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NATURALHY

“Preparing for the hydrogen economy by using the existing natural gas system as a catalyst”

Integrated Project

6.1.ii Call 1 Sustainable Energy Systems

## **Principles of resource allocation relating to pipeline integrity management**

**WP4**

**R0038-WP4-P-0**

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## EXECUTIVE SUMMARY

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This report is the first on a series of three prepared for the WP4 of the European project Naturalhy. The three reports are in connection with the resource allocation within the framework of the integrity management of the gas transmission pipelines taking into account the addition of hydrogen to natural gas.

The objective of this work is to establish a functional specification for a cost optimisation tool that enables resource allocation taking account of hydrogen addition. The cost optimisation tool should be part of the Decision Support Tool (WP6) that integrates amongst others the technical and financial considerations. This tool should cover the considerations and data on the cost of measures regarding to inspection and repair.

This first report “Principles of resource allocation” provides:

- A list of the specific activities, related to costly measures regarding the achievement of a given level of integrity (inspections and repairs), in form of a general organization chart describing also the links between steps (possible routes).
- From the general organisation chart, detailed flow charts describing chronologically the costly actions of each specific activity (in-line inspection, defect assessment, composite sleeve repair...).
- For each specific activity, the hydrogen impact as far as we can assess it based on the WP3 results and knowledge from the literature.

## 1. INTRODUCTION

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- For each specific activity, the hydrogen impact as far as we can assess it based on the WP3 results and knowledge from the literature.

The second report "Demonstration tool of cost evaluation" will provide a tool in form of an Excel sheet to automatically calculate the total cost of each specific activity for a selected scenario on a specific pipeline (the cost of inspection, excavation, selected repair technique for one defect...), using the resource allocation described in the first report and the mathematical functionality described in the third report. This may include the costs of preparation, the costs to execute the job and indirect costs.

The scenarios, related to possible routes that can be followed to maintain a given level of integrity, will be then compared in terms of:

- Safety according to the target of integrity level. This comparison will be carried out in the integrity management tool.
- Integral cost through the calculation of the net present value. This comparison will be carried out in the demonstration tool of cost evaluation.

The third report “Specification functional description of cost evaluation” will provide mathematical formulas (used in the demonstration tool) to calculate the total cost of each activity related to the integrity management (inspection, defect assessment, repair,...) as a function of pipeline diameter and/or other parameters, and the net present value. It will be prepared after validating the cost functions used in demonstration tool.

## 2. GENERAL ORGANIZATION CHART OF THE “MAINTENANCE” ACTIVITIES

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The maintenance activities include:

- The monitoring of pipelines (by in line inspection when they are piggables otherwise by non-intrusive techniques such as direct assessment), which includes the preparation, the stage of inspection itself and the analysis of the results.
- The repair program which includes excavation, defect characterization and assessment, process of repair, and rehabilitation of the site.

The following chart lists chronologically the specific activities, related to costly measures regarding the achievement of a given level of integrity (inspection and repair), and highlights also the links between steps (possible routes).

The cost of the reusable equipment is not taken into account in this report, such as a digital camera or a slide caliper to size the defect...



### 3. ECONOMIC DESCRIPTION OF EACH SPECIFIC ACTIVITY

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For each specific activity, the costly actions are detailed in a chronological chart.

#### ***Remarks***

- The actions in green are economically treated separately from the other actions of the concerned activity.
- According to the maintenance actions to be carried out and the defects severity to be repaired, the pipe has to be put in safety by reducing the gas pressure or even by stopping the transit. These actions (in blue in charts), if they affect the end-users, correspond to the direct economic loss of the gas, which could not be provided in spite of the request.
- The indirect costs and the cost of gas loss appear in red in charts.
- The comments on the economic influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas appear on pink bottom.

#### **3.1. Pipeline monitoring**

The pipeline monitoring gathers all the activities of internal and external inspection with the analysis of the inspection results.

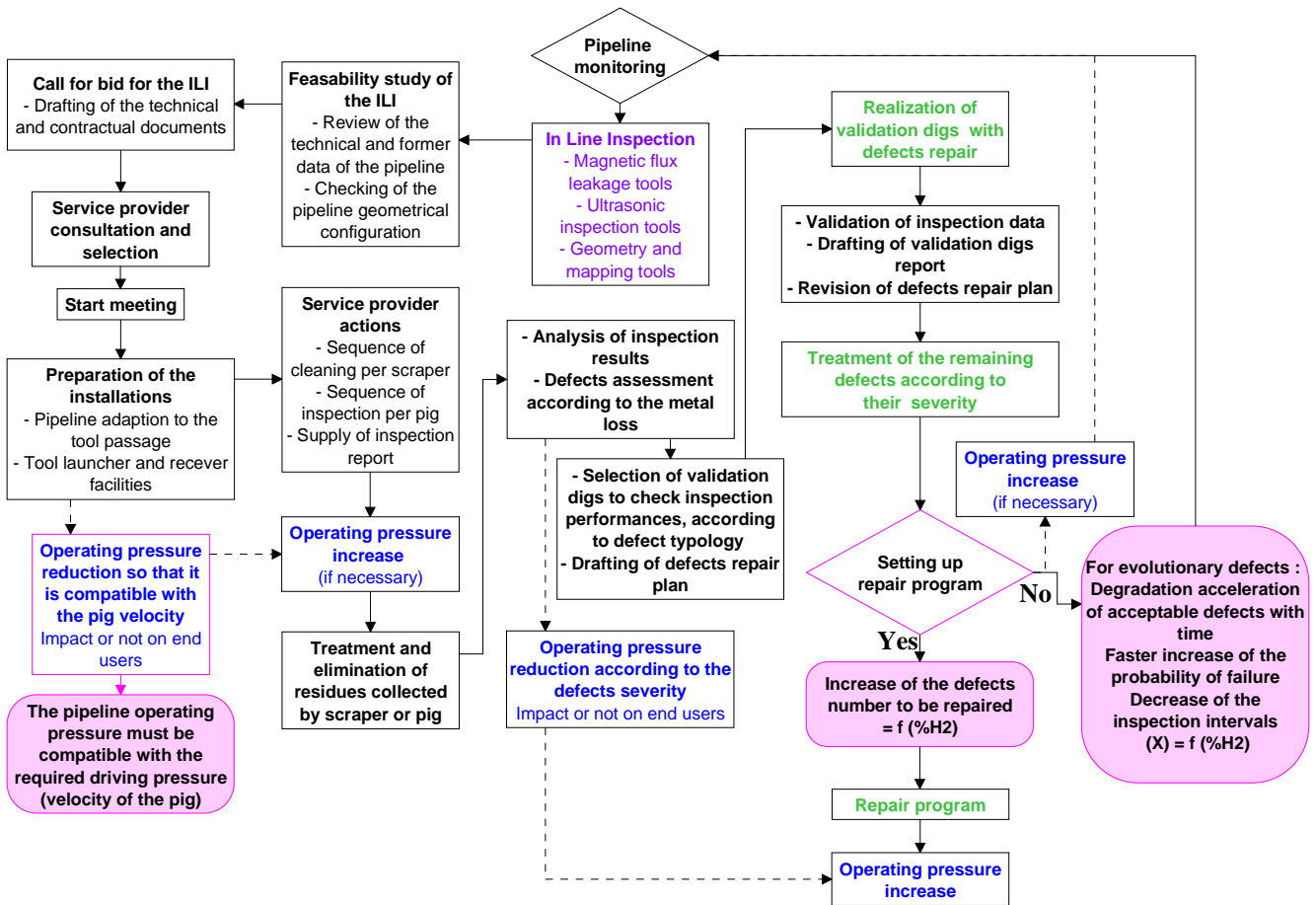
##### 3.1.1. In line inspection (ILI) activities

