Beryllium Facilities in India

B.P. Sharma

Powder Metallurgy Division,
Vashi Complex,
New Bombay 400705, India.

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ABSTRACT

Due to its unique combination of physical, mechanical, thermal and nuclear properties, beryllium is indispensable for many applications in the fields of nuclear and space sciences. Beryllia and copper beryllium alloys have also found extensive applications in the electrical and electronic industries. Beryllium facilities at BARC have been set up to meet indigenous requirements for these materials. Besides developing beryllium technology, the project team has also designed and developed a number of special purpose equipment.

INTRODUCTION

Metal beryllium is endowed with a number of attributes. Table 1 compares some of the important properties of beryllium with those of some commonly used materials. Its thermal properties include a high melting point, a usually large specific heat, good thermal conductivity and a low expansion coefficient which is compatible with those of many other structural materials. The elastic properties of beryllium are equally striking. These include very high Young's modulus and remarkably low Poisson's ratio. Beryllium is endowed with attractive nuclear properties like a low thermal neutron capture cross-section and a high scattering cross-section. Beryllium also exhibits high permeability to X-rays and high infrared reflectivity.

Combination of thermal and elastic properties impart to beryllium an excellent dimensional stability which is quantified by its high precision elastic limit (PEL). PEL is defined as the minimum stress required

TABLE 1

Mechanical and Physical Properties of Beryllium
(Compared with some commonly used materials)

Property	Be	Al	Mg	Steel	Cu
Density (x 10^3, Kg, m^{-3})	1.81	2.7	1.74	7.86	8.89
Melting Point (K)	1556	933	923	1810	1356
Modulus of elasticity (GPa)	289.6	68.9	44.8	206.8	124.1
Linear expansion coefficient (x $10^{-6}K^{-1}$)	11.4	23.5	26.1	12.2	16.4
Poission's ratio	0.025	0.34	0.35	0.27	0.35
Ultimate tensile strength (MPa)	275.8	413.7 alloy	289.5 alloy	517.1	241.3 alloy
Thermal conductivity ($J/m^2/m/K/s$)	161.2	238.5	159.1	71.2	389.4
Specific heat (J/Kg/K)	1780	885	1030	440	385
Absorption cross section (barn)	0.009	-	-	-	-
Scattering cross section (barn)	6.9	-	-	-	-

to induce a permanent strain of E-6.

The unique combination of physical, mechanical, thermal and nuclear properties makes beryllium indispensable for many critical applications in selected areas of modern engineering, especially in the fields of aeronautics, rocketry, nuclear and space sciences /1/. High dimensional stability combined with amenability to high precision machining make beryllium an almost indispensable material for many instrumentation and structural applications in space sciences. Furthermore, the combination of dimensional stability with an infrared reflectivity is used to advantage in morrors for weather forecasting satellites. Nuclear applications of beryllium range from windows for radiation detectors to moderator and reflectors for nuclear reactors.

Beryllium metal also finds extensive industrial applications in the form of copper beryllium alloys, beryllium oxide and aluminium beryllium master alloys. Table 2 lists some of the important potential applications of beryllium materials in India.

The attributes of beryllium are to some extent offset by the difficulties in the extraction and fabrication of the metal. Beryllium is a highly toxic metal and not amenable to conventional fabrication. To circumvent the toxicity hazard, beryllium facilities have to incorporate elaborate engineering measures to ensure effective containment of beryllium materials /2/.

Beryllium metal is almost entirely processed by powder metallurgy. This is because the cast metal exhibits essentially no ductility at room temperature, and contains large columnar grains and micro- and macro-cracks. As-cast metal is extremely difficult to fabricate. Powder metallurgy is employed to produce the metal with fine grain size and isotropic structure. Beryllium oxide layer present on the powder surface inhibits grain growth during consolidation, hot working and heat treatment operations.

