DEVELOPMENT IN UNDERWATER ROBOTS

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SUMMARY

To characterize the development in underwater robots in the areas of subsea oil and gas production, nuclear power plants or oceanography examples have been selected. They are discussed with respect to their degree of automatization and in relation to the sensorial capabilities. Development projects are shown from European Countries like Great Britain, France, Italy and Germany as well as from overseas like Japan and Australia.

1. INTRODUCTION

With large differences in requirements the development of underwater robots is continued worldwide for use of equipment

- in shallow waters, e.g. in coastal or fluvial monitoring, nuclear power plant decommissioning, harbours and ship-yards,
- or in narrow geometry like pipeline inspection devices,
- or for subsea hydrocarbon production especially in water depths beyond 600 m where divers cannot more work for completion, inspection, maintenance and repair (IMR) or decommissioning and
- in oceanology and deep sea research and operation.

Boundary conditions and requirements as pressure resistance, corrosion behaviour, marine growth and antifouling surface treatment, geometrical dimensions, propulsion and energy supply, information and material exchange, inspection and maintenance sequences for those different applications ask for special and at least in some cases also cost effective solutions.

As the market situation is limited and service companies are as well these development areas represent no mass production sectors. This can be clearly seen from the examples selected in the following chapters. Most of the systems in operation to a large extend are of master-slave manipulator type and in a wide range operator guided. Automatic procedures often are limited e.g. by lack of sensors or adequate control systems to operate in unstructured or unknown environment with sufficient operational safety and low risk to loss of equipment.

2. SHALLOW WATER APPLICATIONS

For this chapter three examples have been selected to demonstrate the variety of applications: a pipe and cable trenching vehicle [1], an advanced remotely operated work system for cleaning and inspection of jackets [2,3] and an automatic measuring and sampling system for environmental monitoring [4]. Development problems for nuclear industry are mentioned.

Pipelines and cables used under water on the sea bed or crossing rivers need guaranteed protection against possible damage caused by fishing trawlers, dragging anchors or even falling lost equipment. Additionally burying in sufficient depth may reduce danger of free spans by soil displacement from currents. Fig. 1 shows schematically a pipeline trenching vehicle for operation down to water depth of 50 m also along already laid pipes and cables. The 7x9x3 m vehicle of 240 kN weight in air is supplied by an electro-hydraulic umbilical. The trench cutting by mechanical tools is supported by suction pump spoil material displacement and if required, improved by water jetting. Automation in this case means being guided along the line to be buried and keeping predefined trenching depth also if soil shear strength varies.

As the continuous energy supply of those vehicles from top side service vessel always will be required there is only very little effort towards autonomous systems.

For the Australian Advanced Remotely Operated Work System Jacket Cleaning Vehicle Challenger AROWS JCV [2,3] working boundary conditions as well as tasks are more complex. Fig. 2 shows this SONSUB combination of the existing vehicle with new technology for cleaning and inspection tasks at offshore platform structures. Although the vehicle is operating with a minicomputer based control system with automatic features including dynamic positioning, reversed thruster control, autodepth and altitude and heading control two additional articulated suction arms are available. Those can be hydraulically locked to provide a more rigid work platform. Experience with free flying vehicles in the past showed very bad results in quality and precision of work as well as controlability. This confirms design criteria from mass production robotization where stable and extremely rigid work cells are installed to obtain constant quality over all tasks performed automatically.

This vehicle configuration and the respective R&D programme are very interesting tests for other developments in subsea IMR operations as has been reported [3].

Scientific institutions and industrial partners from Norway and Germany are involved in the development of the Marine Environmental Remote- controlled Measuring And Integrated Detection (MERMAID) system, an EUREKA-EUROMAR project for automatic monitoring e.g. of North Sea pollution data [4]. Automatically operating analytical systems working in robotic mode or triggered remotely from onshore are under development to be combined with meteorological and oceanographical sensors on a buoy. The possible future operation of several buoys in the North Sea in combination with ship cruises will be an important prerequisite for the assessment of changes in water quality caused by pollution reduction measures in the surrounding countries. The main development problems for the analysis robot are to reach robust design e.g. against heavy sea and sufficient sensitivity of the implemented instruments.