According to the state of art on “The in-line inspection technologies” [1], the ranges of tools are:

- Magnetic flux leakage tools ( PII MagneScan®, TranScan®).
- Ultrasonic inspection tools (UltraScan WM®, UltraScan CD®, Elastic Wave®, EmatScan CD®).
- Geometry and mapping tools (CalScan®, ScoutScan®).

The following chart lists chronologically the actions of the in-line inspection process.

The costs of the feasibility study, the preparation, the analysis of the results and the validation of data correspond primarily to labour cost. The cost of the service provider is proportional to the pipeline diameter, the length inspected, and the selected pig tool.



Flowchart 2: In Line Inspection activities

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

The “hydrogen/natural gas” mixture is transported via dry pipelines. The pipeline operating pressure must be compatible with the tool velocity. The following table summarizes the maximum operating pressure and the tool velocity range required. If the operating pressure is higher than the maximum pressure required [1], the pressure must be reduced, which can affect the end-users and involve an economic loss.

With regard to the steel’s embrittlement by hydrogen, UltraScan WM® tool is the only one which can detect the cracks induced by hydrogen [1], nevertheless its effectiveness is not total, and its adaptation (liquid batch) to inspect dry pipelines involves an important additional cost.

**Currently, the ILI cannot be regarded as capable of the detection of the cracks induced by hydrogen in pipelines carrying dry gas, but there are tests underway to prove if the MFL with an adapted model is able to detect cracks as well (WP 4 Task 4, works of PII with Gaz de France).**

The hydrogen addition to natural gas will have also an influence on the inspection intervals for the evolutionary defects. The degradation of these acceptable defects could accelerate with time in the presence of hydrogen. Their probability of failure could increase faster leading to the need of decreasing the inspection intervals.

In-line inspection tools		Nominal tool diameter	Use in dry pipeline	Maximum pressure in bar	Velocity range in m/s (max)	Min/Max Wall Thickness
MFL	PII MagneScan®	6-10"	yes	150	0.3 – 5.0	5 – 14 mm
		12-56"		220		6 – 25.4 mm
	TranScan®	12- 36" (now) 6-56" (future)	yes	220	0.2 – 4.0	5 – 15 mm
Ultrasonic inspection	UltraScan WM®	6-60"	No or in a liquid batch	120	0.2 – 2.0	5 – 45 mm
	UltraScan CD®	22-56"	No or in a liquid batch		1.0 – 2.0	
	Elastic Wave®	20-48"	yes	70	> 8.0 with gas bypass	
	EmatScan CD®	36"	yes	(design pressure: 190)	(2.0)	
Geometry and mapping	CalScan®	6-60"	Yes	100	1.0 – 2.0	
	ScoutScan®	12–56" 24–30"	Yes	220	0.5 – 5.5 (10.0)	
	ScoutScan Solo®	10 – 36"	Yes	120	1.0 – 3.0 (10.0)	

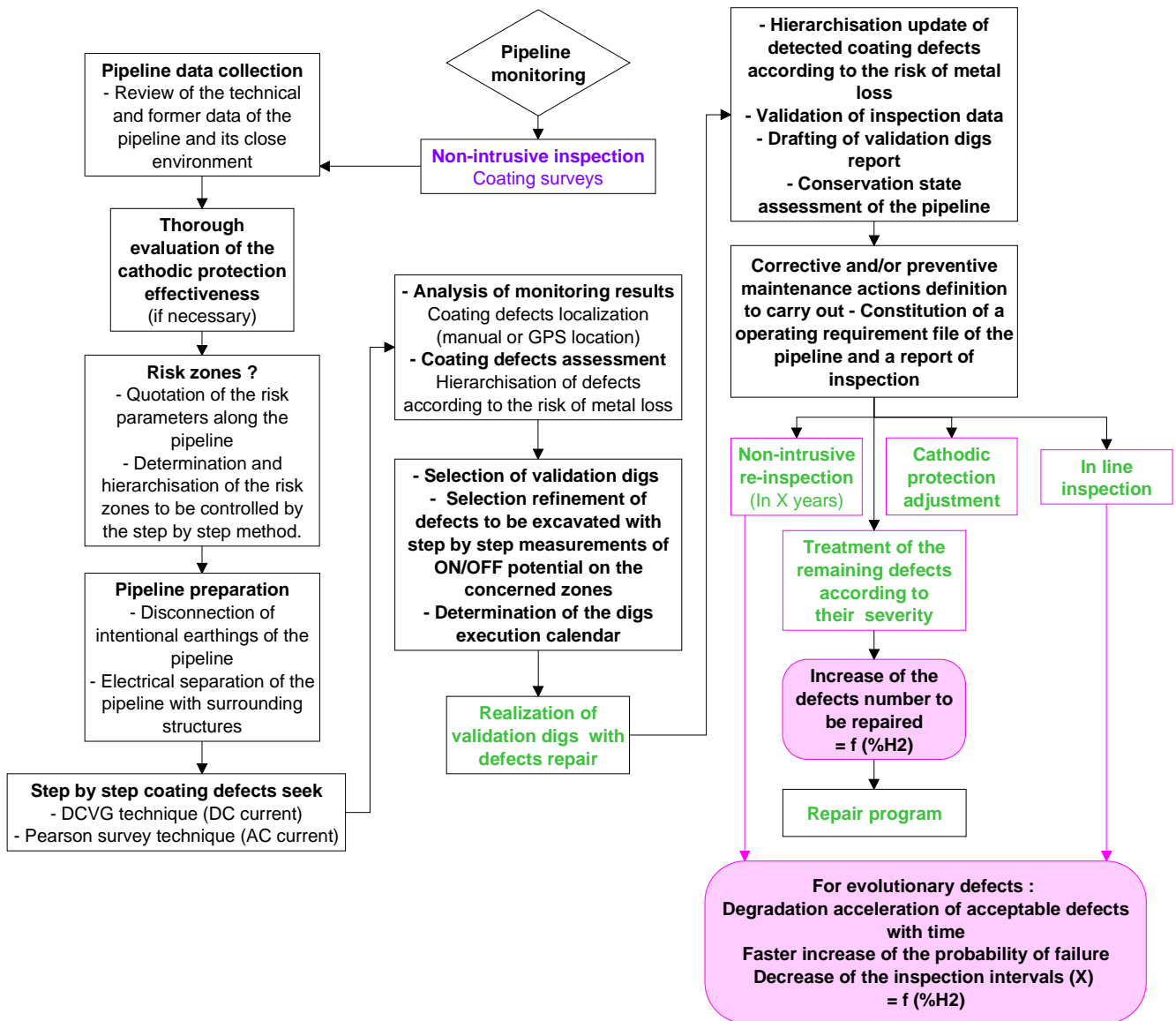
**Table 1: In line inspection tools with their functional characteristics**

