CEA-CONF-11372
FR9302939

Atomic vapor laser isotope separation in France

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1. INTRODUCTION

A general energy policy must be based on long term options. It has to ensure an energy supply in sufficient quantity, but at the same time it must be competitive and reliable, in order to avoid crises like the oil crisis and the greenhouse effect.

France has low natural resources *(oil and coal)*, and therefore for a long time has had a broad approach for its energy policy : energy saving, a logical use of every source, a wide range of suppliers and reasonable domestic autonomy.

France has therefore developed for the generation electricity a very complete nuclear industry, from mining to reprocessing and radwastes managment, and now has a major electro-nuclear park, with 55 power reactors, supplying 75% of the nation's electricity and representing 32% of its energy requirements *(Ref 14)*.

The modern multinational EURODIF enrichment plant in Pierrelatte in the south of the country supplies these reactors with enriched uranium as well as foreign utilities *(30% exports)*. It works smoothly and has continuously been improved to reduce operating costs and to gain flexibility and longevity. Investment costs will be recovered at the turn of the century. The plant will be competitive well ahead of an aging production park, with large overcapacity, in other countries.

The world enrichment industry entered a new era two years ago with the collapse of Eastern European political system and its two major consequences for the enrichment business:

- huge stocks of military highly enriched uranium will probably be available for civilian purposes, after dilution. They can represent 10 to 20% of world needs for 10 to 15 years,

- large military production capacities, in USA and mainly Russia, will be oriented toward reactor grade uranium or will have to be shut down: they represent approximatively 8 MSWU/year, or 18% of world capacity.

Meanwhile world needs will increase only slightly during the next 15 years, apart from the Asian Pacific area, but many world governments are becoming well aware of the necessity to progressively resume nuclear energy development worldwide from the year 2000 on.

2. FRENCH APPROACH TO LONG TERM R & D ON ENRICHMENT

During the first half of the eighties several processes, including advanced gaseous diffusion, chemical exchange, laser photoionisation and photodissociation, and cyclotronic resonance, were simultaneously under study in France. Today R & D efforts on enrichment processes are solely devoted to laser photoionisation, currently known as SILVA *(Ref. 15)*.

The main reason which justified this choice in 1985 was the fact that a highly selective process, such as SILVA, would probably take the lead over statistical processes such as gaseous diffusion, centrifugation or chemical exchange. This is particularly true in France were the need for new large enrichment capacities looks like it will coincide with the replacement of the EURODIF plant which could take place as late as 2010.

As a result the goal aimed at is no longer to confirm this choice, but rather to develop progressively a high performance process, looking closely at every new technology which might be appropriate in the long term. Special attention is given to the reduction of investment and operating costs for a plant which could be set up progressively, following market needs. Briefly, R & D on SILVA todays is oriented toward:

- an extensive analysis of every field of basic research such as spectroscopy, photoionisation, beam propagation, plasma physics and product collection: each phenomenon is studied separately and linked to the others,

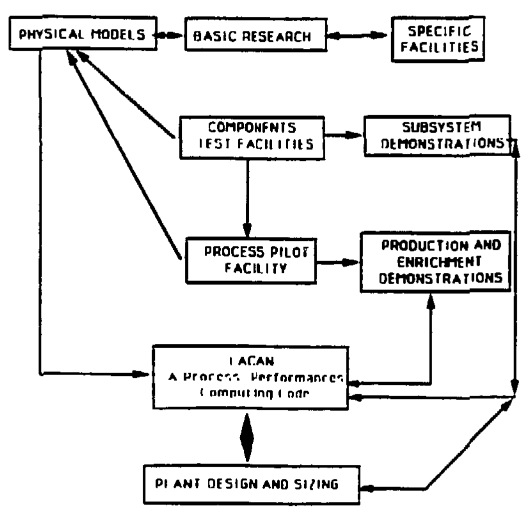
- a modular organisation of the process, for both laser and separator sub-systems and related workshops: the benefit of such an approach is :

  . R & D facilities of reasonable size and construction and experimenting costs,
  . demonstrations can be achieved separately for each sub-system, the general demonstration being built like a puzzle,
  . breakthroughs resulting from advanced technology, particularly in the fields of optics and materials, can be integrated more easily and even at a late date,
  . industrial deployment can be progressive.