Shallow water robot development also takes place for nuclear industry and power generation where water is used for radiation shielding in cases of treating radioactive material like neutron activated structure or contaminated parts. Nevertheless high energy gamma radiation needs additional sufficient precautions e.g. for electronic sensors and control elements to guarantee functional quality and lifetime for the whole system. Additionally complex surface structures have to be avoided for applications with danger of radioactive contamination either by gases, liquids or dust and aerosoles. Easy decontamination reduces maintenance and repair costs.

3. SUBSEA HYDROCARBON PRODUCTIONS AND OCEANOGRAPHY

Recent offshore developments indicate an increase in the demand for techniques, which are able to conduct automatically underwater tasks with increasing water depths. Actual depths for subsea work are presently 530 m in the Gulf of Mexico, 760 m in the Mediterranean Sea and about 2000 m in the Campos Basin at the east coast of Brazil. As the water depth passes the 600 m threshold for saturated diving, diverless technology such as robotics gets increasing significance, considering economical aspects in offshore activities like periodical inspections of subsea structures combined with high quality enforcement, safety for men, cost effectiveness and independence of sea state conditions.

Based on this background, R&D concentrates on the application of e.g. a modified industrial robot for subsea work under hyperbaric dry and wet conditions up to 10 bar [5]. Main working processes, which have to be automated in the first steps of this development are IMR operations. These operations require also auxiliary equipment as tool changing device with direct coupling of energy and data flow. Additionally, underwater sensors are necessary for NDT-tasks and monitoring of process specific parameters.

Market research has indicated, that e.g. the German six axes universal robot Manutec r15 meets the necessary requirements (Fig. 3). In a first step the robot forearm has been qualified for operation in sea-water down to depths of 1100 m [6]. In the second step the experience and the results of forearm tests in wet and dry environment at working pressures up to 110 bar have been transferred to the complete robot. Main modifications are

- the complete robot is filled with a special compensation fluid for passive pressure equalization
- several components, such as brakes and incremental rotary encoders, are modified for operation under pressurized fluid
- special seals have been placed at each rotation joint. For sealing the robot housing gaskets have been selected, which are resistant both against sea-water and the compensation fluid.

The hardware testing is accompanied by software developments, focused on off-line programming and graphical simulation of the underwater handling system to detect basic problems in early planning stages. The off-line programming and simulation system has been used for generation of control programs, simulation on the graphical display, and verification at the test site. The work with the off-line programming showed, that the systems is helpful for the planning of underwater handling tasks. Nevertheless, some further developments have to be completed to create an 'ease of use' system, which supports a wider range of applications:

- The graphical simulation and optimization for the practicability of planned tool trajectories.
- For efficient collision detection and avoidance, it is necessary to implement an automatic collision algorithm.
- Considerable efforts are necessary for the programming and processing of sensor signals, which indicate unexpected events, such as currents or changes in structure geometry e.g. by marine growth on structure surfaces. This might enable the program to realize intelligent decisions on-line.
- Further developments of the programming module for the submersible control are necessary.
- Moreover, an improved user interface for parameter input, a better structured menu on the graphical display, and an improved coupling of the processes on the graphical and alphanumerical computer systems are in preparation.

Within the Japanese advanced robot development program a subsea robot is one of three prototyps under detailed construction [8]. The untethered vehicle is the most advanced concept today within all civil R&D programs performed worldwide. Fig. 4 shows an artists view of the subsea robot under development. The autonomous system with around 50 kN of weight in air and a volume of about 8 m^3 (not considering the room necessary for the fixing legs and the two-arm manipulator) shows very clear the mass and volume requirements for energy supply, propulsion and manipulation system including control and communication. As the main purpose for this prototype also has been directed to cleaning and inspection techniques, such energy consuming working techniques like welding will probably limit the operation time or need additional R&D.

The concept in fig. 4 shows a very clear antropomorphic structure especially regarding the manipulator area with a shoulder like two arm arrangement and a short range vision system in the head above. The shown ultrasonic 3-D visual sensor in the body in many cases will not be able to observe or control the active working area under all circumstances e.g. because of the hydraulic actuator "shaddow".