Beryllium facilities at the BARC Complex, Turbhe, New Bombay, were commissioned during 1982. These facilities are a collaborative venture among the three Departments of Atomic Energy, Space and Electronics. These facilities have been set up with two

TABLE 2

Potential Applications of Beryllium

BERYLLIUM METAL	COPPER BERYLLIUM ALLOY
* *Nuclear* - Windows for X-ray and radiation detectors - Neutron sources - Moderator/reflector for experimental reactors	* *Electrical & Electronics* - Contacts, springs, bimetal relays, resistance welding electrodes
* *Space* - Components for instrumentation - Mirrors for weather forecasting satellites and other applications - Structural parts of satellites	* *Mechanical* - Bearings, bushings, springs, diaphragms, non-sparking tools
BERYLLIUM OXIDE	ALUMINIUM-BERYLLIUM ALLOY
* *Electronics* - Heat sinks, substrates	- Hardener in Al-Mg alloy melting
* *Ceramic* - Refractory crucibles	

Fig. 1: Copper-beryllium alloy products produced in the Atomic Fuels Division from BPP castings.

basic aims: (i) to provide an indigenous base for beryllium technology in order to exploit the resources of beryl ore in India, and (ii) to meet the immediate requirements of beryllium materials in the country.

Today, the main products of these facilities are:

* Precision-machined beryllium components for nuclear and space research
* Copper beryllium master alloys
* Aluminium beryllium master alloys
* Copper beryllium alloy castings (Fig. 1)

Due to in-house development efforts, the facilities will in the near future be able to meet requirements for:

* Windows for hard X-rays
* Beryllium metal foils for soft X-rays and nuclear detectors (Fig. 2)
* High purity beryllia for ceramics
* Beryllia crucible

BERYLLIUM METAL PRODUCTION

The Beryllium Pilot Plant (BPP) processes beryl ore to produce vacuum hot pressed (VHP) beryllium blocks and copper beryllium alloy castings. The flow sheet adopted in the pilot plant (Fig. 3) was developed at the Metallurgy Division, BARC /3,4/. The speciality of this flow sheet is the choice of anhydrous beryllium fluoride as a common intermediate for the production of beryllium metal and its master alloys. The traditional

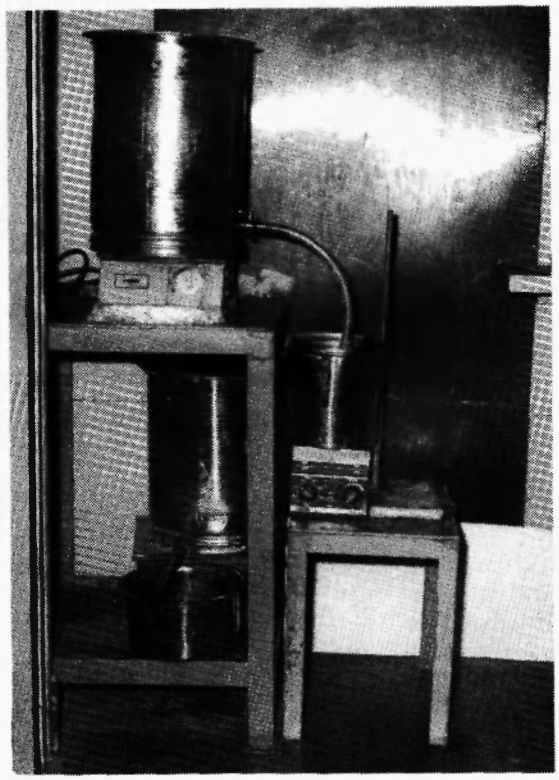

Fig. 2: Chemical milling set up for making beryllium foils.

Beryllium foils down to 2 mil thick, 10 to 15 mm diameter (vacuum leak rate less than 5 x E-9 std. cc per second) have been made. Scaling up for regular production is in progress.