- limited fully integrated experiments, oriented towards the physics of the process,

- the development of a general process model, including operational and economical data, fed with qualified physical and chemical models and related computer codes.

Fig.1: General pattern of R & D organization



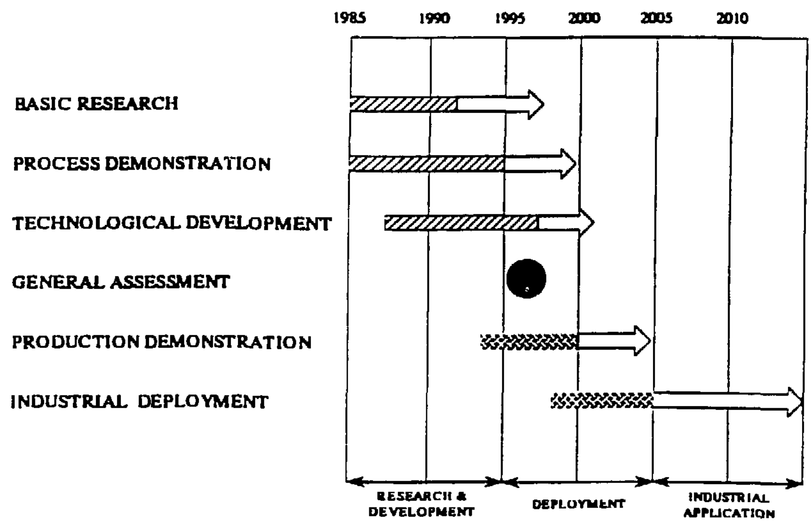
The SILVA process is periodically assessed from both scientific and industrial points of view in close cooperation with COGEMA. A general assessment will be made between 1996 and 1997. It will include demonstrations related to each of the main process functions:

- enrichment performances *(product and tail assays, production capacity),*
- handling of uranium fluxes in a separator,
- long term operation of laser chain and laser system,
- reliability of specific components and materials in process conditions,

as well as an evaluation of the economics of an industrial application with qualified and advanced technologies.

The date of construction of a fully integrated demonstration pilot plant, at near production size for the main components and sub-systems, will then be decided, as required by market conditions. It will be set up progressively and will include the most advanced designs.

Fig.2 - SILVA general schedule



3. STATE OF THE ART

The following papers will give a more detailed view on SILVA's progress today. Only a general view of the main researches and facilities devoted to this program are given hereafter.

3.1. Basic research

Uranium spectroscopy :

It has been researched extensively for nearly 15 years and two papers are presented on methods used to explore the main spectroscopic parameters *(Ref 1)*, and on the results and interpretation of experiments on the hyperfine structure *(Ref. 2)*. Good spectroscopic three steps-four wavelengths schemes have been identified.

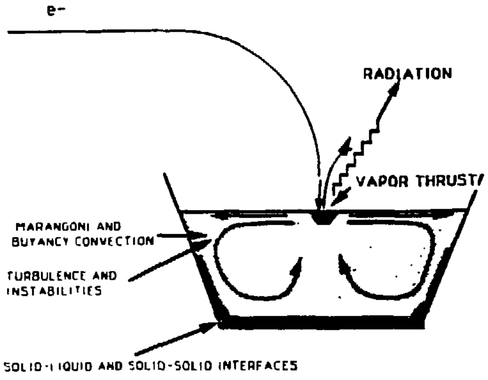
Light matter interaction :

Photoionisation yields up to 95% have been experimented on U vapor emitted by E.B. guns. Resonant propagation phenomena in optically thick vapor has been modelized and experimented on thulium and uranium *(Ref. 3)*.

Evaporation :

Optimisation of the uranium vaporization by an electron beam is one of the key parameters for the economy of the process. The results acquired on several dedicated facilities, including process scale size, are compared with the theoretical results obtained with TRIO-SILVA. It is a computing code taking into account thermal hydraulics phenomenas occuring in the crucible and including a multi-component version for alloys *(Ref. 4)*.