As in other developments the importance of docking and thereby establishing a stiffer "working cell" has been seen very early. The fixing of the massy body by three legs with suction pads or paramagnetic devices certainly needs special dynamic testing to examine the positioning behaviour and precision of the end effectors under combined sea current, controlled propulsion and mass-spring-system forces in real operation. This will be of paramount importance if the system shall operate in the wavy near surface zone or even in the splash zone of structures. There extreme loads may be put also on the propulsion system control to stabilize the vehicle during manoeuvring.

The European EUREKA project EU 191 Advanced Underwater Robots AUR is an industry initiated and industry driven project between an Italian collaborative group and one of the UK [9]. The respective prime partners are technomare (Italy) and Ferranti ORE (UK). The two robots under development in the long term project are the Autonomous Robot for Underwater Survey ARUS and the Work and Inspection Robot WIR. The underwater survey system ARUS will be a tetherless robot with onboard energy systems also for long range missions up to 2000 km and 240 hours. The submarine like body of 9 m length and 1,2 m diameter with twin thrusters at the tail will carry payload for oceanographic preprogrammed survey missions with and without operator interference. The robotic capabilities shall include navigation with GPS (Global Positioning System) updating when surfacing as well as survey program performance like sub bottom profiles, salinity, temperature or current data sampling in connection with position and time.

The work and inspection robot WIR is planned as a tethered system in a compact powerful design under supervisory control from e.g. a service vessel control centre. The "free" swimming telerobot with 2 docking clamps and 6 suction pads aims to contuct IMR assistance and salvage operations subsea. One manipulator with 7 dof on an extendible boom with position and force control and feedback shall handle interchangeable tools from a magazine for different practical use. The tethered system allows stronger power supply and very high communication rate by use of fibre optics but asks for tether management especially in unstructured environment to avoid entanglement and trapping of the vehicle.

A very special in-liquid robotic development is related to inpipe operations especially oil and gas pipeline inspection. This narrow geometry boundary condition requests for miniaturization and special "train"-type design and also in cases of long distance operations for special developments in energy supply systems [10,11]. Transport in pipeline inspection in most cases is promoted via fluid pressure differences acting on the inspection pigs (Fig. 5). The inspection techniques (magnetic flux, ultrasonic, eddy current, tactile, visual or neutronic (Fig. 6)) require special environmental conditions like fluid coupling, clean surfaces or sufficient conductivity. In this area the automatization is oriented to a position related sensitivity and documentation of detected defects e.g. by corrosion or fatigue and in many cases the evaluation of defect growth over years to trigger the repair or replacement decision at the economically optimal time.

4. FINAL REMARKS

As can be observed in all R&D projects in underwater robotics aside the operationally induced requirements they include always the same type of key technology areas:

- the energy supply systems for autonomous systems have to be driven to higher economy either by reducing energy needs or by increasing the efficiency and power per weight ratio;
- the sensorial capacity like 3D-vision (optical or ultrasonic) for scene identification, navigation and obstacle/collision avoidance as well as work/process control is one of the most important development areas. This is directly related to the optimization of man-machine in-

terface as visual perception is the most important sensory requirement for human operators;

- manipulation dexterity and accuracy together with processing infrastructure especially in operation under difficult dynamic load without damage - at least until docking and formation of a rigid working cell is performed - needs additional considerations including standardizations to increase equipment economy;
- although it might be an engineering challenge to create an all-purpose system the economical boundary conditions are forcing R&D towards low cost and high efficiency products. This should be also kept in mind in cases where tax founded governmental projects are run - because they finally shall end in a market conform product.

