The PIAFE Project - Command and Controls of PIAFE Phase 1.

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THE PIAFE PROJECT.

What is PIAFE ?

Atomic nuclei with a large excess or deficit of neutrons with respect to stable nuclei are known as "exotic". Such nuclei are highly unstable and thus radioactive with short lifetimes. The study of exotic nuclei will be one of the main topics of research in nuclear physics in the coming years. Indeed, several projects are already being studied or are already being built around the world in order to produce accelerated beams of exotic ions.

The opportunity that SARA, the heavy ion accelerator of the Institut des Sciences Nucléaires (ISN) is adjacent to the high flux reactor of the Institut Laue Langevin (ILL) has been taken in the proposal PIAFE [1] ("Production, Ionisation et Accélération de Faisceaux Exotiques") for the production of beams of neutron-rich ions with masses between 80 and 150, with a particularly high intensity. An ion source consisting of a target of a few grams of uranium 235 would be placed close to the reactor core of the ILL. The resulting fission products would be ionised and accelerated to 30 keV. After mass separation the ion beam would be transported in a few milliseconds to SARA via a 400 meter tunnel, for further acceleration. Energies between 2 and 14 MeV/amu could be attained.

Further information is available at *https://isnwww.in2p3.fr/piafe/piafe.html*.

The Scientific Interest of PIAFE.

Beams of exotic ions permit the observation of nuclear reactions which cannot be otherwise obtained. These reactions offer many new and exciting possibilities to nuclear physicists, in particular the validation of the current models of the atomic nuclei very far from the stability line. Other areas of physics are also concerned, such as the study of nucleo-synthesis in astrophysics and several aspects of solid-state and surface physics. Radioactive beams can also be used in the production of radio-isotopes for medical physics. Studies of the transmutation of radioactive waste are also proposed.[2]

The Main Points of Phase 1 of the Proposal.

The first phase of the project will verify the operation of the source. The beam produced will contain singly-charged ions at 30 keV, so low energy physics of exotic ions will be possible, such as measurement of ground state masses, moments and the spectroscopy of radioactive nuclei.

Figure 1. shows the overall layout of the installation.

The uranium ion source, placed in a "glove finger" beam tube of the reactor is designed to produce a current as intense as possible, conform to security requirements. The target, 4 g. of ^{235}U in the form of uranium carbide, is dispersed in a matrix of porous graphite. It is submitted to a flux of on average 3. 10^{13} neutrons per square centimeter per second to obtain 10^{14} fissions per second. The fission products are slowed by the graphite and the power dissipated will heat the source up to about 2400 ^{o}C. This temperature represents the best compromise between the maximisation of the diffusion of fission fragments out of the source and the elimination of heat from the source by radiation. A higher temperature would tend to evaporate the graphite and thus reduce the source lifetime. The source is placed in a container which will probably be made of rhenium. The container must be able to withstand heat, chemical attacks from the constituents of the source and of course resist the aggression of the neutrons. A second container in the form of a metallic grill completes the heat shielding and mechanical protection of the reactor beam tube. The source also contains electrodes which will ionise the fission products and accelerate them to 30 keV. Uranium ion sources of this type have functioned since 1967 in Sweden [3] although at a much lower neutron flux.

The installation includes a mechanism for the introduction and removal of the source from the reactor and also must provide for the loading of a new source and the disposal of a used radioactive source into a disposal bin.

After extraction from the reactor the ions must be transported to the experimental beam lines. The beam line contains 2 dipoles (bending magnets) 2 quadrupoles and 2 electrostatic lenses for focusing and 2 slits. The beam line also contains 5 beam diagnostics of various types. The ensemble consisting of the first lens LE1, the first dipole (D1) and the slit F1, acts as a pre-separator. Only ions with a mass of $\pm$ 4% of the reference mass will pass the slit F1. Many unwanted isotopes will be stopped here, and this part of the beam line will be the most active, so it is housed in a separate bunker. D1 must also have a special structure (large gap) to permit the passage of the source and its trolley. For the same reason, LE1 will be mounted on a jack to permit vertical movement. The rest of the beam line is more classical: the beam is transported to the spectrometer from where it is dispatched to the physics areas.

