TRAINING MATERIAL

TECHNICAL FEATURES FOR QUALITY PROCEDURES IN TUNNELLING

Prepared by W.G. 16 "Quality"

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What is Quality?

For the International Standards in Industrial Production

"Quality is the amount of features and characteristics of a product or service that demonstrates its ability to satisfy stated or implied needs "

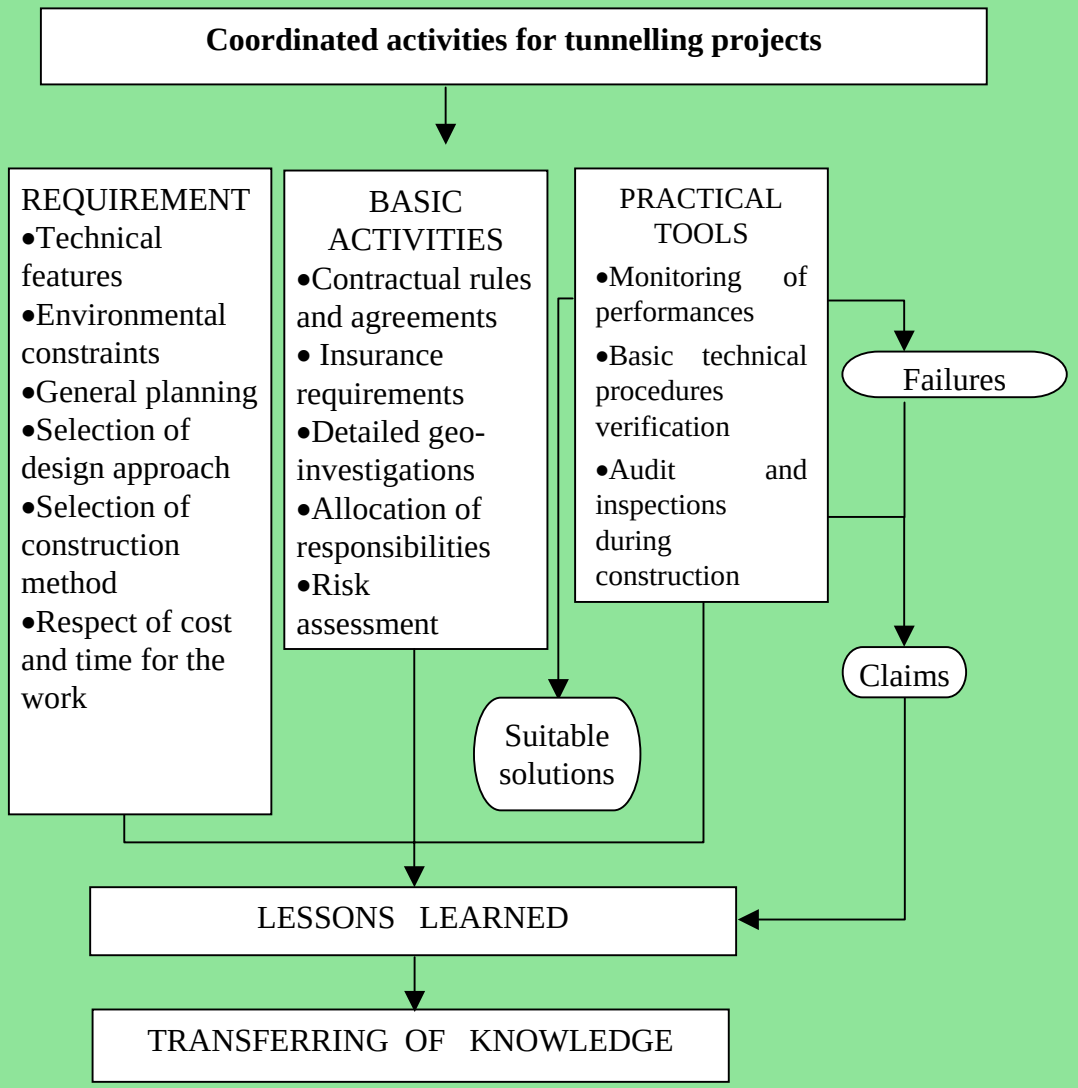
For the experts in Quality

"It is a way to follow a process by means of procedures and it is the structure to perform the various actions."

For practitioners in tunnelling, for daily application of Quality procedures,

"Quality means knowledge, experience and capacity to identify and follow the procedures, to avoid and solve some of the critical problems of tunnelling"

Tab. 1. Schematic relationships between the various keypoints of the Quality approach.