5. REFERENCES

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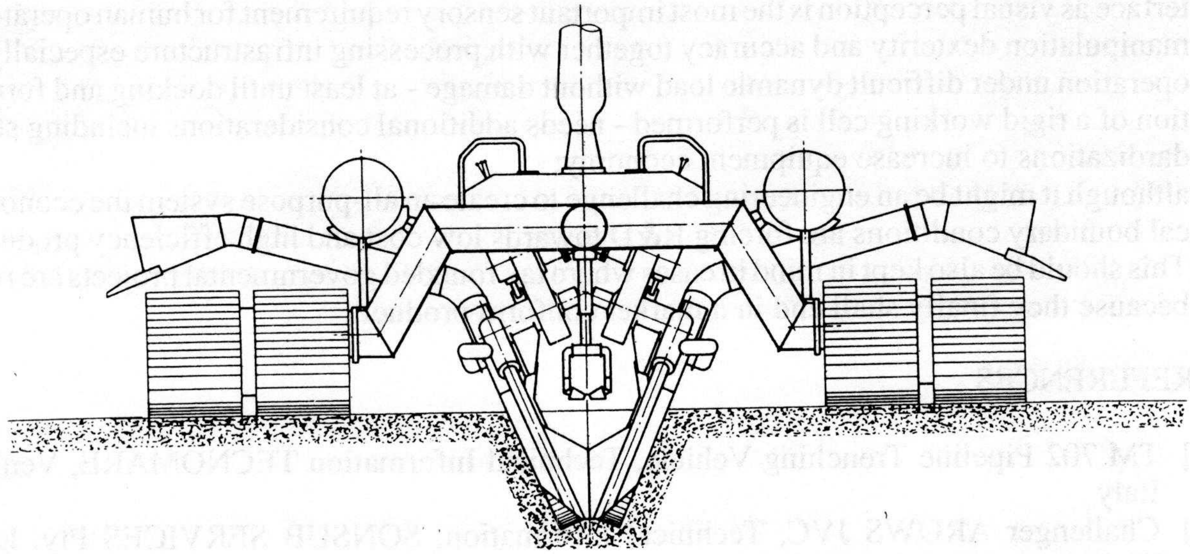

Fig. 1 Schematic view of pipeline trenching vehicle TM 702 produced by tecnomare, Italy, for undertrenching cable and steel flowlines up to 20 inches O.D.