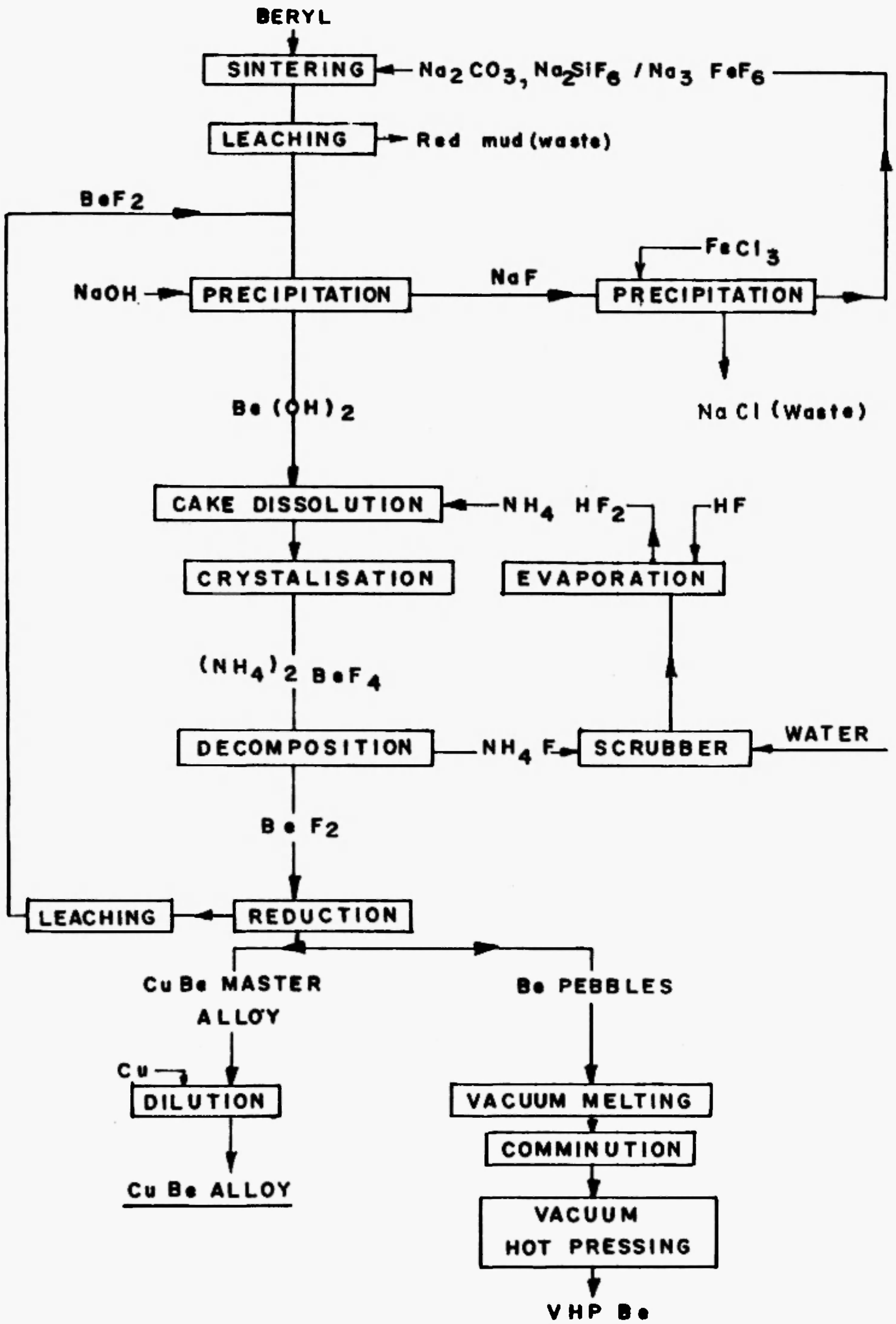

Fig. 3: Flow sheet for the production of VHP beryllium and copper-beryllium alloy castings.

way to produce Cu-Be master alloy is carbothermic reduction of BeO. However, the limited domestic requirement for beryllium metal and Cu-Be alloys did not justify independent ways to produce the two materials, and, therefore, both beryllium metal and Cu-Be master alloys are produced in the Beryllium Pilot Plant by magnesium reduction of anhydrous beryllium fluoride.