### 3.1.2. Non-intrusive inspection activities

According to the report on “Non-intrusive inspection tools available for the inspection of unpiggable pipelines” [2], the ranges of tools are:

- Above ground inspection tools
  - Coating survey
    - The AC current attenuation technique (*not considered in this report, this method is not able to localize the coating defects*).
    - The Pearson survey
    - The Direct Current Voltage Gradient Technique (DCVG)
  - Cathodic Protection (CP) measurements
    - Close Interval Protection Survey (CIPS): ON/OFF potential surveys, depolarised potential surveys and on potential surveys. These measurements are taken in complement of the coating survey to refine the detection of the defects.
    - Continuous ground conductivity survey (*not considered in this report*).
  - Electromagnetic, metal loss detection tools (*not considered in this report because these techniques are currently limited*).
- Remote detection with ultrasonic waves (*not considered in this report because these methods must be improved (applicability and performance)*).

The following chart lists chronologically the actions of the coating survey (ACVG & DCVG). The cost corresponds mainly to labour.



Flowchart 3: Non-intrusive inspection activities

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

The hydrogen transport has no direct influence on the coating survey activities because these techniques of inspection are not made to discern the nature of defect (cracks, loss of metal...).

**3.2. Repair program**

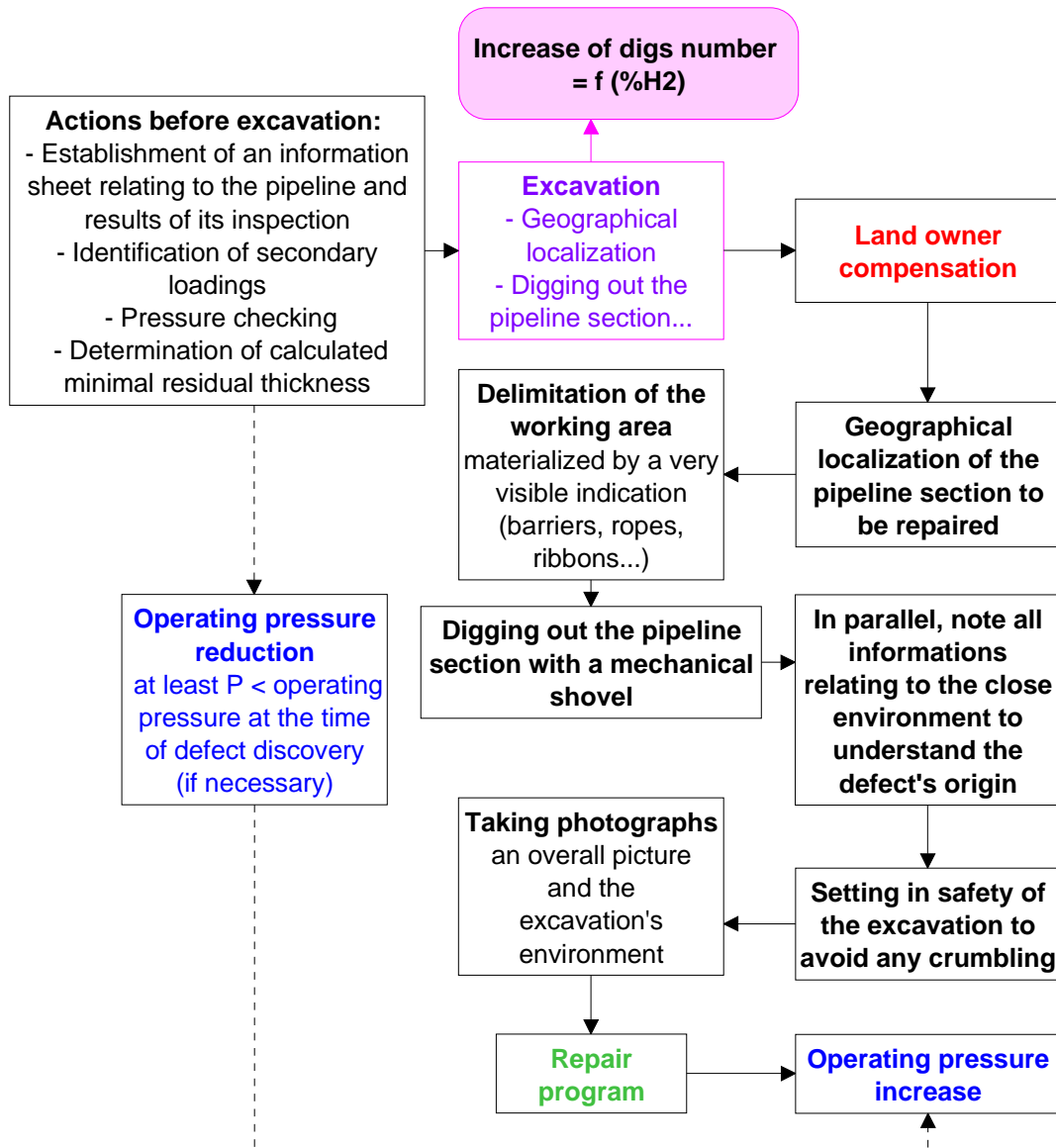
The repair program includes the activities of:

- Excavation: geographical localization and digging out the pipeline section to be repaired.
- Defect characterization: identification, cleaning, positioning and sizing.
- Defect assessment according to its state: the defect can be left in the state, be repaired or be cut.
- Defect repair.