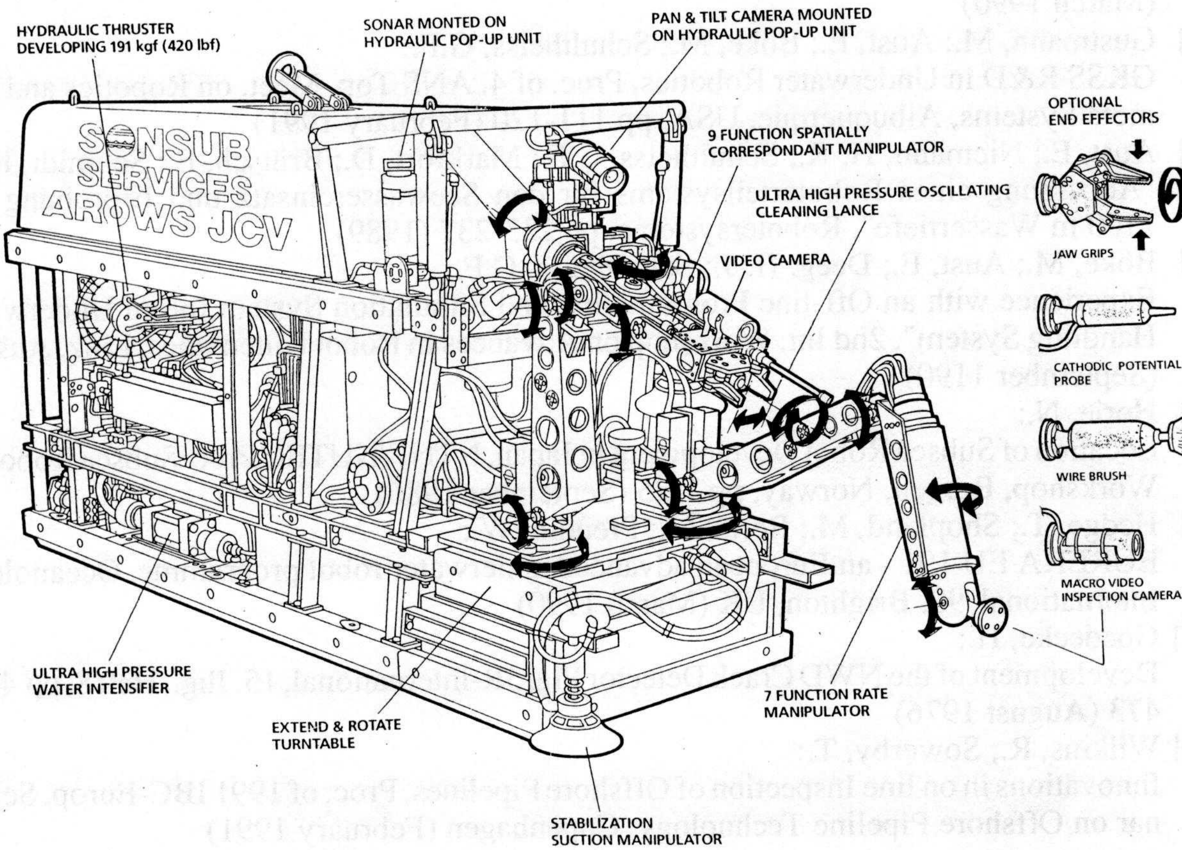

Fig. 2 Challenger AROWS JVC - Advanced Remotely Operated Work System Jacket Cleaning Vehicle - of SONSUB Services Pty. Ltd. [2] with work packages, manipulators and optimal and effectors e.g. for cleaning, visual inspection and cathodic potential check. 2 D Video is provided for operator controlled non automatic task performance

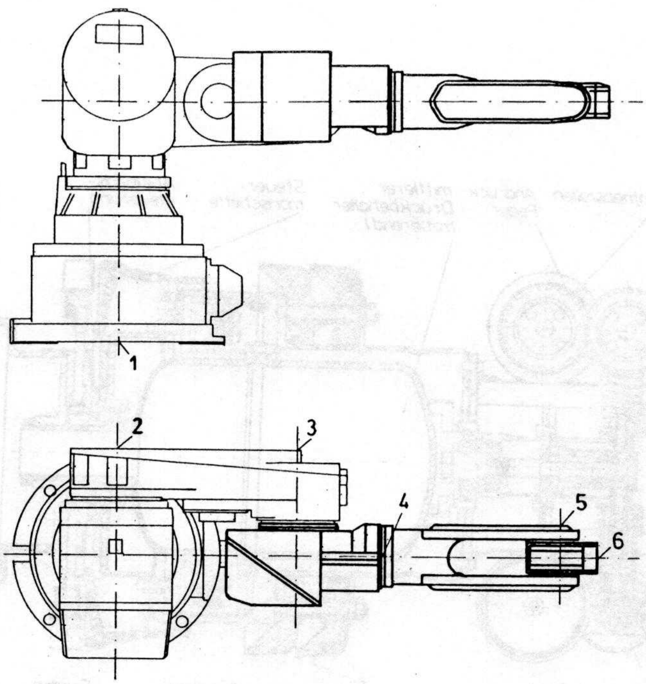

Fig. 3 Structure of the six-axes industrial robot module under development for outside pressure independent operation in water down to depth of about 1200 m [5]. Different forearm length can be selected like in the industrially used series. The weight of the subsea type in air is around 3,5 kN.