This table represents the correlations between the fixed points which define the work conditions to be fulfilled, the main design and field activities which can be put in operation to provide comprehensive design and contractual document, and the principal practical modes to be applied to verify the satisfaction of the requirements. All positive and negative experiences lead to a better and transferable knowledge.

Structure of the Quality concerns:

During the main phases of a tunnelling work, which are summarized in

- Conceptual Planning
- Procurement
- Design
- Construction
- Operation & Maintenance

some practical recommendations should be followed on

- how to achieve Quality
- specify Quality Management (design, contracting,construction)
  Quality Assurance (implementation of procedures)
  Quality Control (inspections)

General recommendations are related to:

- Project preconditions
- Risk allocation – principles
- Allocation of responsibility
- Quality goals

Is it convenient to adopt the procedures suggested and contained in the Quality Plans?
Yes, bacause there are important

possible advantages:

- Good organization and relationship
- Definition of needs and constraints of the work
- Design adapted to needs and constraints
- Control on the evolution of design stages and selection of appropriate contracts
- Evaluation of risks and allocation of responsibilities
- Ability to perform modifications to details
- Historical records of the design and of the performed works
- Reciprocity for communications and problem-solving attitude

Quality procedures can be organized in a system made of 3 levels, characterized by a growing detail of the items, combined in a website solution,

1) Coordination

Steps for the lifetime of a tunnel (for example the list and the connections between the various phases and involved people)

2) Identification of crucial keypoints

For each major phase description of crucial relationships (for example in the phase of Design and Construction Concepts selection)

3) Detailed technical procedures and data to be verified and monitored

For each interactive element identify full definition of current practices, technical specifications and verifications (as examples, in the selection of grouting or conditioning soil additives in excavation by EPB shield, or in the shotcrete daily controls, or in the concrete supplying for the final lining)

Coordination: Steps for the lifetime of a tunnel

ITAVAITES

QUALITY ITEMS ⇓	General planning	Design	Financing	Procurement	Characterization	Monitoring	Construction	Approval	Claims and controvercies	Operation	Maintenance	Installations	Statistics
Management responsibility	Rules and specifications for involved people												
Quality planning	Definition of procedures for the various activities and co-ordinator												
Contracting	Administrative, legal and technical rules												
Control and inspections	All the tests, approval, inspections, verifications												
Document control	Regularity of documents												
Purchasing And Contractors	Control of materials and contractors												
Non conformities	Problem definition and warnings												
Corrections and preventions	Accurate definition of problems and plannong for preventive and remedials												
Audits	All the inspections for organization												
Training and information	Internal and external education												
Data control and elaborations	Data processing of all phases; economical, statistical, technical, measurements												

This is a general layout of all the possible stages of an underground work (1st row) linked to all the specific actions of quality plans (1st column). Depending on the specific case, an interacting matrix can be implemented following the arguments listed in the various rows.

Identification of crucial keypoints

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This is an empty table that can represent a strong tool to identify at each stage of the tunnelling the actions to be observed and monitored to prevent and to solve common problems (what to do and to avoid, what to monitor, expected consequences).

TUNNELLING STAGE	Step of the work	Concerned Elements	Negative Effects	Actions	Notes
Work Planning					
Design & Characterization					
Financing, Procurement & Contractual phase					
Construction & Monitoring					
Operation and Maintenance					

The stages of the whole technical design can be divided conventionally into:

- Geological and topographical surveys;
- Hydrogeology and environment;
- Design and construction concepts;
- Rock support and reinforcements;
- Sealing and linings;
- Excavation and construction equipment;
- Installations and safety;
- Monitoring, inspections, maintenance and statistics;