- External coating rehabilitation at excavation site.
- Backfilling of the dig and restoration of the site

### 3.2.1. Excavation activities

The following chart lists chronologically the actions of excavation activities.



Flowchart 4: Excavation activities

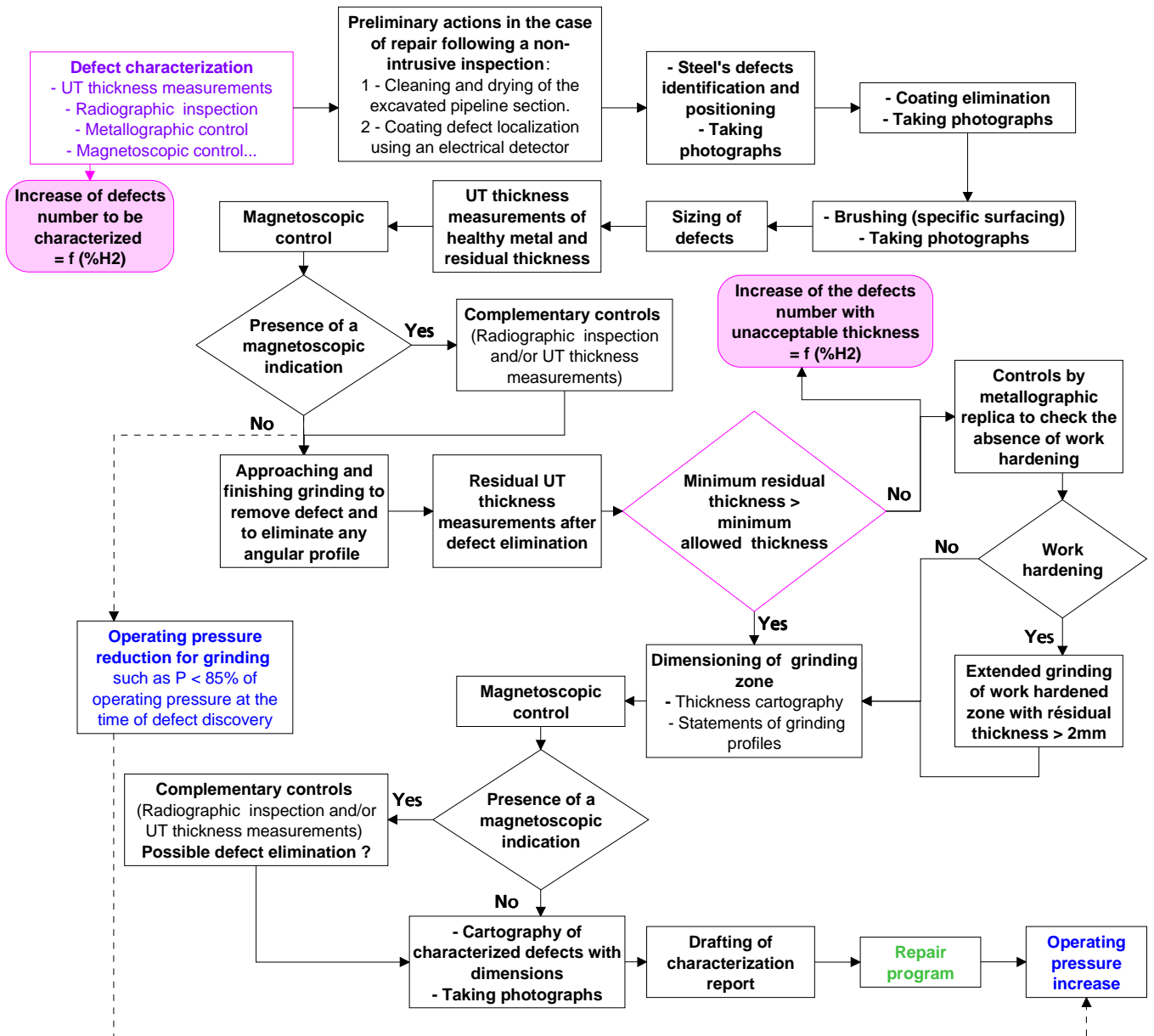
### Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas

The hydrogen transport has no direct influence on the excavation activities.

### 3.2.2. Defects characterization activities

These activities, presented in the following chart, consist in:

1. Highlighting and cleaning the defect (removal of the coating and the oxidized surface layer).
2. Measuring the dimensions of defect (thickness, length, width).
3. Checking with various control methods, the absence of imperfections not observed by visual examination such as UT thickness measurements, radiographic inspection, metallographic and magnetoscopic control.



