ATOMIC VAPOR LASER ISOTOPE SEPARATION IN FRANCE

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1 - INTRODUCTION

France has specific position in the uranium enrichment market. It has a major nuclear park, supplying 75 % of the nation's electricity. On one hand the modern multinational **EURODIF** gaseous difusion plant (10,8 M.SWU/y) works smoothly, and its supply of nuclear generated electricity offers customers a good long term view on enrichment costs.

On the other hand, today's situation of over capacity, accentuated by non-commercial practices, may lead to a brutal restructuring of the world-wide enrichment industry in the coming years. The French approach has a long term goal, with a priority for a high performance process, which will be available when world stocks of enriched uranium are exhausted, and aging enrichment plants have to be shut down.

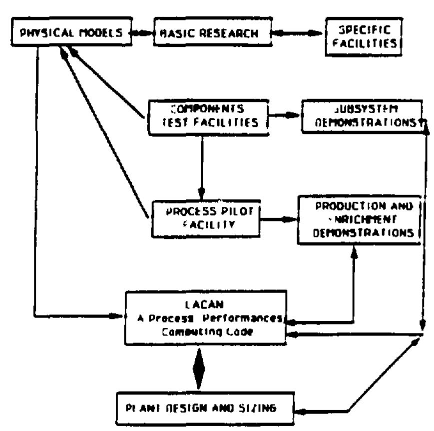
To reach this goal, the French Atomic Energy Commission has focused since 1985 on the atomic vapor laser isotope route, **SILVA**, in agreement with the industrial operator, **COGEMA**.

The program is supported by a network of co-operations with advanced technology companies, particularly in the field of lasers, optical components, materials, power supplies. Some developments have been largely subcontracted (CVL with CILAS, advanced power electronics with GEC-ALSTHOM, optics with MATRA, SAGEM....). Moreover, COGEMA and industries researchers have joined CEA teams and facilities (7).

The technical program, which will be described in detail, is made up of :

- <u>Basic research</u> in each field, with models development adjusted through specific and integrated experiments.
- A <u>progressive development</u> of components with specific facilities.
- <u>Integrated experiments</u> especially with the pilot facility for separative experiments.
- <u>A general process model</u>, including operational and economical data

R&D ORGANIZATION



<u>Figure 1</u>

2 - BASIC RESEARCH

In the following section, we shall give some examples of basic problems connected with different parts of the process.

Uranium spectroscopy

The multistep photoionization of uranium atoms implies to choose an irradiation scheme and this choice is only possible if the following spectroscopic parameters and specific effects are known :

- oscillator strength
- isotopic shift
- hyperfine structure
- lifetime
- autoionization spectrum
- effects of electric and magnetic fields
- effect of laser polarizations
- effect of multiphoton processes upon selectivity

Since the oscillator strengths determine the laser fluences needed for efficient atomic photoionization, this parameter must be accurately measured. Two different methods have been used :

- Saturation method
- Branching ratio and lifetime measurements.

An extensive work has carried out in this field. It enables us to choose the best wawelengths, selected by appropriate criterias.