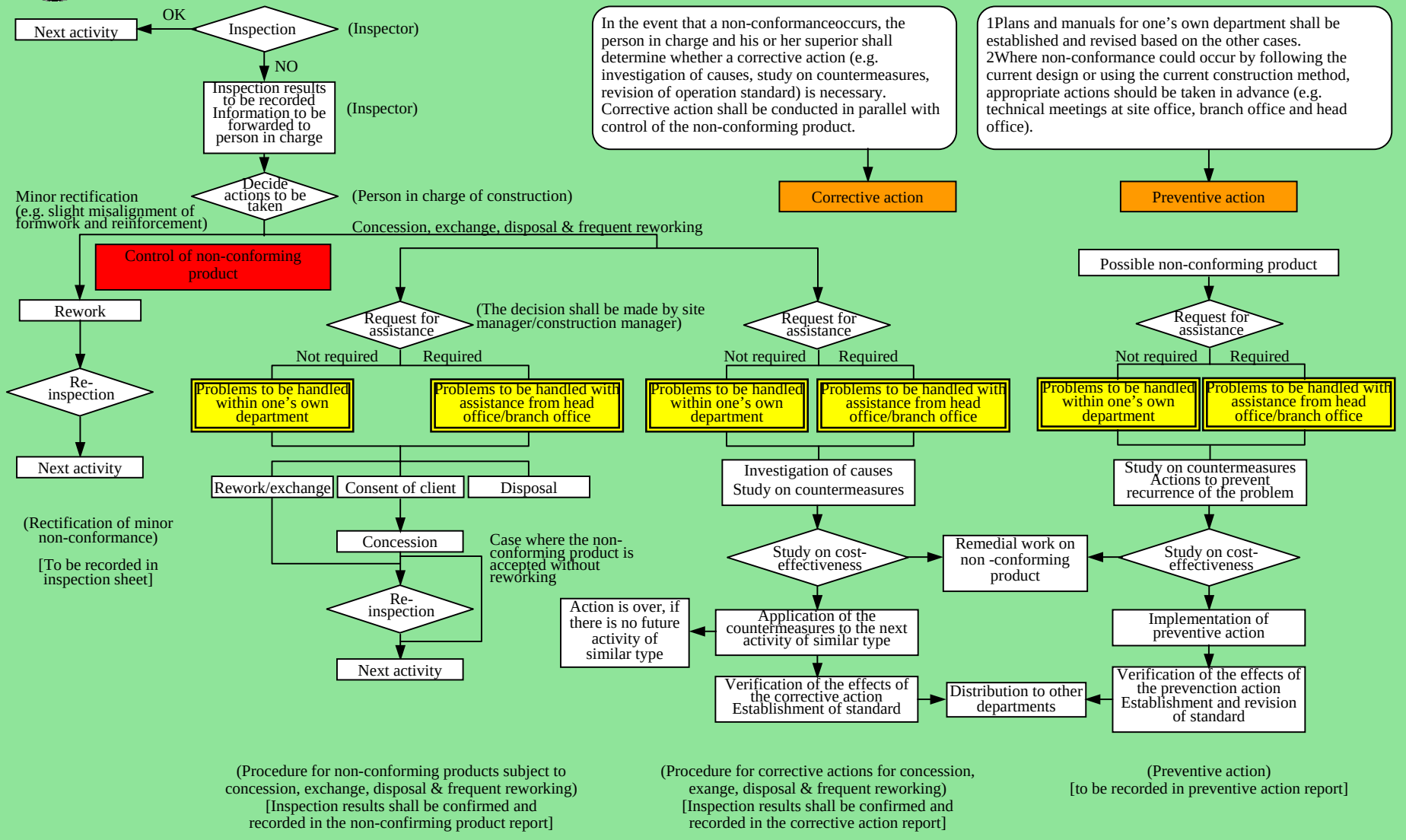
and for each of these stages a matrix can be drawn up.

Detailed recommendations and daily procedures are related to:

- Project requirements
- Materials supplying
- Monitoring of the structures
- Quick solution of simple problems

DESIGN AND CONSTRUCTION CONCEPTS	Step of the work	Concerned Elements	Negative Effects	Actions	Notes
Work Planning	Selection of the geometry of the work and of installations	Type of the work, size and shape, profil. Use of reamer TBM	Unadequacy of the methods or type of work	Experience and lessons learned from similar cases. Adaptability of the project parameters	Discussions and agreements with external parties.
Design & Characterization	Selection of parameters and design methods	Overburden, water, faults, settlements, accessibity. Careful to landslides and rock fall.	Accidents, damages, instability, delays and overcost	Revision of the design and risk assessement	Fundamental step of the whole process
Financing, Procurement & Contractual phase	Detailed description of costs and supplies	Complete knowledge of alternatives; Selection of the appropriate type of contract	Difficulties for the relationship with the involved parties; Resolution of contract	Prepare detailed contracts and establish severe economic constraints	In this step economics, regulations and engineering must agree completely
Construction & Monitoring	Selection of construction method (traditional or mechanized) and site measurements; landfilling or rock waste recovery.	Selection of equipment, personnel, instrumentation, organization of the personnel and phases. Particular conditions for microtunnelling and undersea crossing. Control of blasting profiles.	Surface occupation, vibrations, dust, settlements, stability of landfills	Severe and daily control by the field engineers	Fundamental step of the whole process. Daily discussions and claims.
Operation and Maintenance	Prevision for future works.	Prevision for future work. Performance of the installations.	Difficulties for maintenance and inspections	Prevision of the state of the tunnel after long periods	

This is an example of one of the possible matrix that can be prepared



Example of flow chart for non conformities

At the 3rd level

Detailed technical procedures and data to be verified and monitored,

each single box of each matrix can be reminded by means of procedures to be followed (for example application of shotcrete, mix design, additives, thickness, Scheduled activities etc) and data to be monitored or checked (increase of strength, rebound percentage, data report, etc)

At the same level, the collection of data in difficult conditions can help to face with non conformities and minor claims (both for less occurence and for solution).
But, while not able to avoid them, the quality procedures could help to find the solution also for major failures.