Flowchart 5: Defects characterization activities

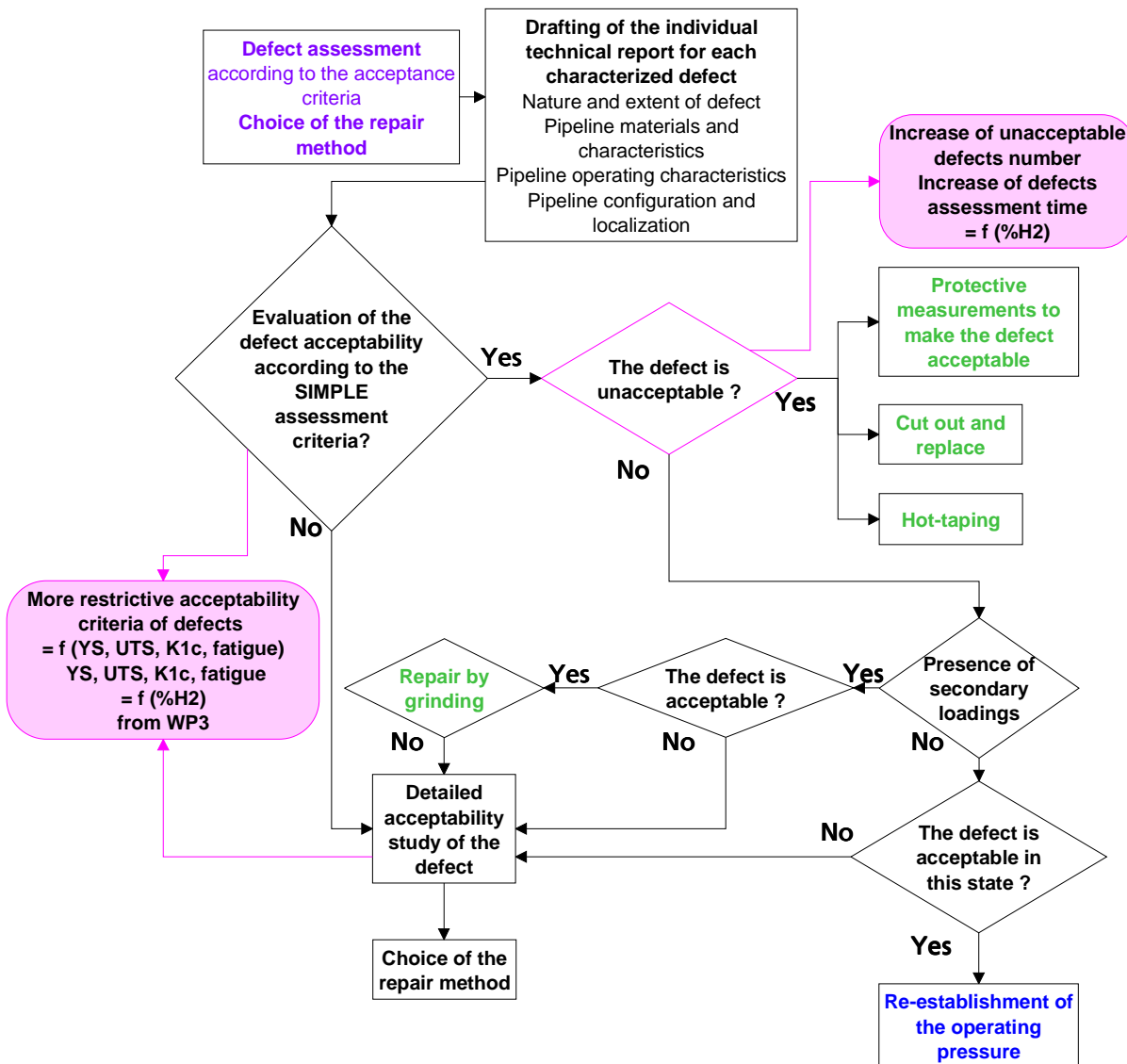
***Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas***

Hydrogen can have an influence on the minimum allowed residual thickness, which could be all the more important as the quantity of transported hydrogen with natural gas. The practised actions remain the same ones. In presence of hydrogen, the number of defects, which must be characterized precisely because their minimum residual thickness is lower than the minimum allowed thickness, will be more important.

The value of minimum permitted thickness will be updated in the WP3 to take into account the effect of hydrogen.

3.2.3. Defects assessment activities

This activity consists in evaluating the severity of the defect according to the acceptance criteria, in order to choose the most effective repair technique. From an economic point of view, the necessary resources for this action correspond to labour cost. The more the defect has a low residual thickness and particular characteristics (secondary loadings...), the more the assessment requires time.



Flowchart 6: Defects assessment activities

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

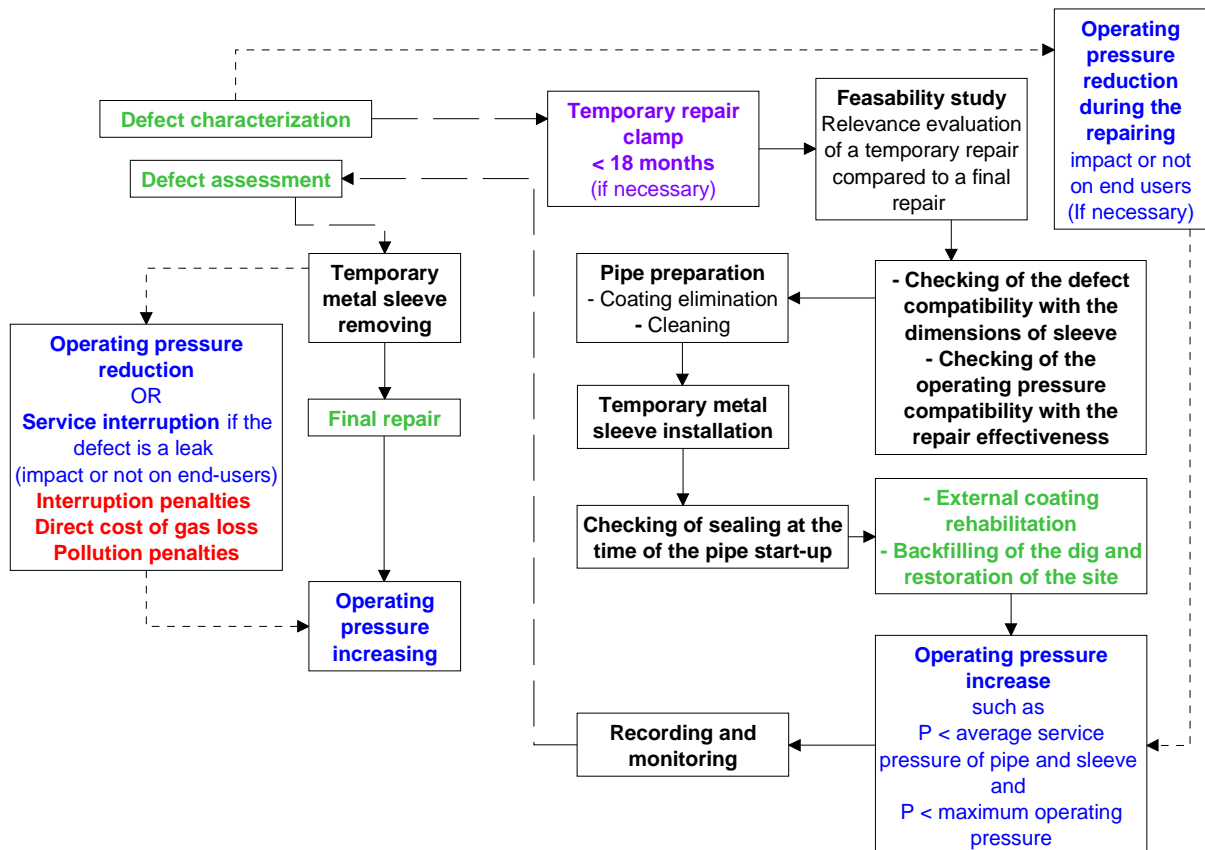
The influence of hydrogen on defects assessment is indirect. The practised actions remain the same ones. With hydrogen, the assessment criteria of defects to be applied will be more restrictive (on the maximum permitted values of YS, UTS, K1c and fatigue). The number of defects which can be assessed with the simple acceptance criteria will decrease, leading to the number increase of detailed acceptability studies of defect, and thus in time.