ANNUAL CAPACITY
Single Shift Operation

*	VHP beryllium	:	200 kg
	Maximum size	:	ø 200 mm x 100 mm
*	Cu-Be alloy casting	:	8 tonnes
	Rounds	:	(up to x 125 x 1000 mm
	or		
	Slabs	:	145 x 80 x 1000 mm

VHP beryllium produced at the plant has been used for:

* Making components for space research programme
* δT neutron spectrometer
* Radiation detectors

Copper beryllium alloys have been supplied to various users. Recently, Alexandrite mineral has been synthesized using high purity beryllia produced in the plant.

Besides developing beryllium technology, the project team has designed and developed a number of special equipment which include:

* A vacuum induction melting furnace (Fig. 4)
* A mechanical attritor for grinding of ceramics, metals and alloys to fine powders (Fig. 5)
* An air classifier for separating powders into different size fractions (Fig. 6)
* Pneumatic conveyors for powders
* A vacuum hot press (Fig. 7)
* Pyro vacuum treatment furnaces

Designs of these systems have been vetted through their consistent performance over the years. Their designs are available for commercial exploitation.

Another major off-shoot of beryllium activities has been the development of a process for the treatment of fluoride effluents. The process has been patented /5/.

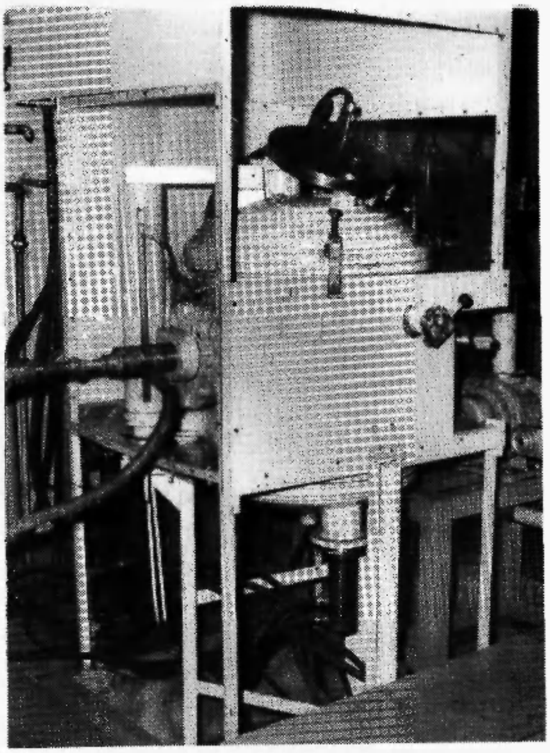

Fig. 4: Indigenously designed 4 kg beryllium capacity vacuum induction melting furnace.

BERYLLIUM MACHINING FACILITY

The Beryllium Machining Facility (BMF) processes the VHP-Be blocks from BPP to various precision components. The facility has been set up according to ISO standards and is equipped with high precision machines (Fig. 8) and a matching metrology lab (Fig. 9) to qualify the components with respect to linearity, circularity, cylindricity, concentricity, sphericity and parallelism.

VHP-Be blocks produced by BPP are subjected to quality audit, i.e., testing for density, radiography, PEL, grain size, tensile strength and percent elongation before being taken up for machining.