Quality problems means usually non conformities; but in some cases the lack of Quality procedures can determine severe problems.

Unfortunately also when Quality procedures are applied failures occur: this is the reason for the distinction between Quality and collapses

Some examples of non conformities in continuous and segmental linings are reported.

At the 3rd level

Detailed technical procedures and data to be verified and monitored.
Example: How and what to check in Q.A. in order to avoid or reduce or manage non conformities in continuous and segmental linings.

Continuous linings (Fig. 15-16-17): casted or sprayed concrete linings.
Check on design, material supply and installation on site.
Particularly: excavation phases (time of installation), lining thickness and shape, role of the lining from the static point of view, waterproofing, strength and curing, reinforcement bar, material types (cement, additives, aggregate grading), construction sequence (invert, sidewalls etc), control procedures (slump, water content, core testing), monitoring of load and ground conditions and convergences, water inflow, definition of trigger levels.

Segmental linings (Fig. 18-19) : manufactured linings.
Check on design and site load conditions, installation and TBM structure, curing.
Particularly: design evaluation of maximum TBM thrust and grouting pressure), factory controls on manufacturing process (reinforcement, mix, curing, cover, quality od surfaces), size tolerances, transportation to site, installation sequence (ring erection details, fixing details, grouting details, tolerances while tunnel is not linear, gasket protection and waterfproofing), evolution of loads and lining deformation due to ground loss and imperfect grouting between segments and ground, surface settlement vs tunnel progression, performances, definition of tigger levels.

Description:

Example of systematic non conformity, in spite of the application of QA.
Development of fractures in the concrete lining in a large section of railway tunnel.

Comments:

Noticeable cracks in new concrete linings, and defects in the concrete joint, due to problems in the casting control; in this case a rudimental monitoring has been added to follow the evolution of the crack, in order to understand eventual progressive damaging actions due to an increase of stresses of the (weak) surrounding geological formation. No problem for stability, but for the durability.

Description:

Example of non conformity. Short fracture and stains of water in a new concrete lining

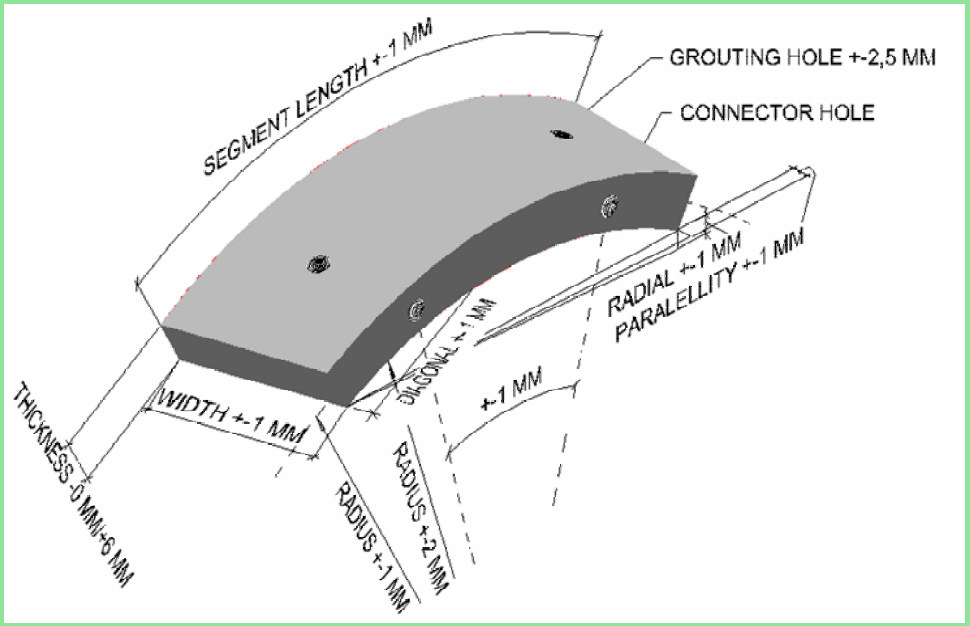
Comment:

The damage is the consequence of a coupled defect in the external water sealing and in the concrete lining construction. These facts are actually quite common, and possible new general solutions for the coupling of impemeabilization and lining should be studied in future.

