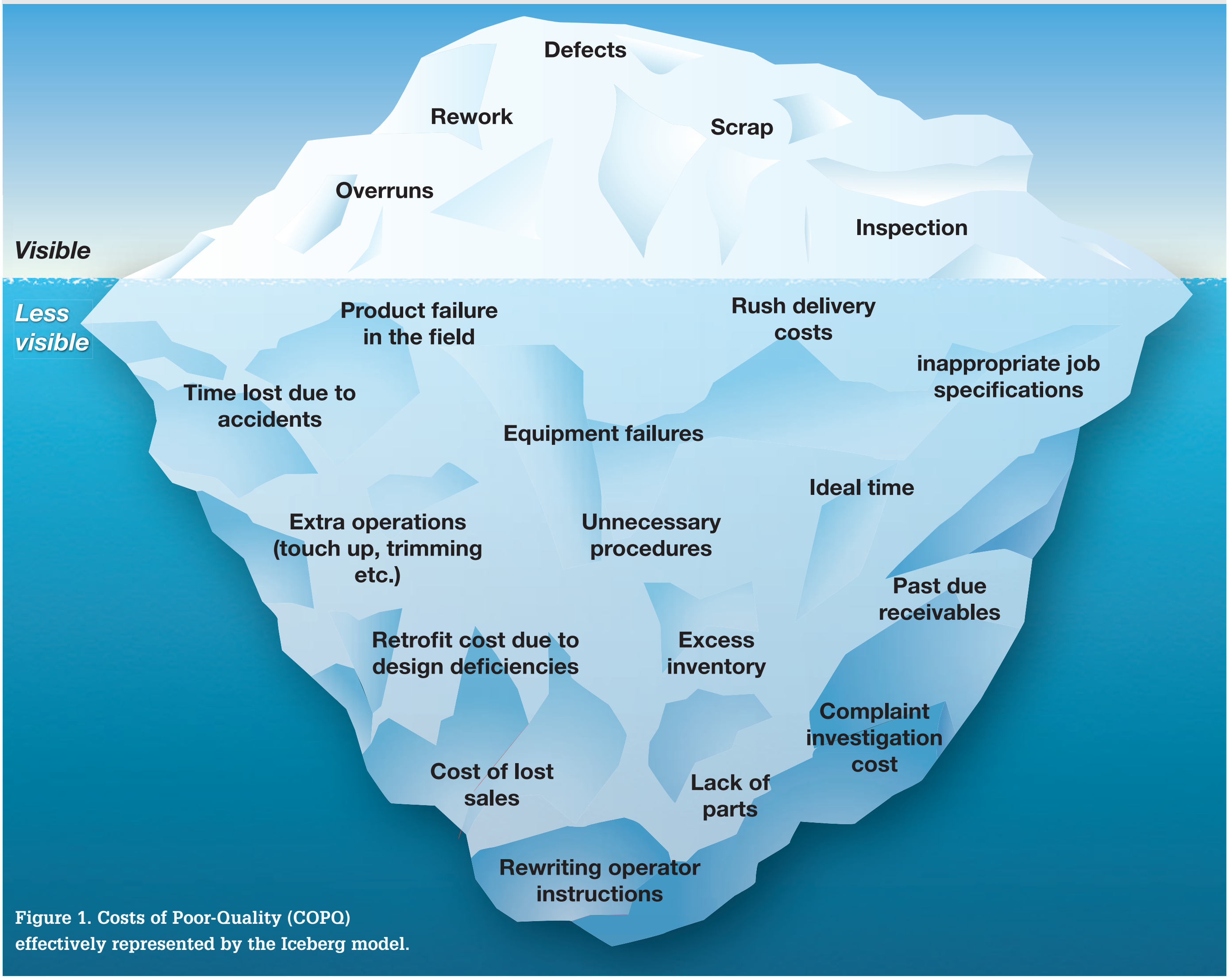

Figure 1. Costs of Poor-Quality (COPQ) effectively represented by the Iceberg model.