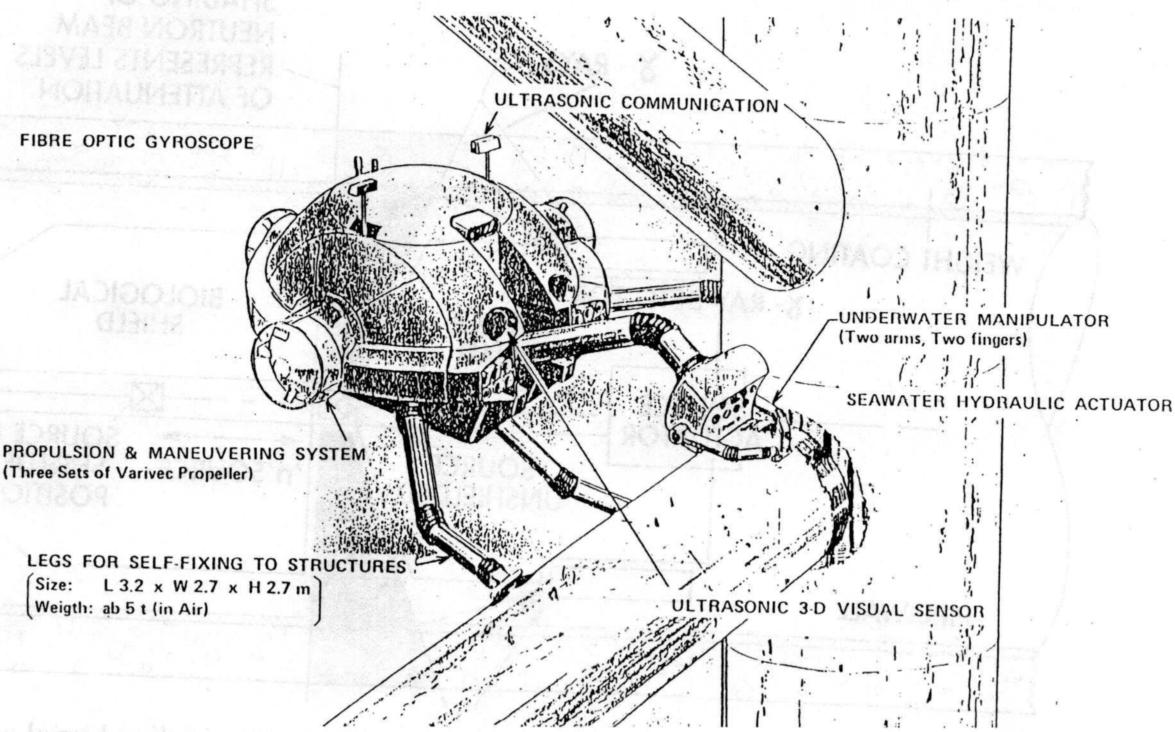

Fig. 4 Conceptual picture of the Japanese Subsea Robot developed within MITI Advanced Robot Development Program as autonomous subsea vehicle prototype for IMR applications [8]. The dockable untethered ROV with a two-arm seawater hydraulic actuated manipulator body will be linked to surface by means of ultrasonic communication

