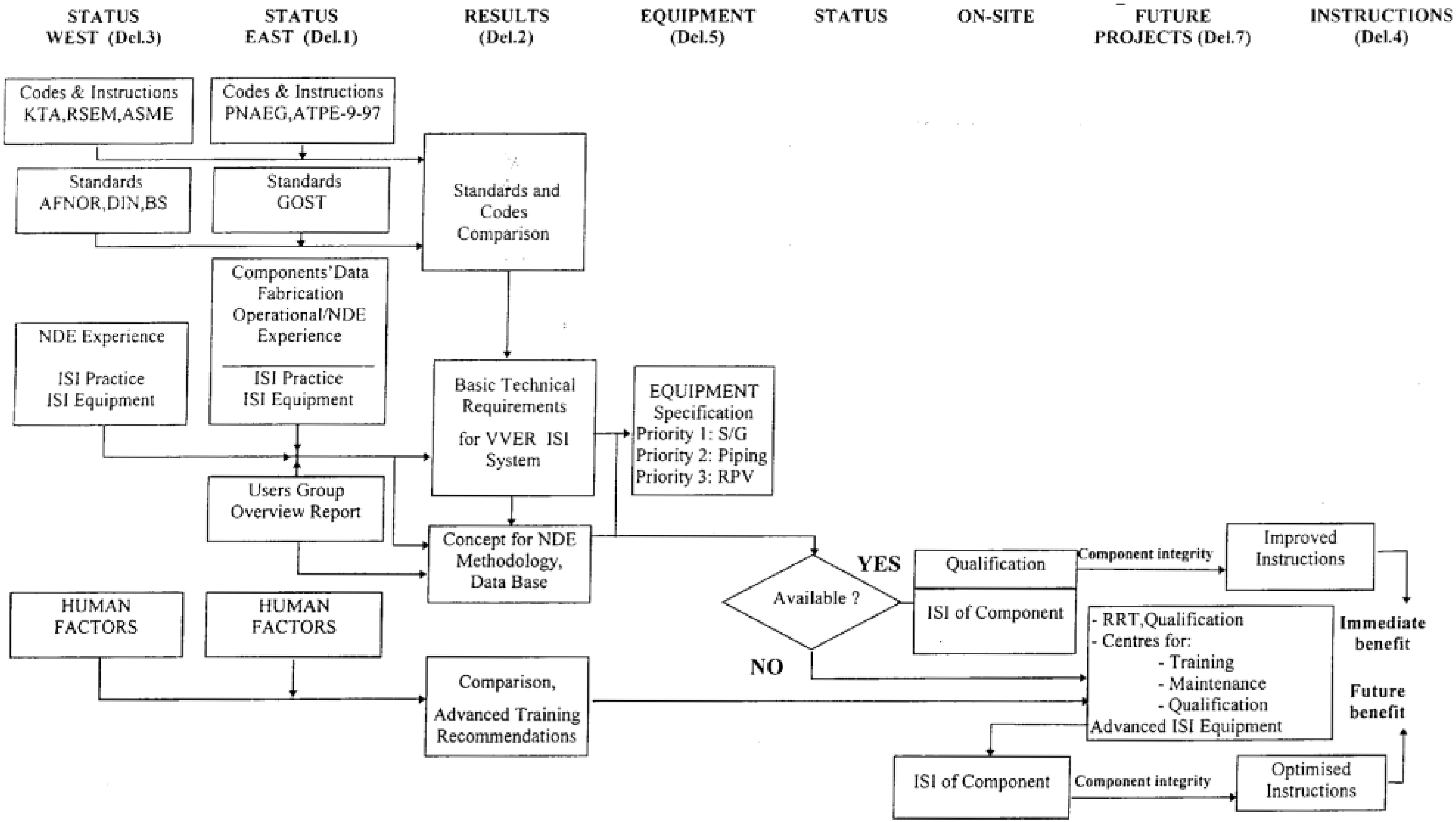


Figure 4: FLOWCHART OF THE WORK ORGANISATION ACCORDING TO THE ENDEF STRATEGY

			DELIVERABLES						
			1	2	3	4	5	6	7
TASKS			Input Data on the status of ISI in Russia	Methodology of improvement and optimisation of instructions for ISI	Western ISI and potential co-operation with Russia	Improved and optimised ISI instructions	Technical specifications for NDE equipment and services	Technical documentation: Reliability and Human Factors	Financial and technical documentation: Implementation of improvement and optimisation of ISI instructions
1	1.1	Codes & Standards, Organisation, Experience (status)	1A: Codes & Standards in Russia 1B: ISI practices in Russia 1C: Methodology in Russia 1D: Organisation and experience in Russia 1E: Side condition report		3A: Codes & standards in Western Europe 3B: ISI practices in Western Europe 3C: Methodology in Western Europe 3D: Organisation and experience in Western Europe 3E: Comparison of Russian and West European codes, standards and practices				
	1.2	Components	1F: Data base & component related criteria				existing equipment		
		ISI methodology & concept	1G: Input from other disciplines (fracture mechanics, …)	2A: Methodology of improvement		4A: Criteria for concept 4B: ISI Methodology	5B: Consequences of ISI concept		
		ISI instructions (« handbook »),	1H: Analysis of existing instructions	2B: Methodology for component specific ISI programmes		4C: Component specific transfer 4D: ISI Handbook-type concept	5C: Equipment related factors		7A: Overview on the integral methodology and performance concept 7B: Consequences of the implementation into the actual plant operation
	1.5	Needed inspection equipment					optimised equipment		7C: Equipment related factors for implementation of optimised instructions

			DELIVERABLES						
			1	2	3	4	5	6	7
TASKS			Input Data on the status of ISI in Russia	Methodology of improvement and optimisation of instructions for ISI	Western ISI and potential co-operation with Russia	Improved and optimised ISI instructions	Technical specifications for NDE equipment and services	Technical documentation: Reliability and Human Factors	Financial and technical documentation: Implementation of improvement and optimisation of ISI instructions
2	2.1	Reliability (techniques, instruments & human factors),	1J: Factors influencing the reliability	2C: Analysis of the information on reliability and of the consequences	3F: Results on reliability (workshop and visit)			6A: Consideration & evaluation of approach to improve ISI reliability 6B: Results of laboratory visit	
	2.2	Assessment of operators	1K: Personnel training and qualification	2D: Analysis of the information on operator assessment and of the consequences				6C: Data collection on the assessment operator training	
	2.3	Comprehensive training equipment					5E: Consequences on operator training programmes		7D: Factors of operator training programme assisting in implementation of ISI instructions
	2.4	Simulators and equipment					5F: Consequences for operator training equipment		
3		Needs for equipment and services for future projects							7^{E}: Review of projects already proposed 7F: Reflection of new structured projects along ENDEF-structure
4		Assistance to the beneficiary for the implementation of future projects							7G: Recommendations fur programming future projects have been made (implementation cannot not be made within the project)

Table 1: OVERVIEW OF THE PROJECT RESULTS (2 PAGES)