Journal of Radioanalytical and Nuclear Chemistry, Vol. 253, No. 3 (2002) 383–388

An automated irradiation device for use in cyclotrons

S. G. Araujo,* V. Sciani

Instituto de Pesquisas Energéticas e Nucleares, Travessa R, 400 – Cid. Universitária, 05508-900, São Paulo, SP, Brazil

(Received July 2, 2001)

Two cyclotrons are being operated at IPEN-CNEN/SP: one model CV-28, capable of accelerating protons with energies up to 24 MeV and beam currents up to 30 µA, and three other particles; the other one, model Cyclone 30, accelerates protons with energy of 30 MeV and currents up to 350 µA. Both have the objective of irradiating targets both for radioisotope production for use in nuclear medicine and general research. The development of irradiating systems completely automatized was the objective of this work, always aiming to reduce the radiation exposition dose to the workers and to increase the reliability of use of these systems.

Introduction

Two cyclotrons are being operated at the Instituto de Pesquisas Energéticas e Nucleares (IPEN): the first one is a positive ions accelerator, model CV-28, from The Cyclotron Corporation (TCC), capable of accelerating protons, deuterons, $^{3}He^{++}$ and alpha-particles at the maximum energy of 24, 14, 36 and 28 MeV, respectively, and beam currents up to 30 µA and is in operation since 1982.[1,2] Due to its versatility, it has great application in general research. The second one is a negative ion accelerator, model Cyclone 30, from Ion Beam Applications (IBA), is in operation since 1999 and it has the capability of accelerating protons at the maximum energy of 30 MeV, and currents up to 350 µA. Its main purpose is to produce radioisotopes in high scale, in order to supply the market with the most used radioisotopes in nuclear medicine: ^{67}Ga, ^{201}Tl, ^{111}In, ^{123}I and ^{18}F.[3,4]

In this paper an integrated control system for the irradiation of solid, liquid and gaseous targets in cyclotrons is presented with the interest towards the development of completely automated modules that can be used by the highest possible number of users, always aiming the reduction the personel exposition to radiation and the facility of its utilization. Beam parameters of vital importance, such as beam current and alignment can also be monitored during the irradiation.

All steps of the process are displayed into a screen in order to keep the operator informed about what is happening at any particular time. So, if the parameters are between the pre-established limits, the process goes on. If not, a program tries to correct and bring them to the allowed limits.

Experimental

Development and assembling of the system

The integrated system is formed by target holders coupled in a chamber in the beam line, a plant-floor (field devices) where all the target infrastructure is installed and a control panel, where the management and supervision of the process are performed.

Target holder for solids: The target holder for solids (Fig. 1), was made in aluminum and the target fixation was made through a pneumatic piston, that allows both its installation and removal. This target holder was projected for the irradiation of solid targets electroplated onto a support plate with dimensions of 72×27 mm^2. The target cooling is made with deionized water running in its back (2π cooling). This target holder is similar to that developed by MICHEL et al.[5] for the irradiation of TeO_2.

Target holders for gases: The target holder for gases is similar to that developed by BLESSING et al.[6] (Fig. 2) and it was made of nickelated copper. The target chamber has a conical shape, with inlet diameter of 13 mm, outlet diameter of 30 mm and length of 120 mm. The target body is cooled by deionized water, the front side of the target has a double window of Havar (thickness of 25 µm), attached to an aluminum flange that is helium cooled in its inner side. Four connectors were attached to its body that were coupled to pneumatic valves, allowing the target filling with the gas, the safety outlet, the vaporizing and collection of the target (recovery).

Target holders for liquids: The target holder (Fig. 3) was made of copper with an inverted conical geometry with 20 mm diameter and 30° angle,[7,8] with fins in its posterior side, allowing for a better cooling. This set is located inside a cryogenic chamber, filled with N_2L (liquid nitrogen), vacuum isolated. This chamber has the function of freezing the target and keep it frozen during the irradiation. An injection system, attached to a linear motion manipulator at the front of the target, does its filling. The target fixation is made through a gate valve coupled to a bellows, allowing a 90° target rotation, after the irradiation and further collection of the target.[7,8]

Automation and control: The PLC software was developed using a SIMATIC S7 software from Siemens. The project keeps a management program to integrate the whole process in real time, from the positioning of the target up to its transport to the processing cell.