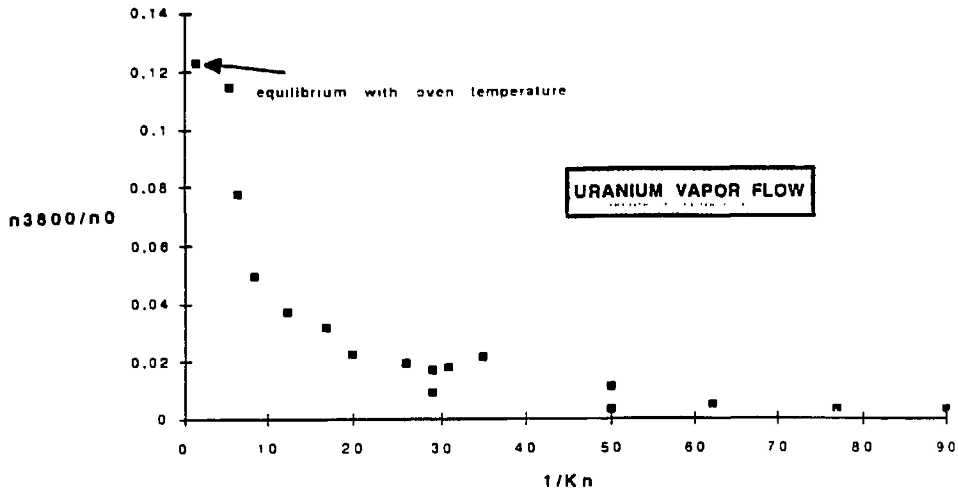
Fig. 3: Vaporization with an electron beam



Vapor flow

Vapor properties must be precisely described where laser-vapor interaction and plasma extraction is achieved. Important items are velocity, non selective flow mixed with the enriched product depending on transverse velocity, background ions, metastable atoms above 620 cm-1 level *(fig 4)*.

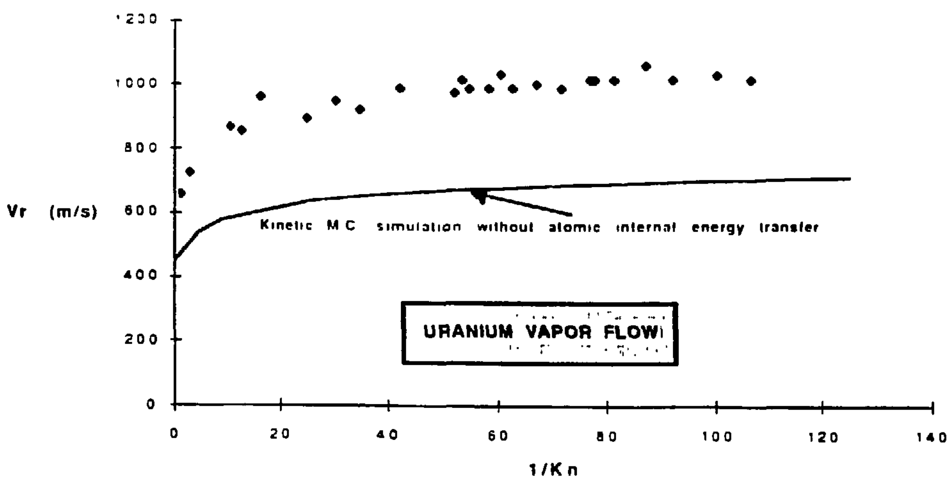
Fig. 4: Metastable evolution with inverse Knudsen number



Monte-Carlo computing codes *(Ref. 12)* have been developed, including a multi-component version for alloys, and are qualified on reduced and full scale experiments on the complete vapor volume, with several E.B. guns.

For instance variation of the radial velocity with vapor flow is not properly described if only elastic collisions are considered (fig 5) : the excess velocity is related to internal energy transfer from metastable atoms in collisional vapor expansion.