Description: **old lining in masonry for rail tunnel. Damages to to weathering and long term creep phenomenon.**

Comment: **the Q.A. is involved in the management of a large number of tunnel for the railroad administration. In these cases a rational procedure for data base arrangement and verification of maintenance works is essential.**

Tolerances control for segments



Gasket control for segments

Description: **the installation of segmental lining should follow precise instructions. Some non conformities can occur: 1- mortar repair, 2- rupture at the corner for stress concentration or for poor handling, 3- thin crack due to excess of stress, 4- poor alignment between rings for unaccuracy of the design along the curves.**

Comment: **Q.A. foresees strict controls both for the design, the construction and the installation of segments. Also critera for acceptance can be assessed in Quality procedures.**

Description: **Room in a large underground car park facility, with a very thin high performance shotcrete layer (3-5 cm).**

Comments**: The example of a successful sequence of stages shows the good results: it is the case of in site controls in Finland, where the proper geomechanical design, the excellent blasting profiling and the careful shotcrete application (plus bolting) offer a final "Quality" underground work.**

Conclusions

ITAVAITES

General features for Quality in Tunnelling

- site characterization and design model
- proved equipment
- good contracts
- responsibility and experience
- exchange of knowledge, both for case histories and new techniques
- fundamental role of Universities and Associations for collection and record of cases

For design staff and field engineer

- for each action (calculations, assumptions, observations, prospection, measurements, construction)
  ask permanently WHAT and HOW the action is done

WHAT	WHERE	HOW	WHEN
PROCEDURES AND OVERALL SYSTEM	YOU MANAGE FROM THE OFFICE, BEARING THE SYSTEM IN THE MIND	OPTIMISATION OF PROCEDURES CONCERNING WHAT WE KNOW, IN ORDER TO AVOID OVER COSTS, DELAYS, CLAIMS	ALWAYS
GEO – CONDITIONS (PHYSICAL, GEOLOGICAL, STRUCTURES)	YOU MANAGE IN THE TUNNEL AND IN THE DESIGN OFFICE	PREVISION OF WHAT WE DON'T KNOW EXACTLY (INVESTIGATIONS, GEOLOGY, GEOPHISICS, MONITORING)	DURING PROSPECTING AND CONSTRUCTION
REAL PERFORMANCES, HAZARDS AND RISKS, COLLAPSES 1) STABILITY OF THE FACE, WALLS AND SURFACE 2) ADAPTABILITY OF THE METHOD OF ADVANCE 3) PHYSICAL CONDITIONS AND STATIC OF THE STRUCTURE	IN THE TUNNEL	MANAGING OF WHAT IS NOT CURRENTLY CONSIDERED IN THE QUALITY CONCERNS; EXPERIENCE HIGH KNOWLEDGE OF PERFORMANCE OF EQUIPMENT AND SUPPORT CAPABILITIES (NOT WRITTEN IN QUALITY HANDBOOKS)	1) DURING EXCAVATION 2) JUST IN CASE, D&B ALLOWS REINFORCING, DRAINAGE, PARTIAL SECTIONS ETC; FFE ALLOWS CONDITIONING OF SOIL AND BY PASS; 3) JUST IN CASE

Q.A. implies continuous check while tunnelling: it is better to stay in a permanent warning state rather than relax and risk to find bad surprises (**Tunnel collapses**)

Quality checks what is easy to be checked (**non conformities**): noboby will be able to check continuosly the perfect implementation of details of a complex model, nobody will be able to check each action made in laboratory or field characterization, nobody will be able to check continuosly the correct use of shotcrete nozzle.

The solution is to train, experience, pay the personnel at each level to be some probability that people will demonstrate self responsibility.

In order to really let Quality to become a successful approach, the monitoring of design and field performances by means of National and international data base concerning the construction and refurbishment of tunnels should be regularly applied.
Also the diffusion of technical data concerning difficult conditions and collapses can help to understand the reason for non conformities.

Finally, in the future it should be of help the definition of new classification describing the expected time/cost for the various ground conditions based on the tunnelling method, a way to consider together risk and quality.

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The observations suggested in this presentation arise from the work of members of ITA-AITES Working Group 16 involved in this project, from different nations:

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