* E-mail: sgaraujo@net.ipen.br

0236–5731/2002/USD 17.00

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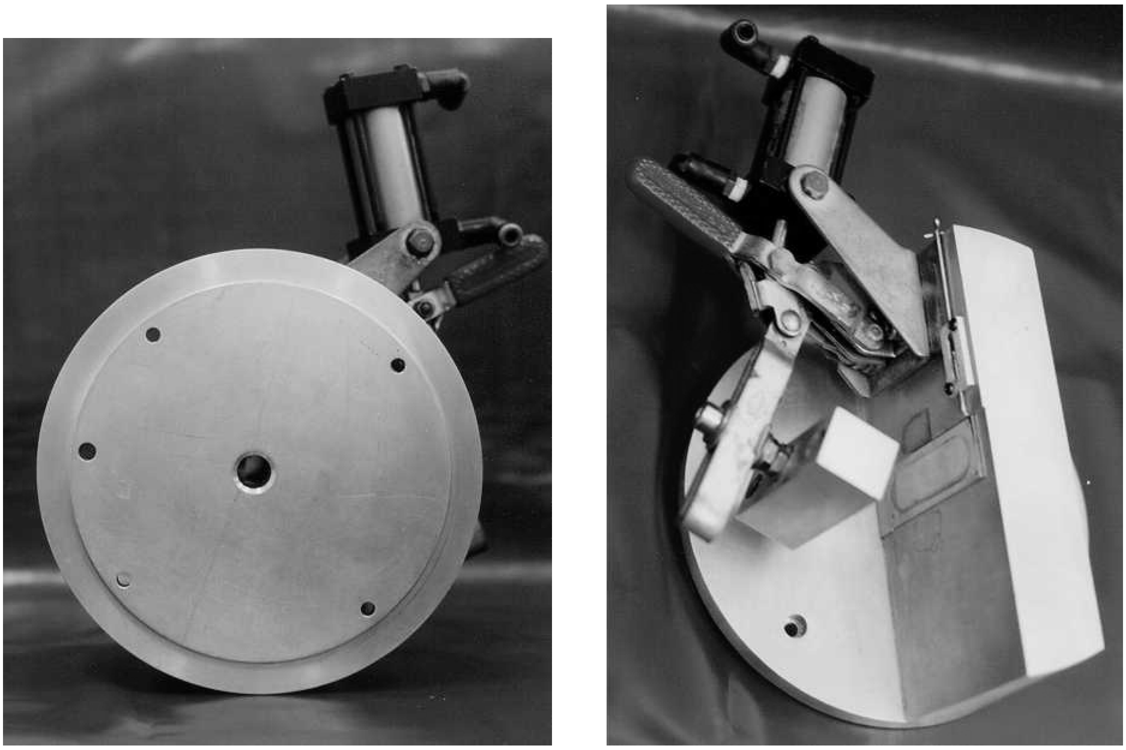

Fig. 1. Target holder for solids

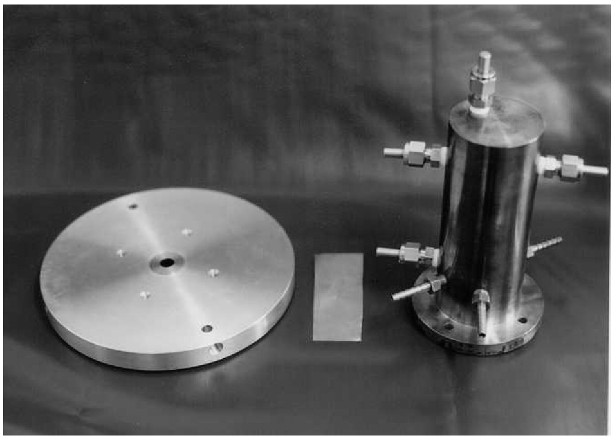

Fig. 2. Target holder for gases

An applicative software from Unisoft, was used for the supervisory system and the definition of the working logic. This enabled to: construction of the screens, linking sequence and the independent selection for each type of the target, development of sending messages and alarms events, definition of the procedures for navigation through the screens.