The presence of highly radioactive gases close to the source also determines the techniques which must be used for the pumping. In addition to the usual electromagnetic valves closed during primary pumping, the beam line will be divided into zones in order to attenuate the gas flow during operation. In the beam direction the contamination of the transport line by radioactivity must be limited and in the other direction the source must be protected from an accidental pressure increase, for example, from an experimental area. To achieve this, separation diaphragms will be placed after each slit. The opening of each diaphragm will be slightly larger than the slit to avoid irradiation, and their length will be at least 150 mm. Each zone will possess its own dedicated pumps. No conventional pumping is however possible in the source, but the average vacuum must be better than 2 10^{-5} mbar in this zone.

Current Status of the Project.

Preliminary studies for PIAFE began in Grenoble in 1992. The project quickly aroused international interest and the PIAFE collaboration is at present composed of 11 different laboratories (5 French, 2 German, 1 Belgian, 1 Swedish, 1 Danish and 1 Russian). The scientific interest and the originality of PIAFE have been recognised by an independent committee of international experts (D, F, GB, NL, USA). They have recommended support and rapid realisation for the project.

At present an 18m. beam line exists at the ISN as a model for the transfer of singly charged ions at 30 keV from the ILL: the first results are very encouraging. Good progress has also been made in the development of the ECR source which will capture these ions and render them multi-charged.[4] Both of these studies concern PIAFE phase 1.

Although the Scientific Committee of the ILL is favourable to PIAFE, the Board of Directors has yet to give its agreement to the project. A report has been submitted to this committee and the formal decision should be taken during the month of November 1995. If this decision is positive, financial support for PIAFE phase 1 should become available from the various supporting government agencies. PIAFE phase 2 will of course be considered only if phase 1 is successful in attaining radioactive beams with the required intensities.

CONTROL AND COMMAND OF PIAFE PHASE 1.

Introduction.

The control and command part of PIAFE phase 1 has just entered into the requirements gathering stage. Only a general description can be given at this time. The proximity to a nuclear reactor, coupled to the fact that highly unstable particles will be extracted from the PIAFE source itself, impose particular constraints on the control system hardware architecture as there will be zones where it is not possible to place active material. It seems fairly certain that the overall architecture will be based on a "standard model" LAN of PCs because both of the main participants in the collaboration (the ISN and the ILL) have experience with this hardware and also because budget constraints imply that there must be low-cost solution. In fact it is hoped that some ageing PCs in each laboratory may be recycled as data-servers; high performance machines are really only needed for the user interfaces. It is also certain that industrial PLCs will control the vacuum. Here also it is possible that the actual system used at the ILL could be extended to include PIAFE.

Four functional subsystems can be distinguished and are described in the following sections.

Beam Transport and Diagnostics. Beam Tuning.

Apart from the constraints of radioactive protection mentioned above, the beam handling and diagnostics control should be completely standard.

- Control of the power supplies of the magnets and other elements (a precision better than $\pm 10^{-4}$ is required)

- Supervision of certain elements with an automatic action in the case of detection of abnormal incidents.

- Control and command of diagnostics for the beam tuning - movements and current acquisition.

In addition the system must exchange information with the reactor control system and be designed to allow easy extension to PIAFE phase 2 in the future.

There will be a central control position, but some decentralised control may be required.

Command and Control of the Uranium Fission Source.

When the uranium source is in place permanent surveillance will be imperative. A malfunction would be potentially dangerous for the reactor. On the other hand the action which would be taken after the detection of such a malfunction is of such consequence that the system must not raise false alarms. Several methods are proposed and they may, and indeed must, be used simultaneously to permit a majority vote.

- Optical methods : Monitoring of the temperature of the central part of the source will monitor its correct operation and position. A metallic mirror will be lowered into the beam line on the vertical axis of the source, between the valve V1 and the magnet D1 (see figure 1). Note that the beam never passes in this part of the tube which serves uniquely to manoeuvre the source. Light from this mirror will be analysed by a 2 wave-length pyrometer.

- Beam Analysis : The presence of a beam is a very good test of the correct functioning of the source (the source well placed, electrical isolation in place etc.). Once the beam is correctly established and passes the pre-separator (ensemble D1-F1), a destructive measurement of the beam taking a few milliseconds every few seconds could be used, just downstream from the slit F2.