Selectivity

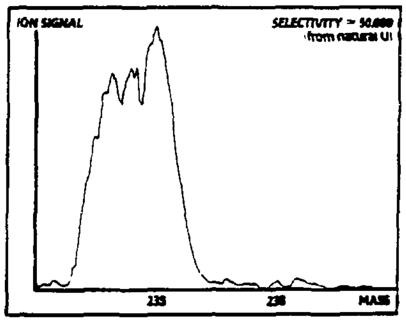


Figure.2

Cross section measurement

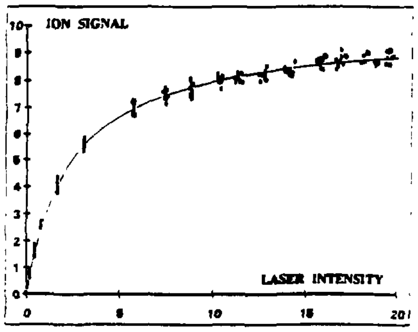


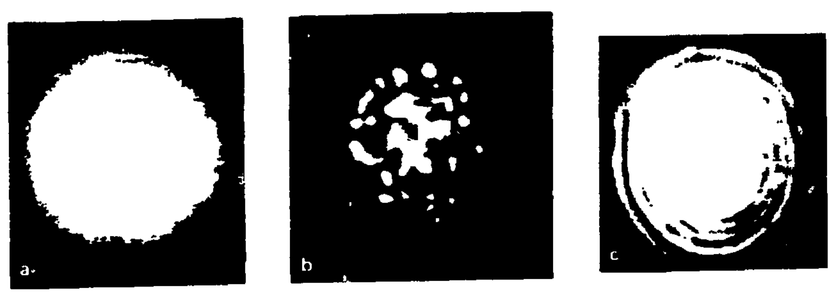
Figure 3

Light matter interaction

Several computing codes have been set up for coherent interaction calculations *(Bloch equations)*, in order to compute ionization yield and its variations with the pulse energy density. The resonant propagation phenomena in an optically thick vapor may have an important influence on the process, as we should make the best use of photons. Unfavourable effects can occur on the spatial and temporal laser pulse profiles, which will lower the ionization yield. In order to study this problem we have set up a computing code for propagation, which includes transverse propagation effects. Propagation experiments in thullium are compared to the numerical results. An interesting example of this propagation phenomena consists in the *"healing"* of the hot spots structure (Fig. 4b) which are removed through the second step excitation and replaced by an annular structure (Fig. 4c) (1).

Figure 4

Laser beam patterns



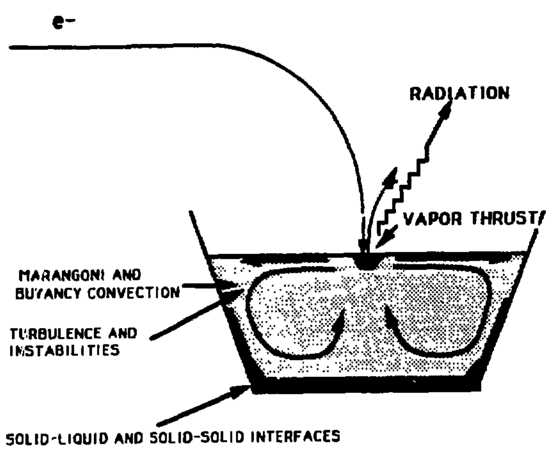
input beam — without leak transition — with leak transition "healing"

Evaporation

Optimization of the uranium vaporization by an electron beam is one of the keys of the **SILVA** process. Experiments are made on several benches of different sizes including process scale size **(HORUS)**. The measurements results of the leading parameters *(temperatures, flow rate, etc...)* are compared to theoretical results obtained with **TRIO-SILVA**. **TRIO-SILVA** is a computing code which takes into account thermal hydraulics phenomenas occurring in the crucible (Fig. 5). This code includes a multi-component version for alloys.

Figure 5

Vaporization by electron beam



Vapor flow

All vapor properties must be known in all the regions where laser-vapor interactions takes place, as they take part in the process optimization. Thus, the laser pulse repetition rate and light-matter interaction zone heigth must account for the radial velocity v_r (mean value and spread); the non selective flow which dilutes the enriched product depends on the transverse temperature T_θ; background ions in the vapor also take part in this non-selective flow and must be extracted. Metastable atoms above the 620 cm^{-1} level will increase the waste concentration (Fig. 6) for not photo-ionized.

Monte-Carlo computing codes have been developed (2) in order to interprete the vapor measurements obtained on the evaporation facilities. For instance, comparison between experimental and theoretical variations of the velocity v_r with evaporation flow rate, is not good if only elastic collisions are considered (Fig. 7): the excess velocity is related to internal energy transfer from metastable atoms, along the collisional vapor expansion (Fig. 6).

Figure 6

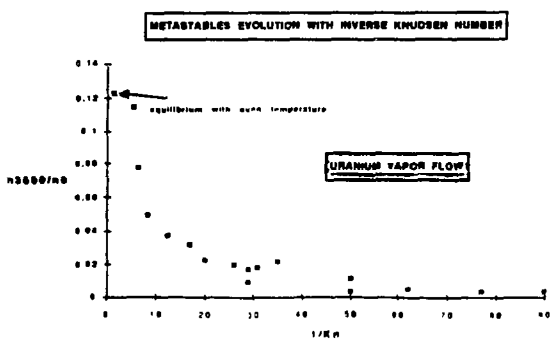
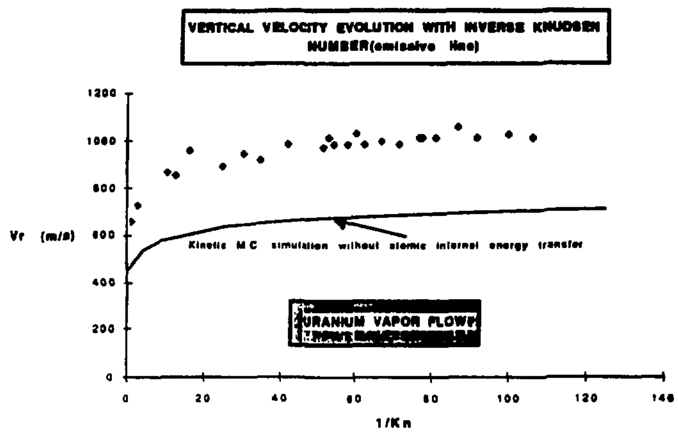