The supervisory screen for the liquid target can be seen in Fig. 4. It can be noticed in which step the process is. In this case, it is the "Rotation". On the right side of this figure, the command screen can be seen, and when the icon is pressed it allows the operator to act in: "Target Selection", "Reset Command", "Manual/Automatic Command" and "On/Off Command". On the left side, a valve window appears (only in the "Manual Command"), wherever it is pressed and needed. This kind of command is used for all the target holders. The one that is put into action will remain erased on the lower part of the screen. This does not avoid that the two other target holders (solid and gas) screens can be selected by the operator for visualizing purposes only.

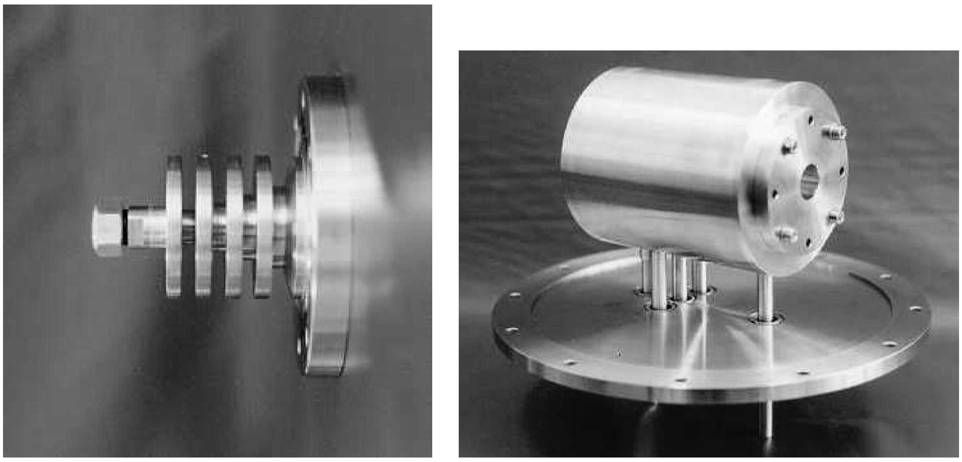

Fig. 3. Target holder for liquids

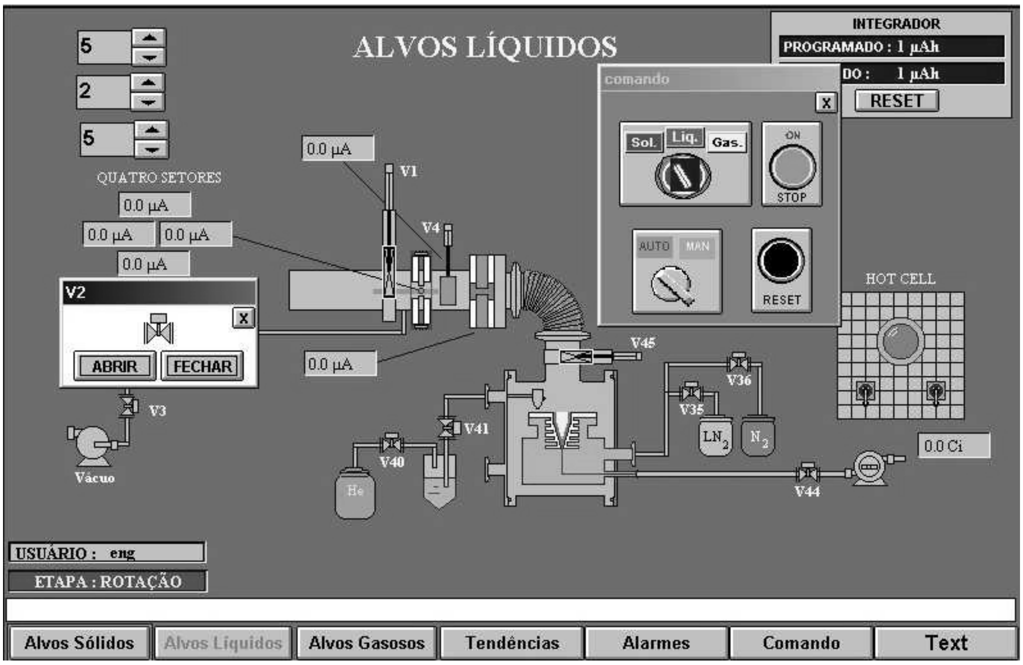

Fig. 4. Supervisory screen for liquid target

The operation sequence for the process of irradiating the liquid target follows the steps: (1) Insert the target holder on the beam line; (2) Start-up vacuum in the cryogenic chamber and in its insulator layer (thermal insulator for N_2L); (3) Fill the cryogenic chamber with N_2L in order to cool and freeze the target; (4) Load the target chamber with H_2O using the injector system; (5) Irradiate; (6) Rotate the target holder in 90°; (7) Purge the N_2L; (8) Collect the irradiated material with a peristaltic pump; (9) Transport it to the processing cell.

The supervisory screen for the solid target is shown in Fig. 5.

The operation sequence for the process of irradiating the solid target follows the steps: (1) Install the target holder on the beam line; (2) Position the target onto the target holder by succion; (3) Lock the target; (4) Start-up vacuum; (5) Circulate the water cooling; (6) Open the beam gate valve; (7) Irradiate; (8) Purge the residual water used for cooling; (9) Venting in order to vacuum release; (10) Release the target holder; (11) Collect it into a capsule; (12) Send the target holder to the processing cell.

The supervisory screen for the gas target is shown in Fig. 6.