- Electrical Methods: When the reactor is stopped neither of the two previously mentioned methods can be used as the source will be cold and there will of course be no beam. When no accelerating voltage is applied to the source the conductors could be used to verify its correct insulation. When this voltage is applied, control of the currents will permit the detection of possible short-circuits or defects in the electrodes.

The Manipulation of the Source.

The source will be manoeuvred on a trolley by a rack-and-pinion steering drive. Collinear with the source, at the exterior of the reactor, is an area known as the "trolley station". It is housed in a separate bunker and serves as its name implies, as a parking place for the trolly during the experiment and also for its introduction. Just in front of the trolley station, the beam line is traversed by a vertical chamber which will be used for the introduction of a new source and the removal of a used source. This chamber will house an articulated robot arm equipped with a pincer. During the manipulation of the source the electrostatic lens must be displaced to allow the trolley to pass. D1, as mentioned above, will have a large enough gap to permit the passage of the trolley.

Figure 2. shows the sequence which will be followed to place the source in the reactor beam hole.

A) The source will be mounted in its container and placed manually into the introduction chamber (above the beam line) on a rolling support.

B) The support will move the source under the robot arm, which will then take it up.

C) After withdrawal of the support into the lock chamber, the door of the introduction chamber will be closed, and the lock chamber will be pumped out. When the vacuum allows, the valve V5 will be opened, and the robot will lower the source onto the trolley waiting below.

D) The trolley will then be moved and the source placed in its operating position.

The source will stay in position for 3 reactor cycles (90 days). After use it must be removed from the reactor and allowed to cool for several months.

Figure 3 describes the procedure for source removal.

A) The trolley will take the source out of the reactor and move it to the position above its "dustbin". The robot will grasp the source and raise it to allow the trolley to regain the station.

B) After removal of the trolley the robot will turn the source through 90^o.

C) The robot will lower the hot source into the disposal container which can then itself be isolated and removed to a protected zone.

The trolley manipulation is an adaptation of the system currently used for the Lohengrin experiment at the ILL

The Vacuum Control System.

The vacuum system control will resemble that of SARA. Elements will be controlled using an industrial PLC with the user interface on a PC. The PLC will supervise the system and will take action if an incident is produced, although certain security related actions will of necessity be hard-wired. The philosophy will be to keep the commands as flexible as possible whilst preventing forbidden manoeuvres by the pre-programmed logic.

The opening of the security valve (see figure 1) is particularly delicate as on the one hand permission will be required from the reactor control system and on the other hand no pumping is possible in the beam tube itself.

Another particularity of the vacuum system is the series of reservoirs required to stock the pump exhaust gases, which will be radioactive. Three reservoirs are planned:

- One will be in use.
- One will contain gas in course of deactivation; three months storage should be sufficient.
- The third will be to stock the gases from the primary pumping cycle, i.e. before the beam is present. These exhausts will contain only radioactive dust which will be filtered. After monitoring, this gas can be released into the atmosphere. This third tank will also act as a back-up.

Much of the vacuum system equipment will become radioactive and must be housed in controlled zones. This means that the maintenance of the pumps (oil-changes) must be telecommanded. If a pump breaks down it will simply be replaced.

People, Money and Time.

It seems unrealistic in a research environment to define the manpower needed for this project. Rather one should consider the manpower available, with its acquired expertise and include these factors as criteria in the system design. It is to be hoped that various groups from the different members of the collaboration will undertake the parts of the work for which they are most suitable. In particular the manipulation of the source should be done by a team with experience in this domain.

The latest estimate for the total cost for PIAFE phase 1 is 12 MFF (about 2.5 M$) not including salaries. The controls and commands budget is expected to be 1.75 MFF. including all the robotics and the beam diagnostics.

It is hoped that the first beams could be delivered for physics in the second half of 1998.