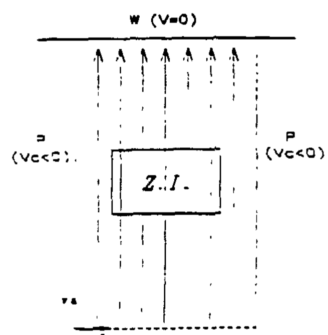
Fig. 5: Vertical velocity evolution with inverse knudsen number (emissive line)



Extraction :

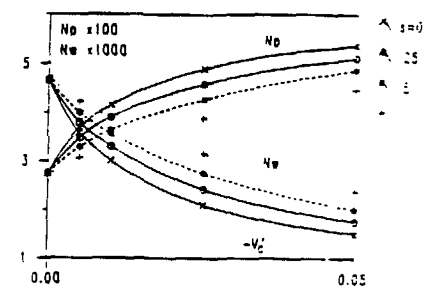
Extraction is extensively studied using background ions and photo-ions, with various geometries and at process densities. Monte-Carlo particle-mesh method has been introduced into computer codes applied to charged particles. Fig. 6 and 7 show an application of the Monte-Carlo code to a standard configuration of electrostatic extraction of a plasma of photo-ions between two plates.

Fig 6



Simulated apparatus and boundary values of potential

Fig. 7



Product and waste concentrations versus polarization, for different values of s e o n L.

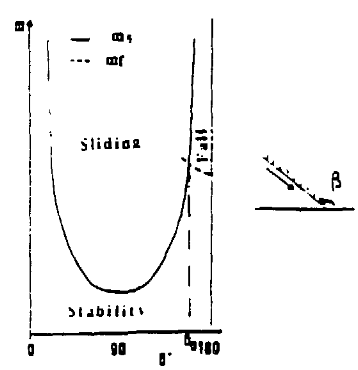
An application of the particle-mesh method is given in Ref. 5.

Condensation and collection mechanisms :

Collection of enriched product and waste tail at liquid metal temperature is one of the most difficult problems to solve in order to be able to design the collectors. It is linked to various fundamental phemomema connected to substrate and liquid metal interaction (*adhesion energy, wetting angles, chemical interaction*), and hydrodynamics (*film and drops stability under various conditions, vapor flow*).

For instance the stability diagram of drops on a wall can be used to determine the necessary conditions to prevent drops failing and promote drop sliding (Fig. 8).

Fig. 8: Drop stability as a function of mass and wall orientation



3.2. Technological development

A wide range of experimental facilities have been devoted to component and process function development, in Saclay and Pierrelatte.

Separator system

Special attention has been given to material testing under process condition. For instance the **CORDY** facility (Ref. 6) allows testing of various components under realistic vapor conditions, and gives access to corrosion and leaching effects and to flow conditions on long-standing tests (*over 100 hours*). Draining conditions are studied in **IRIS** facility *(Ref. 7)*.

Uranium vaporisation is studied with various electron beams and crucibles in high power facilities (***AMON*** *for linear E.B.*, ***APIS*** *for spot E.B.*) and facilities devoted to various physico-chemical conditions (***ANUBIS***).

Ion extractors and collectors are experimented on two dedicated facilities, **ISABEL** and **HORUS**, uranium evaporators with high temperature super-structures.

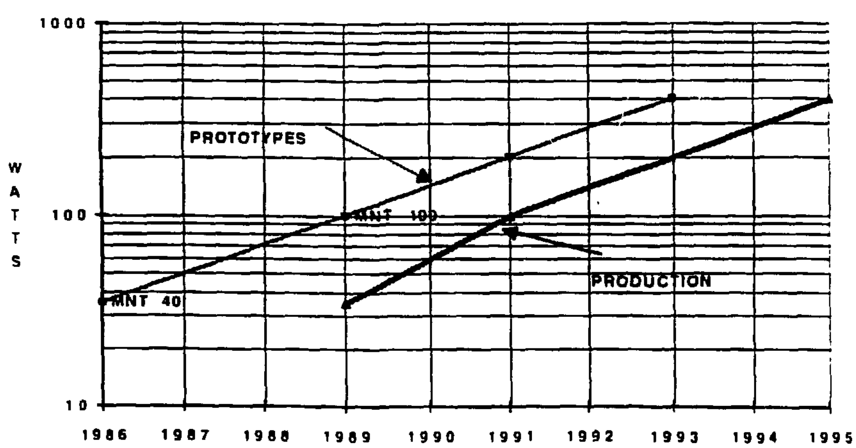
Complete liquid metal management, including uranium source and gestion of the three fluxes of uranium is tested on the **MAEVA** facility, for long-lasting runs, over 100 hours.