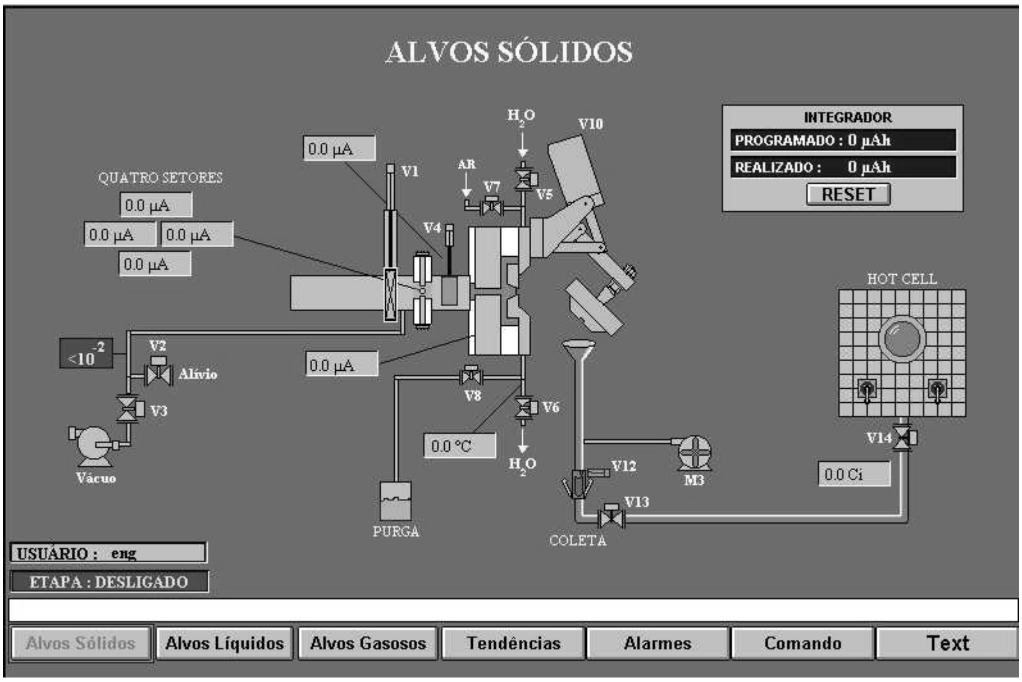

Fig. 5. Supervisory screen for the solid target

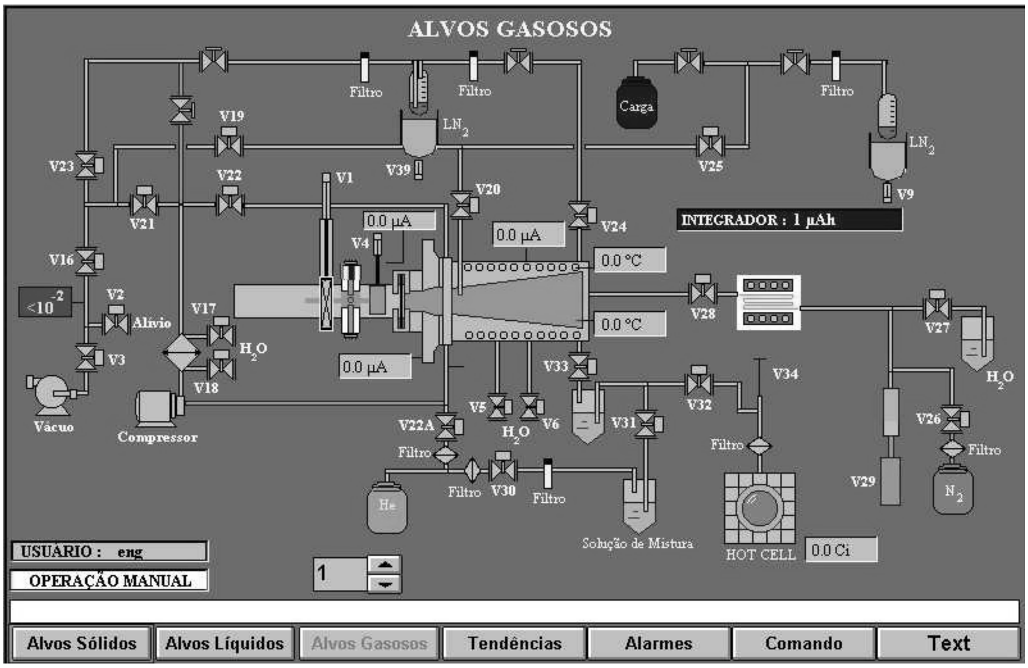

Fig. 6. Supervisory screen for the gas target

The operation sequence for the process of irradiating the gas target follows the steps: (1) Start-up vacuum; (2) Cool the windows with helium and the target holder body with deionized water; (3) Load the target with gas; (4) Irradiate; (5) Recover the enriched gas target through a cryogenic method; (6) Remove the irradiated gas isolated in the target walls through the introduction of vapour; (7) Collect the condensed water containing the radioactive gas; (8) Transport it to the processing cell.