The currently used defect assessment criteria (YS, UTS, K1c and fatigue) will be updated in the WP3 to take into account the effect of hydrogen.

3.2.4. Repair methods

3.2.4.1. Temporary repair clamp

The metal sleeves (with two parts) allow the realization of a provisional repair when a pipeline is damaged in service. The defects can be leaking or not. This technique presents, compared to final repair, the advantage of notably reducing the times of start-up of the pipeline. The sleeves do not require to be welded on the pipe.



Flowchart 7: Temporary repair clamp activities

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

The hydrogen transport has no known influence on the temporary repair clamp.

### 3.2.4.2. Grinding

Grinding is widely accepted for the repair of superficial defects, usually under the following conditions [3]:

- The operating pressure level should be reduced to 80 percent of that at which the defect was discovered during the repair process [4].
- The limits for metal removal for non-indentated defects should be the same as ASME B31G criterion for corrosion caused metal loss [5].
- For defects resulting from mechanical damage (gouges, grooves) or cracks, where any associated indentation of the pipe is not greater than 4% of the nominal diameter of the pipe, grinding removal of damage is allowed by ASME B31.8 [6] to depths up to a maximum of 40% of the nominal wall thickness if the length of the ground area does not exceed the value given by the following equation :

$$L = 1.12 \sqrt{Dt \left\{ \left( \frac{d/t}{1.1d/t - 0.11} \right)^2 - 1 \right\}}$$

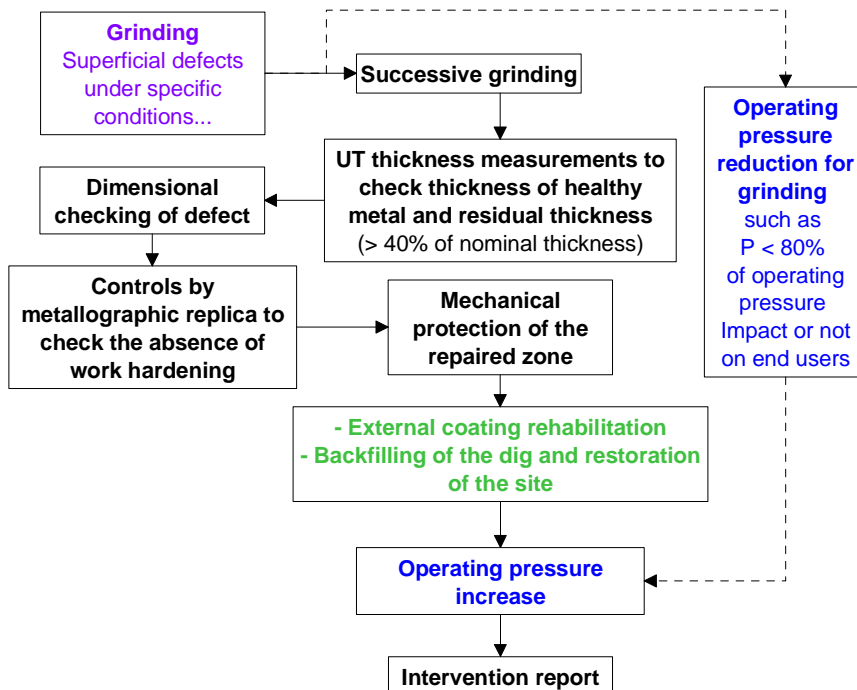
D : nominal outside diameter of the pipe

L : maximum allowable longitudinal extent of the ground area

d : measured maximum depth of the ground area

t : nominal wall thickness of the pipe

- Grinding of indented defects should be limited to removing the stress concentrating effect of a gouge or scratch prior the installation of a filled reinforcement sleeve (metallic or composite). In any case, grinding shall not be used as the sole means of permanent repair of an indented defect.
- The removal of all cracks should be verified by NDT examinations during and after grinding,
- If the crack or metallurgically affected material found in the defect cannot be entirely removed by grinding, an alternative repair method should be used instead.



Flowchart 8: Activities of repair by grinding

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

After checking the absence of cracks in the grinding area, the hydrogen transport shouldn't have influence on the optimized grinding.

3.2.4.3. Weld deposition

Weld deposition is a technique by which metal is applied to a section of pipe which requires build-up of wall thickness after a metal loss has occurred by corrosion, gouging, or from the removal of metal after grinding [3, 7, 8].

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

This technique of repair could lead to a risk of hydrogen cracking [3]. However, the first result of TNO, on weld deposit in hydrogen environment, doesn't exhibit cold cracking by hydrogen, but it is necessary to study this risk to assess if it is significant or not in the field conditions.

3.2.4.4. Composite sleeves

Two different techniques are commonly used to elaborate composite wraps for the repair of pipeline. One is based on pre-cured and pre-fitted to standard pipe diameters composite coils (Clock-Spring®, Wrapmaster®), the other, referred as "wet-tape" technology, involving on-site impregnated fibres mats (Armor Plate®, Technowrap 2k®, Strongback®), the curing of the resin being accomplished during the implementation of the repair (on-site curing) [3, 9, 10, 11, 12, 13].