REFERENCES

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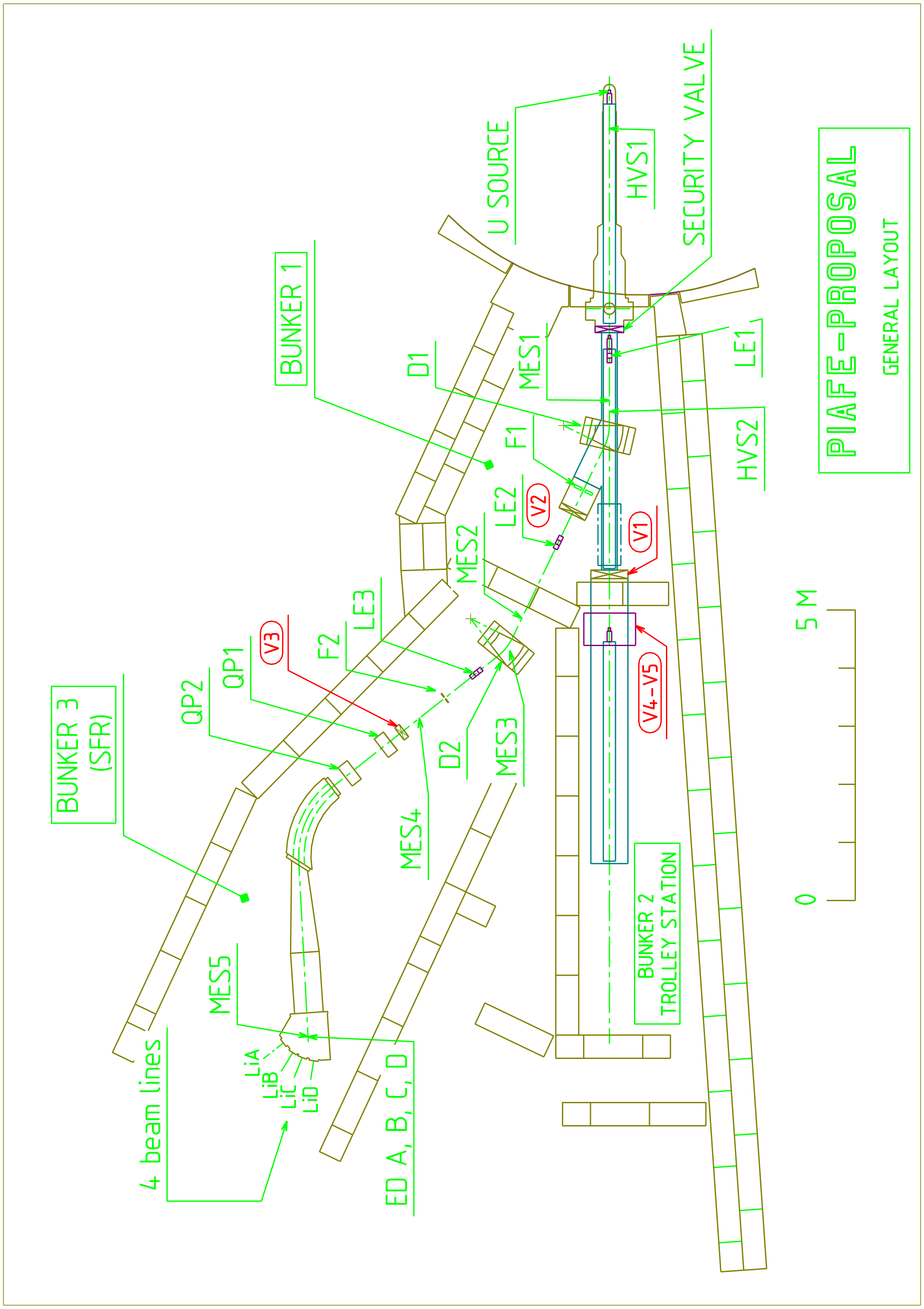
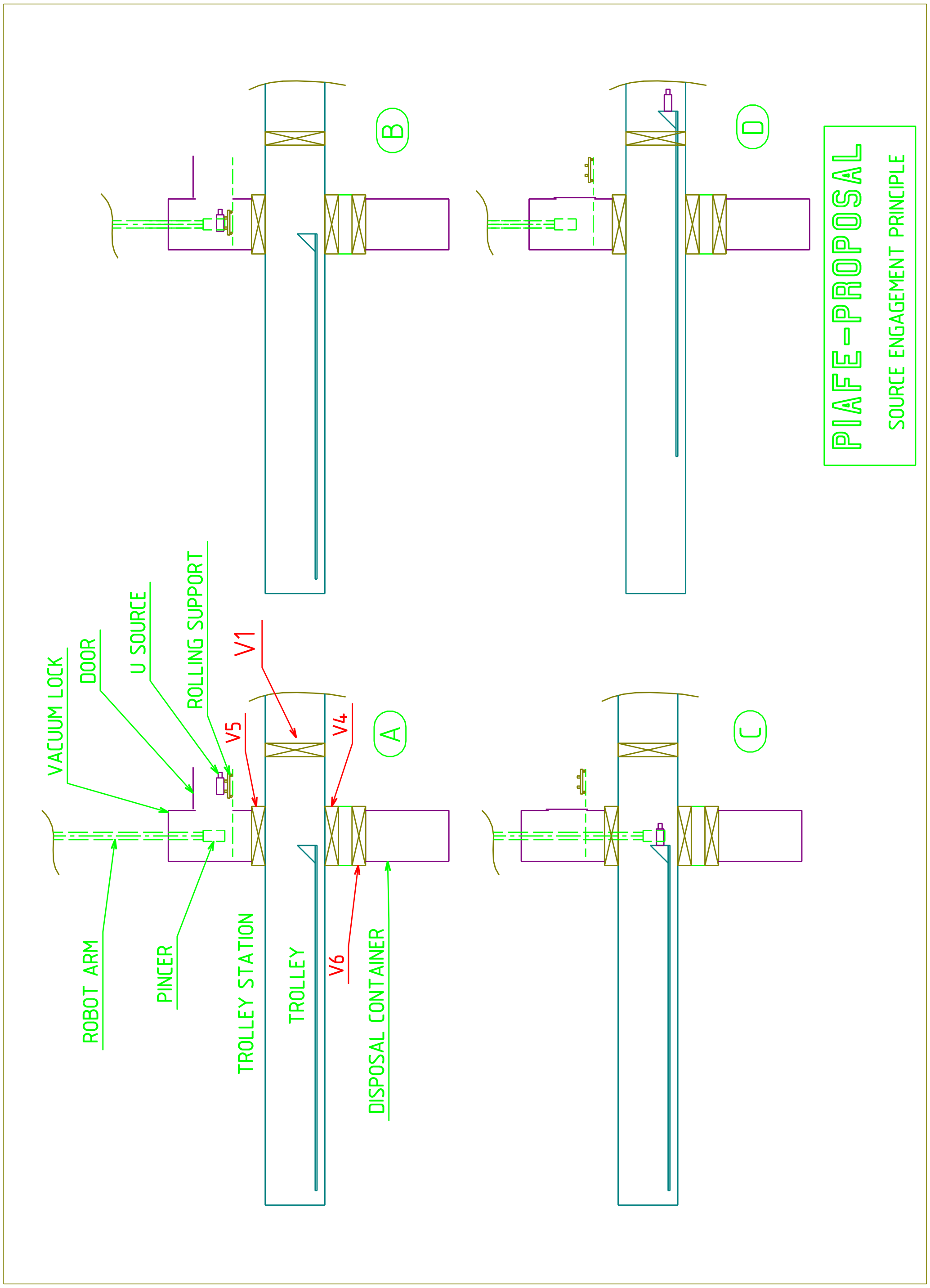