Figure 7

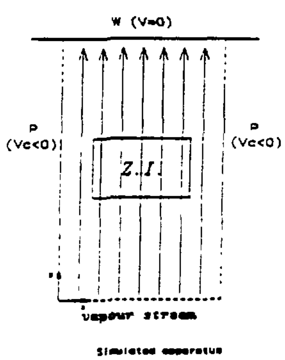


This relation is confirmed with the vaporization results obtained with several other metals. For instance, velocities and temperatures *(spread)* will be correctly interpreted for the Cerium evaporation only if internal energy transfer is included. However copper evaporation, for which internal energy is negligible (at evaporation temperature), a purely kinetic simulation appears to be correct (3).

Extraction

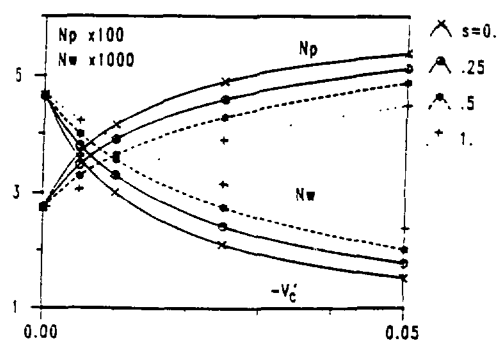
In order to choose and optimize the best extraction system, beside experimental set-up, a **MONTE-CARLO** computation code applied to charged particles has been performed (4). Ions flows submitted to electric or magnetic field are simulated. Fig. 8 and 9 show an application of this code for the simple case of electrostatic extraction between two plates of the photoions set created by a laser pulse *(Z.I. note on Fig. 8)*. The two plates are negatively polarized ($V_c < 0$), and charge exchange effect is also considered (Fig. 9, (4)). Comparisons between simulation and experiments are excellent.

Figure 8



Simulated apparatus and boundary values of potential

Figure 9



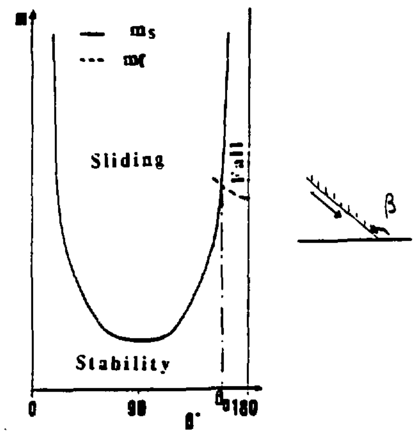
Product and waste compositions versus polarization, for different values of s = σ n L.

Collecting flows

High temperature liquid metal collecting of enriched product and waste tail is one of the most difficult problem of this process from material and technology points of view. It is also connected with various fundamental problems linked to material and liquid material interaction *(adhesion energy, wetting angles, chemical interactions)*, and hydrodynamics *(film, drop, stability under various orientations)*. For instance, a stability diagram for drops (Fig. 10) condensing on a wall helps to prevent drop falls and promote drop sliding.

Figure 10

Drop stability as a function of its mass and the wall orientation



3 - TECHNOLOGICAL DEVELOPMENT

URANIUM VAPORIZATION AND MANAGEMENT FACILITIES

C.E.A. has quite numerous specific facilities, each of them mainly devoted to one process function. Most of them are located in **PIERRELATTE** :

- **HORUS** is devoted to vaporization process optimization. Three new test benches (5) will soon operate in this domain.

- Material test and behaviour in conditions similar to those found in a separator is the main aim of **CORDY** facility (Photo 1). This facility includes an evaporation apparatus and a thermic control system. The experimentation concerns two kinds of tests : short duration tests for checking solutions during their development *(6 to 30 hours)* and long duration tests for high performance solutions *(time higher than 100 hours)*.

- Uranium flow handling outside vapor deposition areas is studied on a special facility called **IRIS** (photo 2), which is used to generate uranium flows and generates drops and films flows. Various shapes and slopes of guiding components are tested with this facility.

- Technological studies for ions extraction and collection are especially undertaken in **ISABEL** Laboratory *(located in SACLAY)* with two evaporation facilities. They are also one of the pilot facility targets.