From a general point of view components will be tested in the next years between half and full process scale on these benches.

Laser system

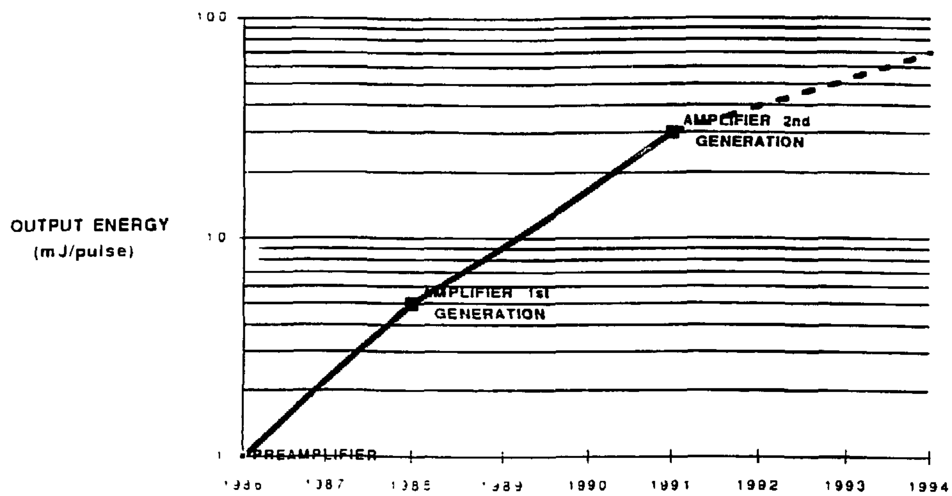
Several pumping systems are still conceivable for industrial use, including solid state lasers. Nevertheless the main effort has been carried out on **copper vapor lasers *(CVL)***, developed by CILAS Company. FIG 9 shows the development schedule, and points out the time necessary to achieve production capability for the standard production of reliable lasers after the first prototype success. Today 100 W CVL are commercialized and 315 W have been obtained on prototype lasers *(Ref. 8)*. The next generation, 400 W CVL will be using solid state power supplies developed by **GEC-ALSTHOM** company *(Ref. 9)*.

Fig. 9: Development and production of CVL



Dye lasers have been conceived by CEA and are experimented on specific laser chains at various repetition rates *(Ref. 10)*. Fig 10 gives the development situation of qualified power amplifiers, this development being adjusted to pilot process facility needs.

Fig. 10: Dye laser amplifiers development



Meanwhile optical components for pumping and adjusted light have been developed in cooperation with university and CNRS laboratories and industrial companies such as **SAGEM** and **MATRA**. Specific benches have been devoted to optical components testing *(Ref. 11)*.

3.3. Process Pilot Facility A2

This facility includes a complete four wavelengths laser system, and a separator. It has been working for 6 years and an extension, **ASTER**, with additive laser power (ten times higher) and a larger separator is under way. Its goal is to test the extractor/collector system at process scale and under representative physico-chemical conditions. The tests involve:

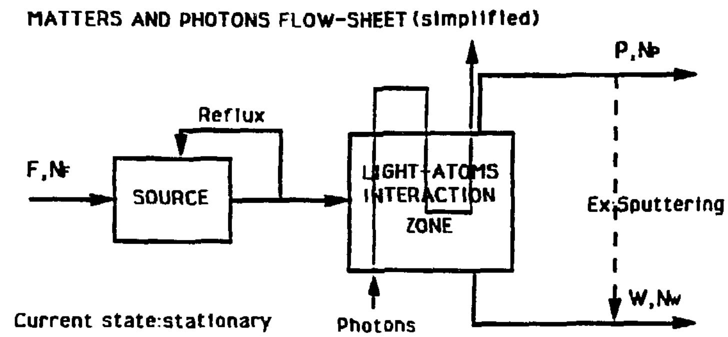
- analytical and parametrical experiments on photoionisation, plasma, extraction and collection.
- separative tests with process vapor densities and laser fluence.