PIAFE-PROPOSAL
GENERAL LAYOUT
U SOURCE
HVS1
SECURITY VALVE
BUNKER 1
D1
MES1
LE1
HVS2
F1
LE2
V2
V1
MES2
5 M
0
LE3
F2
V3
QP1
QP2
BUNKER 3
(SFR)
D2
MES3
V4-V5
MES4
BUNKER 2
TROLLEY STATION
MES5
LiA
LiB
LiC
LiD
4 beam lines
ED A, B, C, D

Figure 1.



PIAFE-PROPOSAL
SOURCE ENGAGEMENT PRINCIPLE
A
B
C
D
VACUUM LOCK
DOOR
U SOURCE
ROLLING SUPPORT
V1
V5
V4
ROBOT ARM
PINCER
TROLLEY STATION
TROLLEY
V6
DISPOSAL CONTAINER

Figure 2

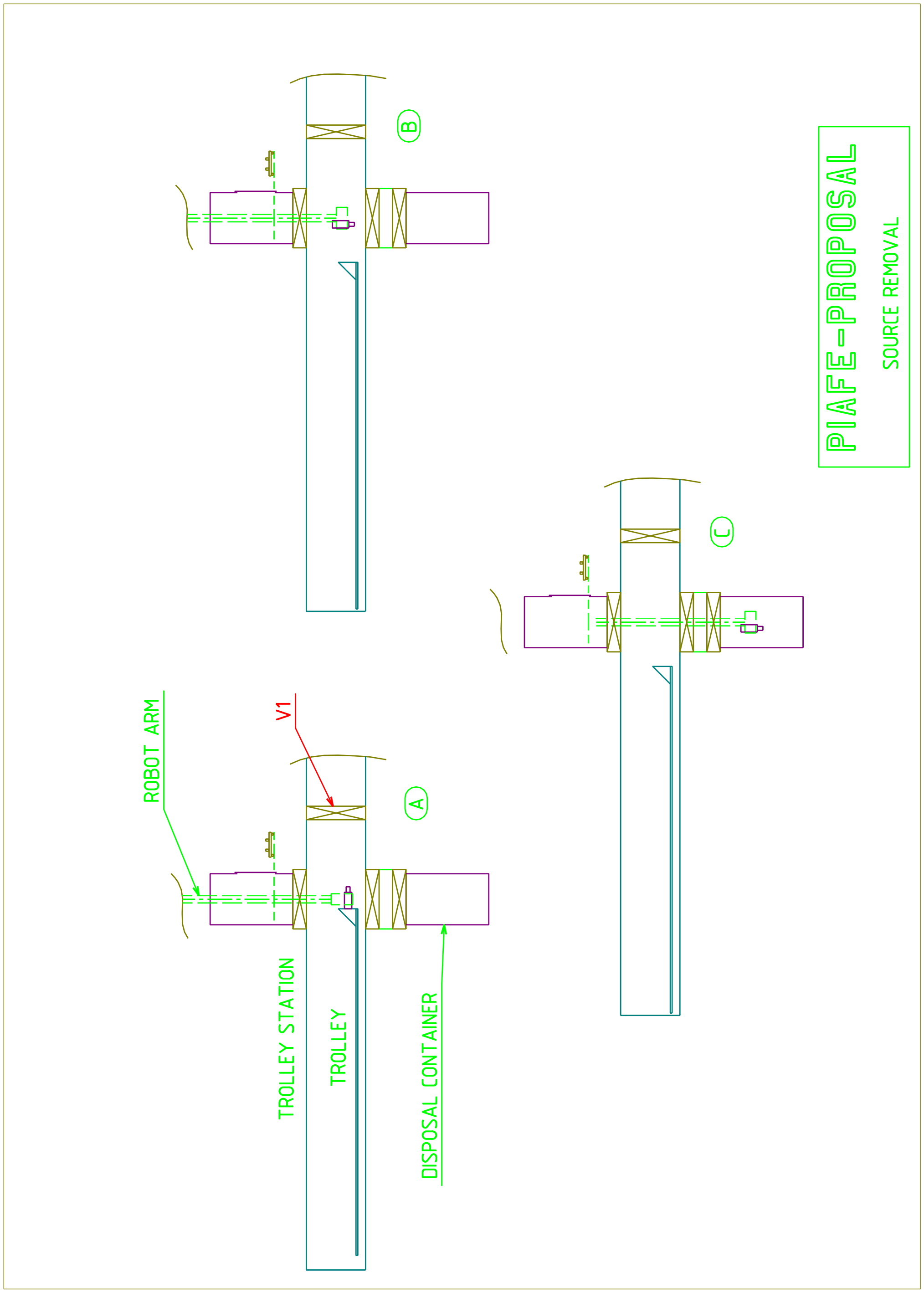

PIAFE-PROPOSAL
SOURCE REMOVAL
ROBOT ARM
V1
TROLLEY STATION
TROLLEY
DISPOSAL CONTAINER
A
B
C

Figure 3.