Continuous quality surveillance

During the construction of hydroelectric plants, poor quality can have a hugely negative impact on construction time, plant performance and safety. A method known as the Continuous Quality Surveillance Scheme can keep the manufacturing of the most critical components, such as pressure parts, rotors and valves, under control with a view to minimising the Cost of Poor Quality (COPQ). This can be effective when used in a systematic manner and requires the formalisation of some main elements such as the Pre-Inspection Meeting (PIM) at the start of construction; the Inspection and Test Plan (ITP), with specific witness points for all critical manufacturing phases; and the use of Notification for Inspection (NOI) to formalise the intervention points.

Hydroelectric power plants need strict requirements with regards to the safety and productivity of the plant. Poor quality revealed during the construction, commissioning and operation of the plant may lead to huge costs with regards to safety (loss of human life), as well as productivity (in a few days loss of production costs may overcome the single component cost).

The sooner manufacturing defects (dimensional, non-conforming raw material, NDT detectable defects) are found, the less overall quality and delivery time will be affected.

Introducing a follow-up method specifically intended to minimise the Cost of Poor Quality (COPQ) during manufacturing can considerably reduce safety risks and failure costs, keeping general extra costs down. Such methodology, not unknown in the hydroelectric industry, requires a systematic approach in order to achieve the highest effectiveness (as occurs in other industrial sectors such as the nuclear, oil and gas industry), and the formalisation of fundamental elements. These are:

- The continuity of interventions carried out by

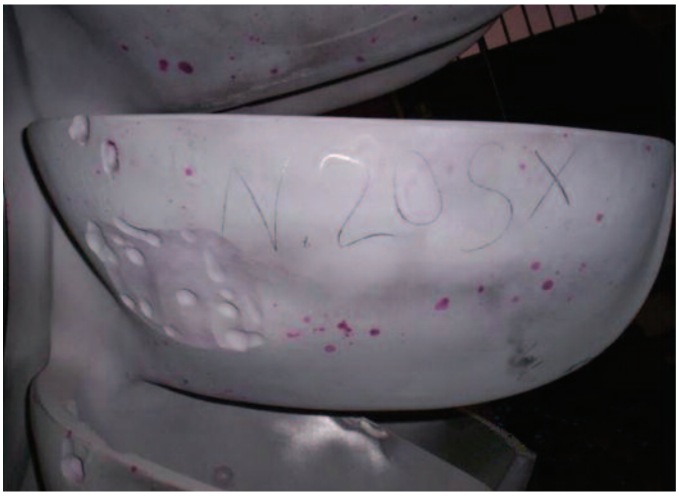
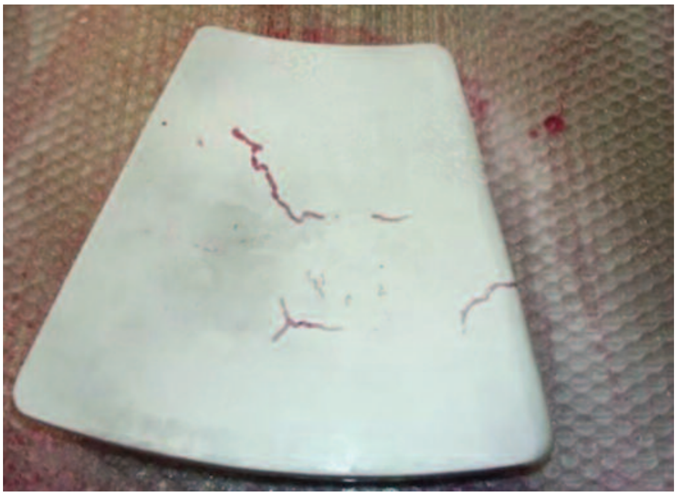

Figure 2. **Example of defects on a Pelton runner and white metal bearing segments detected during a liquid penetrate examination.**

the appointed inspector (typically leaning on independent inspection agencies).