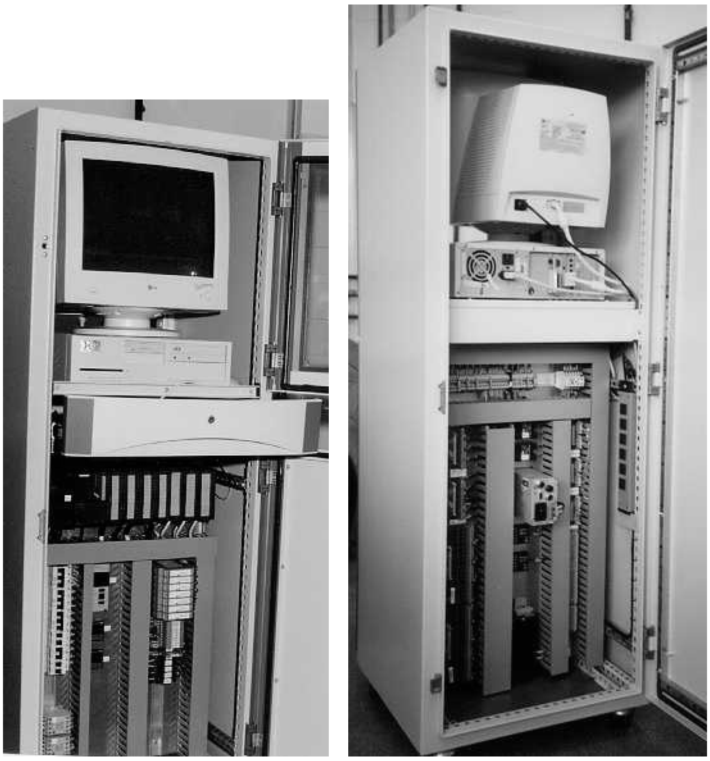

Fig. 7. Control panel of the automation process of the three target holders

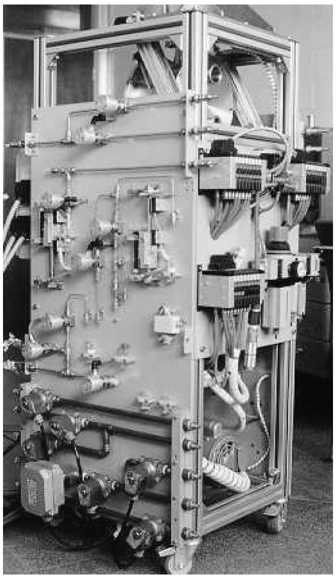

Fig. 8. Plant-floor with all the components involved in the three processes

Hardware: The hardware is formed by control panel and plant-floor (field devices). In the control panel of the process are: the power supply for the motors, pumps and valves and the microcomputer for the supervisory; programmable logical controller (PLC) S7-300 (Siemens); Modules of digital and analogical inlets and outlets. It is located at the control room of the CV-28 Cyclotron 30 meters from the beam line, where the first tests were performed, allowing all the supervising necessary for the management of the parameters involved in the automation processes of the three target holders (Fig. 7).

The plant-floor (field devices) is made of an aluminum frame, where all the components involved in the three processes are installed. The assembly was made as shown in Fig. 8, the valves are installed in the laterals and the pumps in the inside. The top is used as support for the target holders in the beam line and it is also where the looping system for collecting the liquid target is installed.

Results and discussions

System tests

Several cold simulations were performed in order to verify the operationality of the control system, as follows: simulated functional test; adjustment of the field devices (limit switches, pneumatic cylinders, etc.); test of operation systems without irradiation; vacuum tests to verify the leaking proof of the system; operation tests with load and perform tests.

In the system all the functions that are necessary for use in the respective irradiation devices are asked by the interface Operator-PC, executed by the system through the PLC, according to the pre-established control logic and if any anomaly occurs during the process, a feedback tries to correct the default or an alarm indicates the occurrence. So, if during the process a locking happens, the control tries to correct this default or failure, without having the process returned to its start. The operator has the option of turning the command to manual and then tries to correct the default, without changing its sequence. This information of anomaly is given through a sound signal and an information sign written at the display, every time that something doesn't happen as foreseen by the operator, giving him access to any valve, motor, pump, etc., individually.

Several sensors and measure points were added for detecting these failures, in order to feedback the control system: four sectors diaphragm, target, proximity sensors for the solid target, gas pressure during the irradiation, temperature, level of nitrogen, target flow, helium flow and vacuum.