Enrichment assay up to 5,5% and production between 1 and 10 g/h have been achieved.

3.4. LACAN, a general simulation code

The first target of **LACAN** computer code (Ref. 13) is to simulate global separator performances through a modelisation of the light distribution system and vapor production and selection (Fig. 11).

Fig. 11: LACAN flow sheet



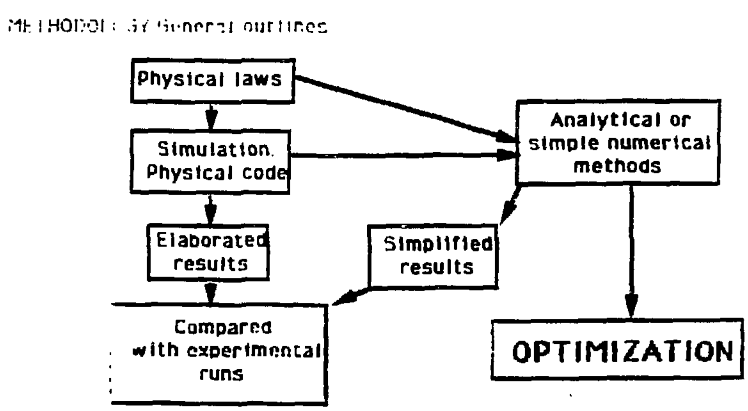
. The code has three main applications *(Fig. 12)* :

- confrontation to the results of experiments, mainly on the process pilot, for validation of the physical models introduced in this code,

- tool to design new facilities and production plant,

- process and economics optimization.

Fig.12: LACAN, methodology



For this last target technological and operationnal datas are added as well as cost functions and general economical assumption.

4. CONCLUSION

The SILVA program in France is conducted cautiously, step by step, in order to benefit most economically from the most advanced technology.

Close relationship between the Atomic Energy Comission and COGEMA, the world leader in the nuclear fuel cycle industry, ensure a good analysis of the required technical programm. The results achieved up to now give them and their industrial partners confidence in the potential success of this innovative process.

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SILVA : Atomic Vapor Laser Isotopic Separation in FRANCE

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Submit to : "LASER ISOTOPE SEPARATION"

Presentation : ORAL PRESENTATION

France has a 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 diffusion 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. A program to improve its performances and to extend its lifespan is well in progress. It will offer a fast modulation capability, with advantage of off-peak power for about 3/4 of its electrical requirements.

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, french Atomic Energy Commission has focused since 1985 on the atomic laser 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, powers supplies. Some developments have been largely subcontracted (CVL with CILAS, advanced power electronics with GEC-ALSTHOM, optics with MATRA, SAGEM...), and COGEMA and industries researchers have joined CEA teams and facilities.

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

. a progressive development of components, conducted by function analysis and process optimization studies. To make the best choice in a fast moving world, technical options for components will be kept open as long as possible, with one or two basic concepts to be periodically compared to most recent options. Experimental facilities on Saclay or Pierrelatte sites, are devoted to each process function (pumping light, tuned light, evaporation, collection of uranium, ...).

. Demonstration experiments, whose performances are ajusted to present time proven and reliable technologies and components, are limited to reasonable investments and operating costs. These experiments have been themselves split into several pieces, like a puzzle, and related facilities are devoted to each field of expertise : production and distribution of light (one tunable wawelength), handling of metal, and a Pilot for integrated separative experiences.

. Basic research in each field, and models development adjusted through specific and integrated experiments, especially in the following areas :

. uranium spectroscopy and ionization
. coherent light propagation in resonant vapor
. evaporation and vapor characteristics
. plasma physics and extraction
. liquid metal behaviour
. lasers physics.

. A General process model, including technical, operational and economical data.

Therefore fully integrated pre-industrial experience, too costly, will be delayed as long as possible, toward the end of the decade. It will benefit from the most advanced options, taking into account the difficulty of changing them once demonstration has been achieved.

The SILVA program is periodically assessed from both the scientific and the industrial point of view and a general assessment is to be made between 1996 and 1997, prior to pre-industrial development.

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