- The Pre-Inspection Meeting (PIM) at preliminary stages of manufacturing.
- The Inspection and Test Plan (ITP), detailed with specific witness points for each critical production step.
- The formalisation of intervention by means of Notification for Inspection (NOI).
- The expediting activities to verify the effective progress of works, detecting and avoiding bottlenecks.

Quality issues

The definition of quality is the "lack of defects" in a product. However, such a definition appears to be more suited to defining the "defectiveness" of a product, rather than its quality. Certainly, defectiveness is not a suitable comparison parameter unless it is associated to other relevant parameters, such as cost. As an example, should we choose between two products, the first defect-free and the second full of defects, for the same price? Obviously we would prefer the first one. However, if the cost of the first product were considerably higher than the second, perhaps some would choose the second despite its defects.

The official definition of quality reported in standard ISO 8402:1986 is "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs".

Therefore quality is not an attribute of the product or service itself, but refers to the use of such product or service, as per M. Juran's definition (2004): "Quality is fitness for use".

UNI EN ISO 9000 standard (2000 edition) had the merit of turning the focus from the product or service to the set of corporate processes concurring to its realisation. In fact, the realisation of good products or services can only result from well managed and well controlled processes.

Quality is a general concept but applicable to all human realities. The variable is the system utilised by both customer and supplier to evaluate it.

Cost of Poor Quality (COPQ)

As well as any other parameter, the quality of a product, process or service must be correctly measured. This could be difficult, since it is based on the perfect knowledge of the technical characteristics required and the efficacy of their transmission through the productive flow. Quality measurement consists of evaluating how far a product is from the ideal one. To do this, it is necessary to consider the characteristics requested by the customer and then implement a method to measure them.

As important is the capability to define and measure how much poor quality can affect both the customer and the supplier. Poor quality related costs are often hard to evaluate and mainly hidden and difficult to identify.

Our experience of hydroelectric plant components leads us to identify the following specific costs for non-quality:

- Costs borne out of delivery delays.
- Costs borne out of manufacturing errors and modifications required on components to allow assembling with defective parts.
- Costs borne out of re-engineering and re-design for suppliers and customers, following the detection of non-quality in a late stage of construction.
- Costs in terms of risks to safety.

So how can costs for non-quality be kept under control by means of continuous surveillance of the construction process? For this purpose it is convenient to deepen the interaction between


Figure 3. **Example of welding defects**

products and manufacturing processes. An effective description of this interaction is shown in Deming's cycle (PDCA - Plan, Do, Check, Act), suggesting that the following need to be kept under strict control:

- Capture of client's needs and expectations on the quality.
- Translation of agreed level of quality into characteristics controllable by the supplier.
- Design of the product.
- Manufacturing process.
- Marketing and sales process.
- After sales and customer care process.
- Process of analysis and improvement of performance.

In this perspective every process must be monitored to improve its performance. The whole set of processes must also be co-ordinated and controlled especially at input/output interfaces.

Every characteristic must be defined and kept under control as soon as possible along its path to the customer. It is clear, therefore, that before starting the production, it is necessary to elaborate a strategy to define and organise the objectives, based on the expectation of the final user. These must be the starting point for every product or service: customer requirements, the intended use for the product but also implicit desires which can remain unsaid.

A fundamental point is the shift from the results obtained to technological solutions. Capitalising its own know-how, the supplier must include customer requirements into its own process or in the different processes involved. This stage requires technical specifications, procedures and instructions to comply with these requirements.

For this reason, it is important that a thorough surveillance of the manufacturing process is applied during the whole path. An error at an early stage is very hard to fix afterwards and could be potentially disastrous, once the mechanical and electrical equipment are delivered to the power plant.

In the Continuous Quality Surveillance Scheme (CQSS), the critical processes must be monitored from the beginning and for the whole duration.