Three modes of operation are made possible with this control system: automatic, semi-automatic and manual.

In the completely automatic mode, once the process is started, it will follow a pre-set logical sequence up to end, with times for each step being previously chosen and easily altered.

In the semi-automatic mode, each step can be selected through a "start command" followed by the pre-established sequence. This means that one can not return to the previous step nor skip a step of logical sequence.

In the manual mode, there is also a possibility of performing routine maintenance without having to turn on all the system.

In the simulation tests, inlet signals were induced in the several feedback points of the system, such as: current at the diaphragm of the four sectors diaphragm and target, temperature variation at the thermocouples, level control, interruption in the water and helium cooling and vacuum release simulation.

Tests with irradiation of targets

The system is being tested at the CV-28 Cyclotron of IPEN through the irradiations with 24 MeV protons and currents up to 10 μA in targets of: (a) solid: natural zinc electroplated onto a nickelated copper support, (b) gas: natural krypton, and (c) liquid: natural water.

The emphasis in these irradiation were concerned to the critical parameters of monitoring of each process, such as temperature, pressure and current, both in target and in the sectors, collimators, beam stopper and calculation of integrated dose.

The system showed reproducibility and reliability in its operation and an easy communication between the operator and the process.

The option of uniting the three kind of targets, specially the cryogenic, was made in order to develop an automation system as complete as possible, embracing the highest number of possible steps involved.

Conclusions

Several important points can be outlined of the automated irradiation device: conditions for controlling three independent beam lines, if it is necessary, one for each kind of target; unified control system, allowing the control of three kinds of targets in different geometries; safe operation and reliability; significant reduction on the dose to the worker; automatic removal of the target, with management and supervision through the computer; indication of the beam hitting the target with control of its homogeneity and profile through the currents in the collimators and four sectors diaphragm; and control of temperature and pressure of the target during the irradiation.

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The authors wish to thank the financial support of FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for the development of this work.

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