Beryllium blocks are dry machined because of the

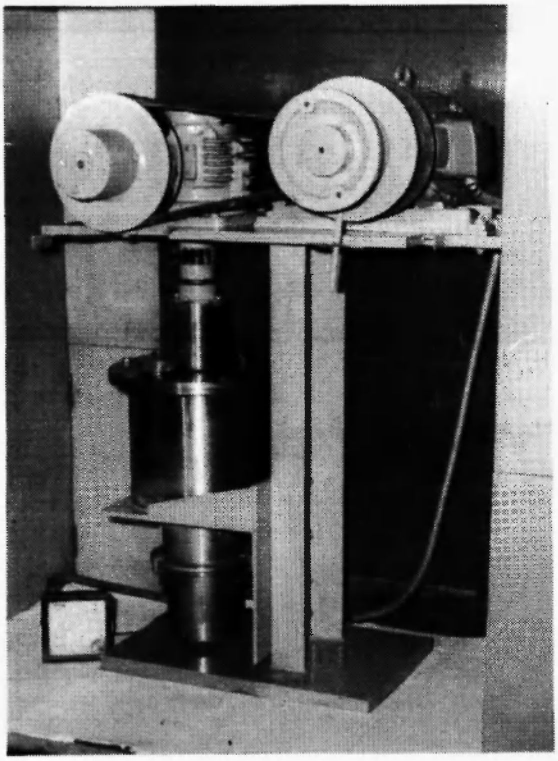

Fig. 5: 50 litres tank capacity mechanical attritor used for grinding beryllium metal swarf.

Indigenous design of attritors has been developed.

high value attached to beryllium scrap. Depending on the quality of the scrap, it is recycled at an appropriate stage of extraction/powder production.

Beryllium blocks are first semi-finished with ± 0.1 mm tolerance on all dimensions. To avoid cracking of beryllium during machining, it is necessary to use precision-ground cutting tools and well-engineered jigs and fixtures. Furthermore, cutting rates are progressively reduced as semi-finished dimensions are approached. Many relief features are machined by the spark erosion technique.

The semi-finished components are subjected to stress relieving treatment (Fig. 10) to further circumvent the brittleness problem and to retain dimensional stability in the finished components. Stress relieved components are machined to specified tolerances. The finished components are then subjected to a final stabilisation treatment (thermal cycling between 193 and 373 K) to ensure that the components will retain their dimensions in a space environment. On-line and stage inspections are conducted to ensure dimensional and geometrical accuracies of the finished components. Fig. 11 shows the machining flow sheet.

Components of the Inertial Navigation System, produced by this facility, are assembled at the Vikram Sarabhai Space Centre in Trivandrum. Rate Integrated Gyros (Fig. 12) assembled from beryllium components have been qualified for use in ASLV and PSLV launch vehicle. BMF has also produced:

* Components for neutron source for FBTR
* Thin Be section for ultra high pressure research
* Components for neutron spectrometer

BMF has initiated development of mirrors for VHRR meant for INSAT satellite (Fig. 13). The

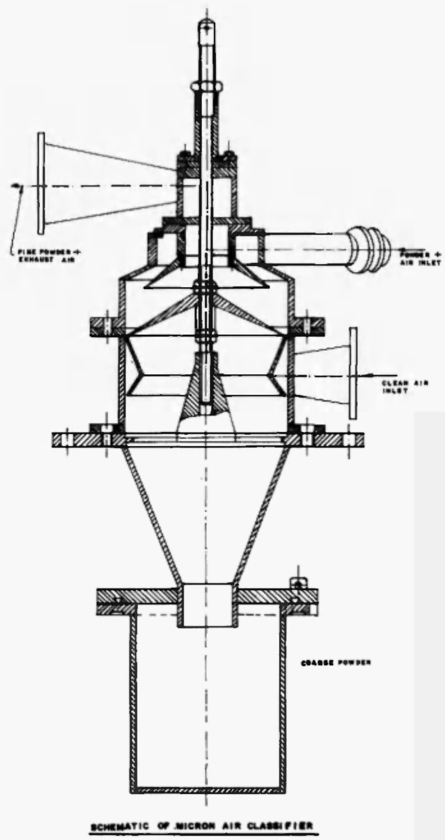

Fig. 6: Schematic of micron air classifier.