Such activity entails high technical skills and surveillance of the incoming material which is to be utilised, through to the final inspection. This makes it possible to detect defects that otherwise would remain hidden until the operation of the plant.

We also notice that manufacturing defects are often due to a supplier's lack of specific experience, to side-effects of the efforts to deliver on time, to misunderstanding of technical requirements, an excessive workload, or general human errors that could be avoided with proper surveillance.

In particular the CQSS relies on the following instruments:

- Continuity of the appointed inspector intervention (typically leaning on Independent Inspection Agencies).
- Pre-inspection meeting (PIM) at the preliminary stage of construction.
- Inspection and Test Plan (ITP), detailed with specific witness points for each critical production step.
- Formalisation of interventions by means of Notification of Inspection (NOI).
- Expediting activities to verify the effective progress of works, detecting and avoiding bottlenecks.

A reference point is fundamental for the surveillance of the manufacturing process. This means allowing a single person (the appointed inspector), with the required skills, abilities and knowledge, to be in charge of the whole project from the inspection's point of view.

Experience leads us to consider the Pre-Inspection Meeting as the point of clarification of all the technical and quality aspects for all the subjects involved in the project (client, contractor, supplier and inspection agency).

The Inspection and Test Plan (ITP) is a document for quality control defining all the inspections and tests required during the construction process. For each point of inspection, the level of control required for each subject involved must be indicated (client, contractor, supplier and sub-suppliers, inspection agency).

This allows the formalisation of surveillance during the whole manufacturing process, until completion and delivery. The frequency of the intervention points assisted by the appointed inspector (witness points) is determined by the client depending on the importance of the component.

Referring to the points of inspection reported on the ITP, the vendor is responsible for notifying the scheduled inspection dates to all the subjects involved. The vendor must issue upon notice a Notification of Inspection (NOI) indicating the kind of control, applicable ITP line, date and duration forecasted for the activity and in general all the information required to carry out inspection activities in compliance with the ITP.

In parallel with inspection activities, if required, periodic visits are carried out at a supplier's premises. These are to find (and help solve) potential problems that could affect construction and cause delivery delays. Problems could include: missing approved documentation, excessive workloads and inefficient technical communication between those involved in the project.

Safety in the plant

A catastrophic accident happened in August 2009 at Sayanogorsk, Russia which affected the turbines hall and transformers of the Sayano-Shushenskaya hydroelectric power plant. The facility had ten Francis turbines of 640MW each producing 24TWh/yr.

Figure 4. **Sayano-Shushenskaya plant, before the accident.**

Figure 5. **The accident at Sayano-Shushenskaya plant, 2009.**

A large quantity of water coming from the Yenisei River knocked down the turbine hall, leading to the explosion of at least one transformer. All the turbines were badly damaged and three of them were totally destroyed.

In total, 75 people were killed during this disastrous incident. The official report of the accident, issued by Russian authorities, was initially published on their website in October 2009. The report identified the cause of the accident to be a bolt failure in the cover of one turbine, due to vibrations. It was found that at the moment of the accident at least six nuts were missing. A further 49 bolts retrieved after the accident were tested and fatigue cracks were detected on 41 of them.

This indicates a bad selection of bolt material, the use of non-conforming material, or again inadequate maintenance and surveillance programmes.

This kind of accident demonstrated the importance of effective surveillance methods for the design, construction and maintenance of hydroelectric plants.

With regards to construction, a systematic CQSS approach can highlight possible errors that would otherwise remain hidden in the materials and components until their assembly on the plant.

Quality surveillance

A Continuous Quality Surveillance Scheme approach makes it possible to reduce Cost of Poor Quality, showing potential problems as soon as they appear and allowing for immediate solutions. Discovering non-quality at a late stage of construction of the single components may bring an exponential increase in costs, with delays and dramatic consequences for the customer. It can also increase the cost for the whole hydropower or water resources project. In some cases, it can also pose considerable safety risks. ■

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