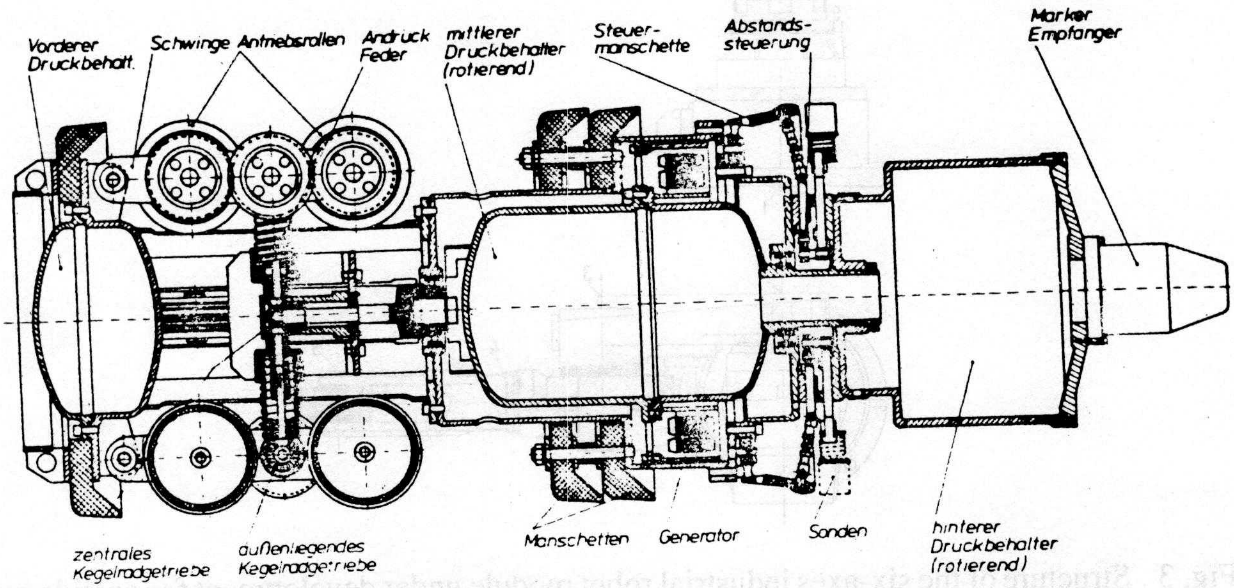

Fig. 5 Cross-section of NWO roller pig with included roller driven electrical generator. The detection system (Sonden) is positioned by a special control-sealing device (Steuermanschette) [10]

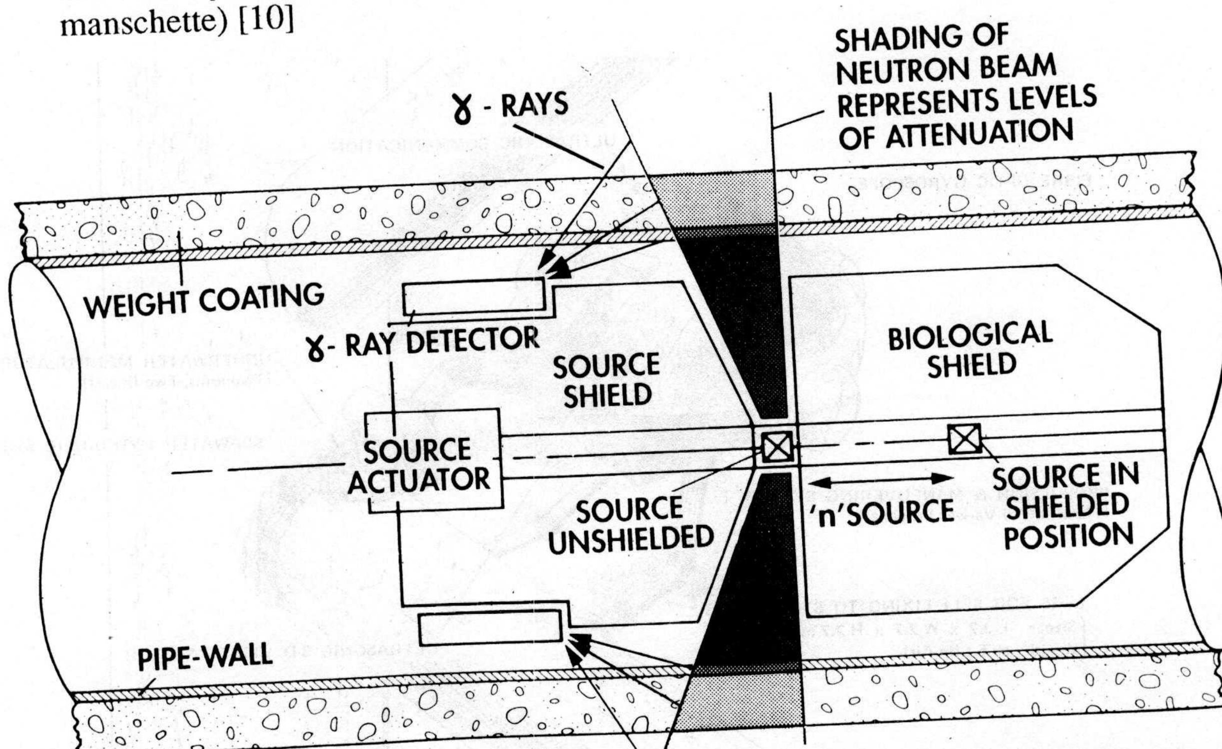

Fig. 6 Scheme of an advanced neutron interrogation system for pipeline burial and coating [11]. At a speed of 2 m/s the system is able to deliver a "picture" every 3 m because of the sampling time span necessary for the γ-ray detectors