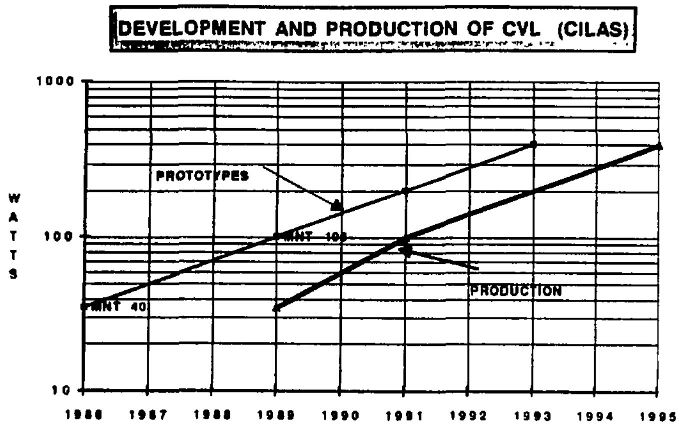
- Complete metal liquid flows management systems are experimented in the **MAEVA** facility, which is the higher sized **SILVA** evaporating facility *(Photo 3)*.

- Facilities for material processing are associated with the previous facilities.

LASER DEVELOPMENT

Nominal optical pumping systems utilizes **Copper Vapor Lasers (CVL)** developed by **CILAS** Company. The first lasers produced (MNT 40) constitute since three years the pumping system of the pilot facility A2. The **next (ASTER)** will include 100 W laser modules, which are now in production. The next **CVL** laser (400 W) is going to be realized *(Fig.11)*.

Figure 11

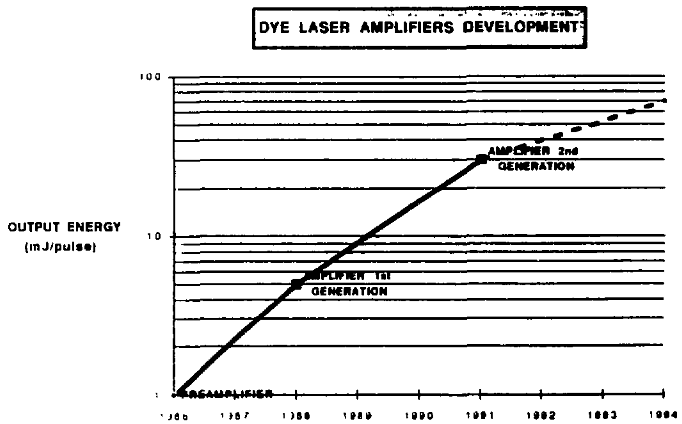


For 100 W CVL, individual running times are several thousand hours, with about 1000 h MTBF.

N.B. - CVL solide state power supply is also developed with ALSTHOM Company.

- Dye oscillators and amplifiers have been developed by CEA (Fig.12). Photo 4 shows the first generation amplifier. Pumpingschemes using solid lasers are also studied.
- Laser chain, optical components and associated automatons are developed by **CEA** teams.

Figure 12



4 - PILOT PROCESS FACILITY "A2"

This facility includes two main parts : the laser system named **HFRA** *(Photo 5 : Dye laser room)*, and the separator named **ANDROMEDE** *(Photo 6)*. More than 90 test runs have been achieved, each run corresponding to an evaporation duration between 2 and 20 hours. The main test are the followings ones :

- Production test : Production rate between 1 to 10 g/h of enriched uranium, with uranium enrichment assay up to 5,5 %.

- Design optimization for :
    - extraction systems
    - matter-light interaction areas
    - photon management

The pilot extension to an higher size facility named **ASTER** is going on : it will include a laser systems with a power output about ten times higher than the present one and a new separator named **ALDEBARAN**.

5 - LACAN : A GENERAL PROCESS MODEL [6]

The first target for **LACAN** is the separator results simulation through matter and photons flow sheet modelings (Fig.13). Modeling and design improvments are continuously added directly or using approximate or simplified formulas (Fig.14). The code has three different applications :

- Comparison with integrated experiments results, especially those obtained with the pilot facility A2.
- New pilot facilities design.
- Production system optimization