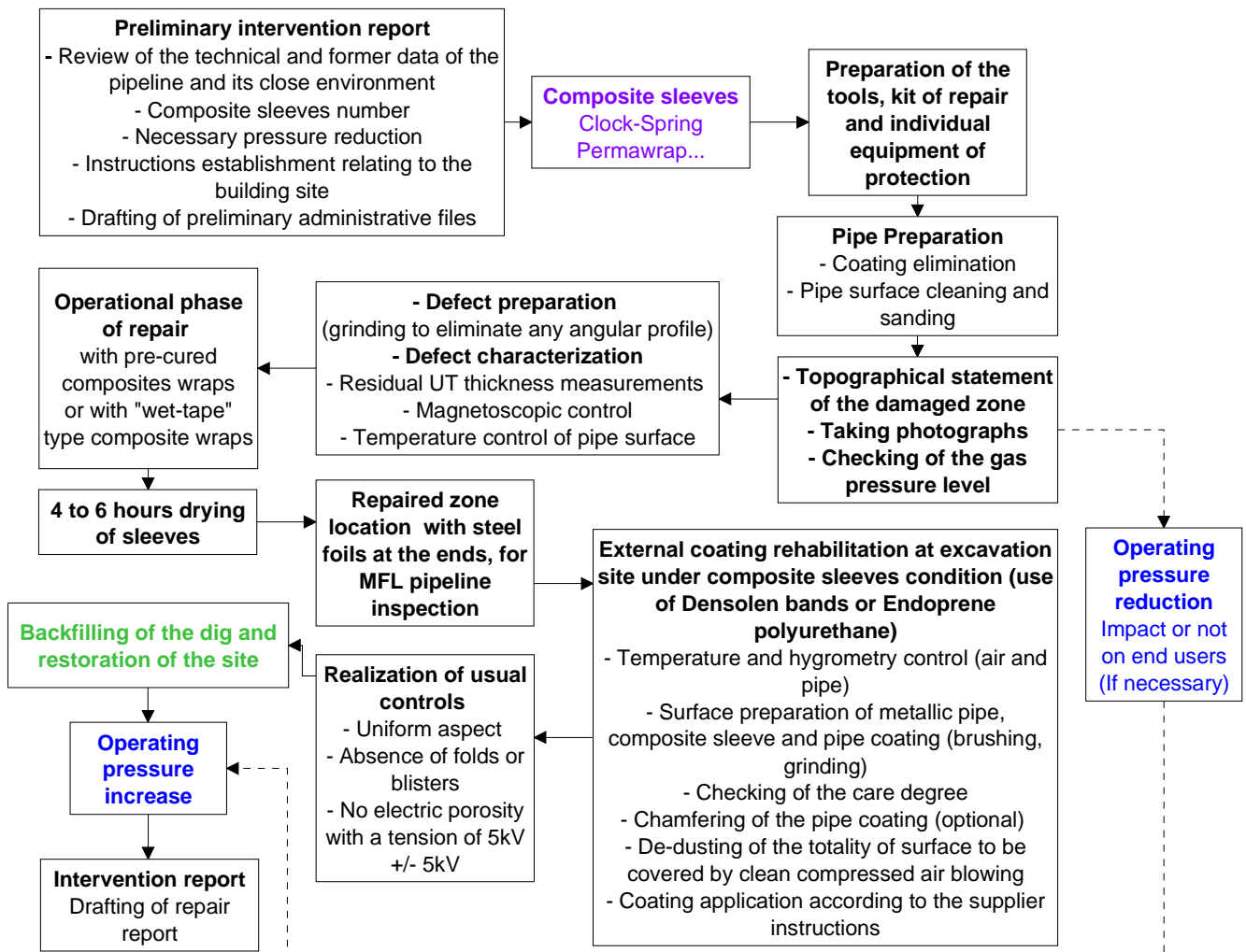
The following chart lists chronologically the actions of composite sleeves repair.

**Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas**

The study of Gaz de France on "Sensitivity analysis of Clock Spring repair to Hydrogen gas – Effect on burst pressure" [14] selects the Clock-Spring as a potential candidate as a repair method for pipelines transporting hydrogen or hydrogen-natural gas mixtures.

Nevertheless, this potential candidate should be confirm by complementary investigations:

- Effect of hydrogen on fatigue behaviour of damaged pipe repaired,
- Possibility of a Clock-Spring degradation by hydrogen gas inside the pipeline and if yes, the effect on the Clock-Spring repair criterion.



Flowchart 9: Activities of repair by composite sleeves

#### 3.2.4.5. Full encirclement steel sleeves

- Type A steel sleeves

Type A sleeves were frequently used to repair sections of damaged pipe, in particular sections of pipe that have suffered from corrosion, before the development of composite sleeves [3]. It is an open full-encirclement metallic sleeve that requires no welding to the pipe to be repaired [15].

- Type B steel sleeves

Since welding on the pipe is required for these sleeves installation (two half parts), it is necessary to await the final results of Tubitak to give a ruling on the influence of hydrogen [8].

#### 3.2.4.6. Epoxy sleeve

In presence of hydrogen, this external repair technique should be have the same behaviour than the Clock-Spring [16].

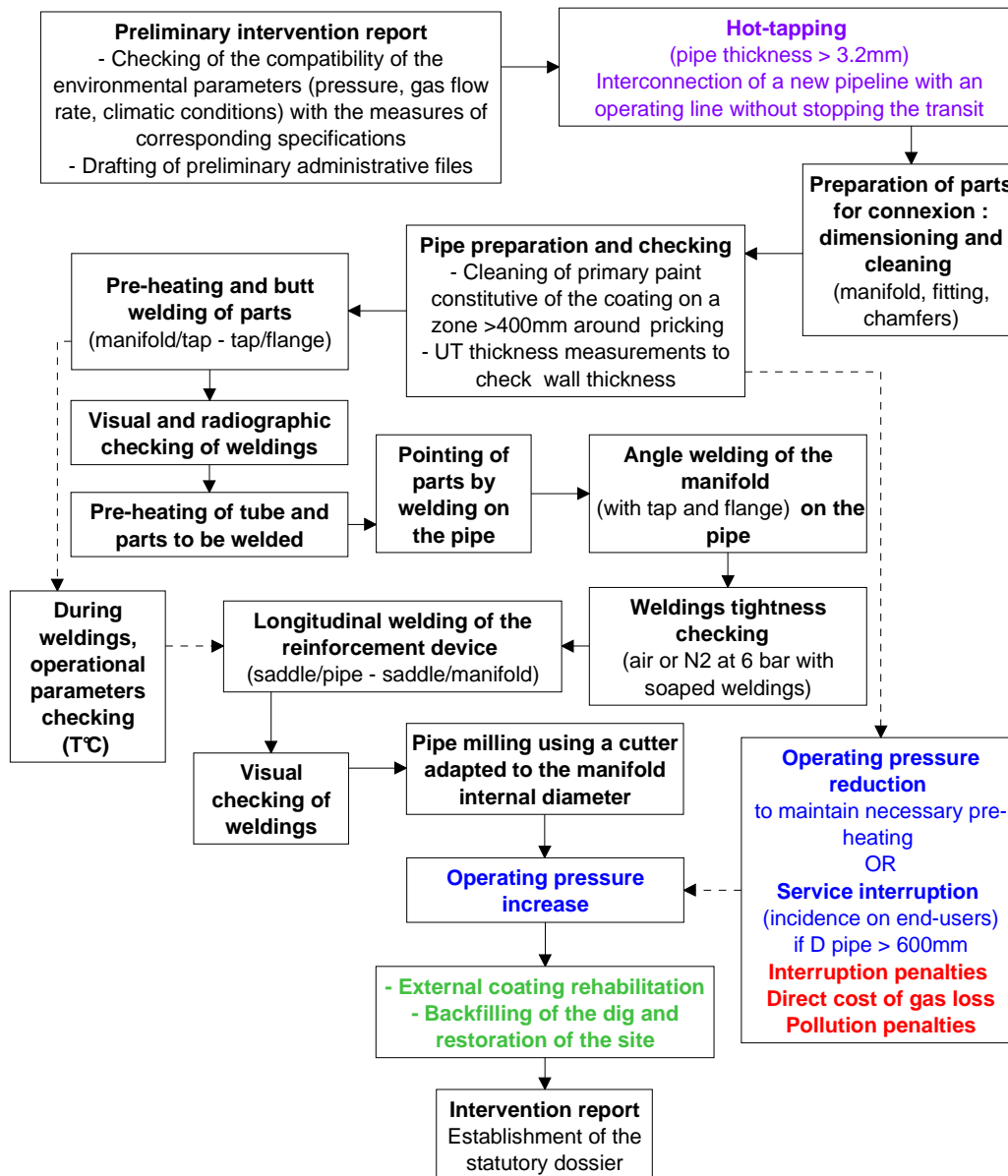
3.2.4.7. Hot-tapping

A hot-tap is an interconnection of a new pipeline with an operating line without the need to stop the transit. This process involves the installation of a welded loop or branch in the area of the defect before cutting out a circular section of pipe containing all of the defects to eliminate [3]. The following chart lists chronologically the actions of Hot-tapping activity.

***Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas***

The influence of hydrogen is not known but will have to be investigated because of the weldings on the pipe are necessary. These last present the major disadvantage of the risk of hydrogen cracking.

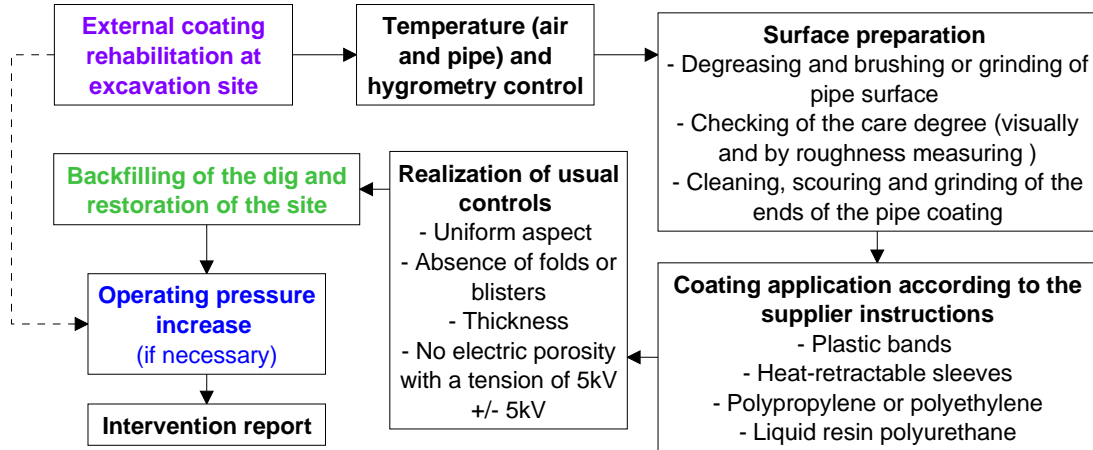
The TNO experimental study on the risk of cold cracking in hydrogen gaseous environment should give an idea on the possible use of this technique in hydrogen medium.



Flowchart 10: Activities of repair by hot-tapping

### 3.3. External coating rehabilitation at excavation site

The external coating of repair must be compatible with the one which is on the pipeline.



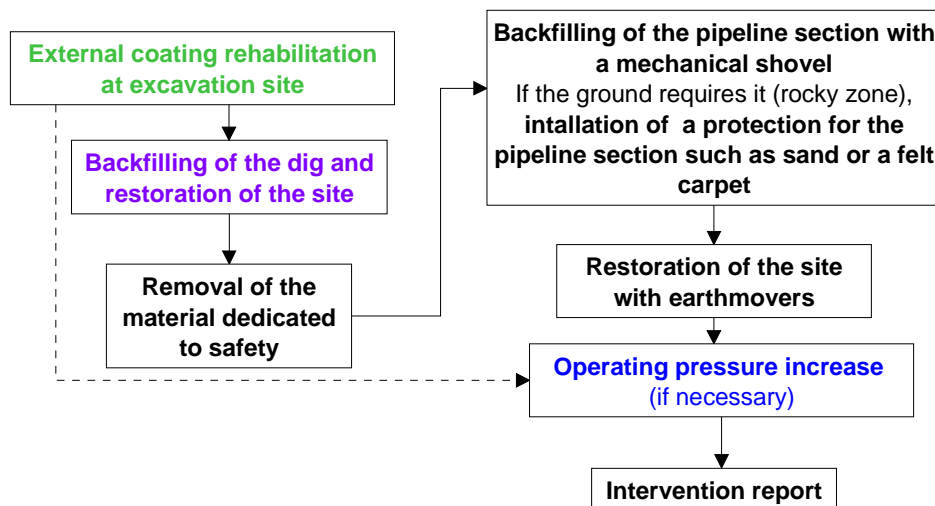
Flowchart 11: External coating rehabilitation activities after reparation

### Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas

The hydrogen transport has no influence on the coating rehabilitation.

### 3.4. Backfilling of the dig and restoration of the site

This activity consists in restoring the site nearest of its initial state.



Flowchart 12: Backfilling of the dig and restoration of the site activities after reparation

***Influences of the transport of hydrogen/natural gas mixture compared with the transport of pure natural gas***

The hydrogen transport has no influence on the backfilling process.

**4. CONCLUSIONS**

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The methods of in line inspection used currently in the case of natural gas transport are not sensitive enough to detect cracks clearly. To remedy this problem:

- the improvement of these techniques is under consideration
- and new innovative techniques are developing or are in form of prototype.

For the same pipeline, compared with the transport of pure natural gas and by considering the hydrogen embrittlement steel of defects:

- the ultimate permitted failure probability of defects will be lower, leading to:
  - a decrease of the inspection interval for evolutionary defect
  - and a number of defects more significant to repair.
  - therefore an increase of the excavation number.
  - The number of defects to be characterized and assessed will increase logically.

The acceptance criteria being more restrictive, more defects will be unacceptable, resulting:

- in a decrease of the defect number to repair (without cutting the pipe)
- and an increase of the number of "cut out and replace" (serious defects).

First conclusions of the hydrogen influence on the repair methods are the following :

- External repair by composite sleeve like Clock-Spring are potential candidate to repair in hydrogen.
- External repair by metallic sleeves are investigated.
- Methods involving welds (like weld deposit, hot-tapping...) in presence of hydrogen environment can caused risk of cold cracking. This point is currently investigated by TNO in an experimental study.

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