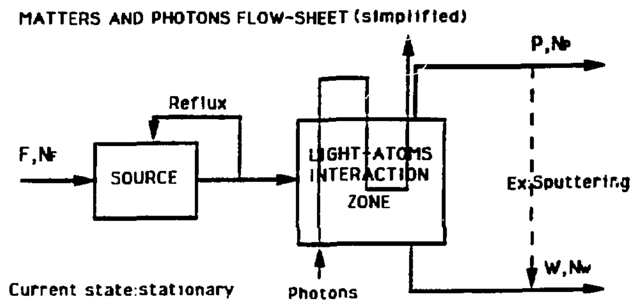
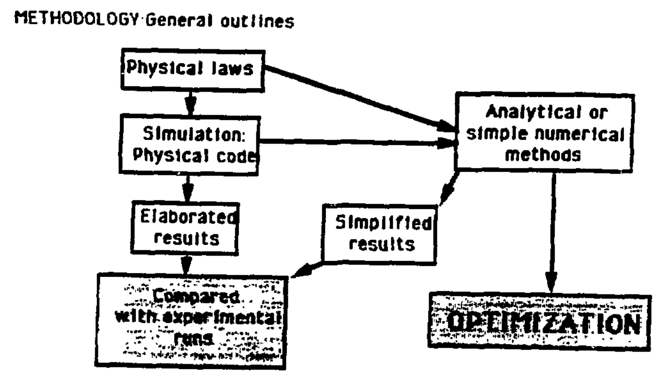


Figure 13

Figure 14



For the last target, technological and operational datas such as cost functions are progressively added, together with general economical assumptions.

6 - SILVA GENERAL SCHEDULE

The **SILVA** programm is periodically assessed from both the scientific and the industrial point of view. A general assessment is to be made between 1996 and 1997. It will include several demonstrations related to each of the main process functions (*"DEMO"*) as well as an evaluation of the economics. The date of the construction of a fully integrated system, at production scale, which is very costly, will then be decided so as to include the most advanced designs.

Figure 15

SILVA GENERAL SCHEDULE

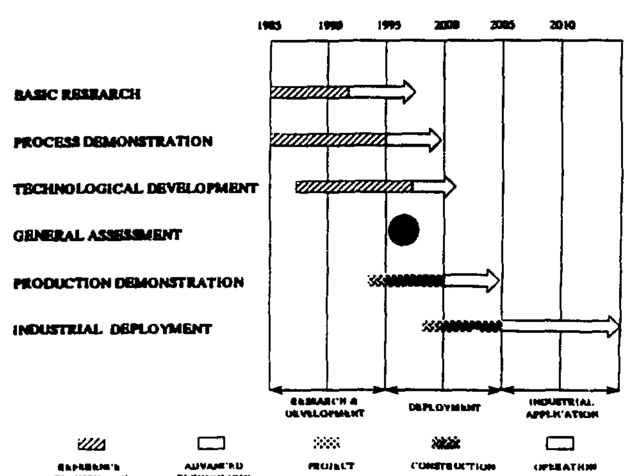


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Photo 1 : CORDY

Material corrosion and lixiviation in liquid metal

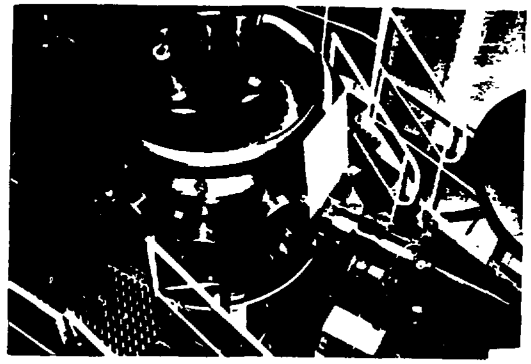
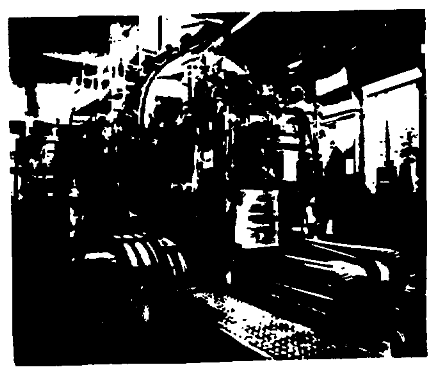


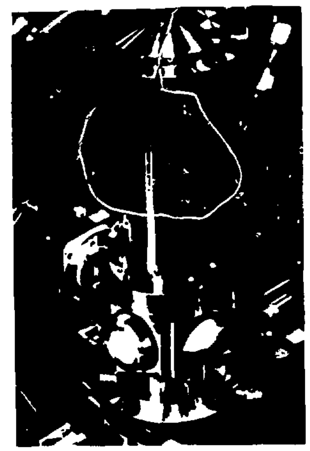
Photo 2 : IRIS

Flow studies on various uranium handling systems

Photo 3 : MAEVA

Liquid uranium managment





<u>Photo 4</u> : DYE AMPLIFIER

First generation

<u>Photo 5</u> : A_2 PILOT FACILITY

Dye Chain HFRA

<u>Photo 6</u> : A2 PILOT FACILITY

Separator ANDROMEDE