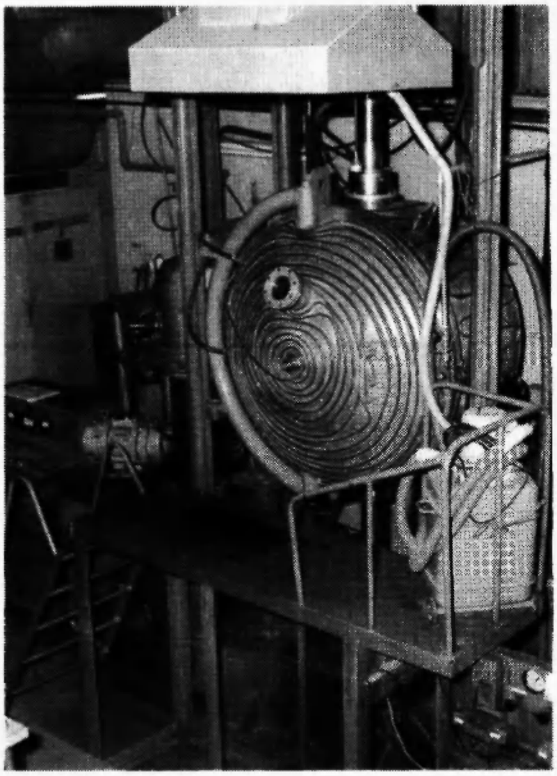

Fig. 7: Vacuum hot press used for consolidating beryllium metal powder (temperature 2000 °C, 30 tonne thrust, E-3 mbar vacuum).

process involves machining of beryllium blank, electroless nickel coating and polishing.

SAFETY ASPECTS

Beryllium, its alloys and compounds are extremely toxic. If inhaled beyond a safe limit, dust and fumes generated during operation can cause berylliosis, a chronic irreversible lung disease. Contact dermatitis also has been reported. The following limits on the occupational exposure of beryllium have been suggested by the Industrial Hygiene Authorities:

(a) Daily time - weighted average exposure over an 8 hour day should not exceed 2 $\mu m/m^3$ of air.
(b) In the neighbourhood of a facility handling beryllium materials, the monthly average concentration should not exceed 0.1 $\mu m/m^3$ of air.
(c) In liquid effluents, beryllium concentration should not exceed 0.1 μg/liter.

Exhaust ventilation and in-house effluent treatment are the principal means for achieving compliance with the above limits (Fig. 14). All operations with beryllium materials which are likely to generate

Fig. 8: View of machine shop: high precision lathes and EDM machine with high velocity dust pick-up.

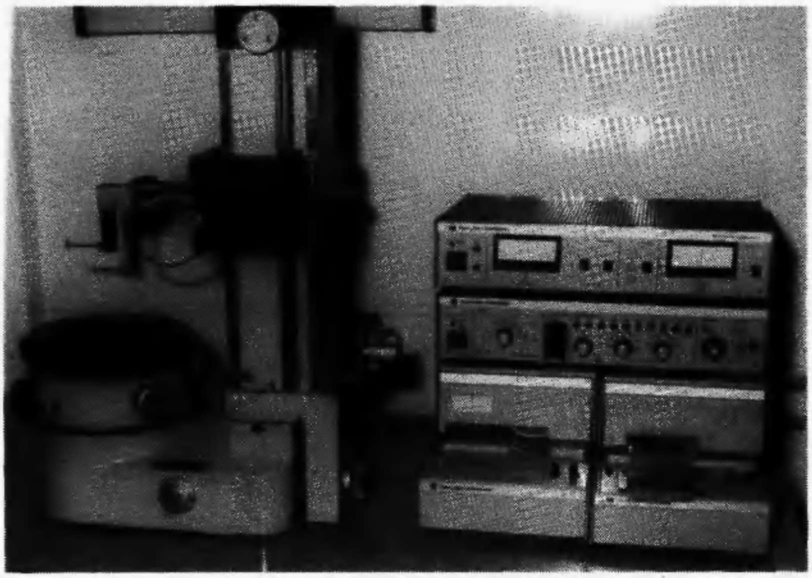

Fig. 9: Circularity, cylindricity and concentricity evaluation setup.

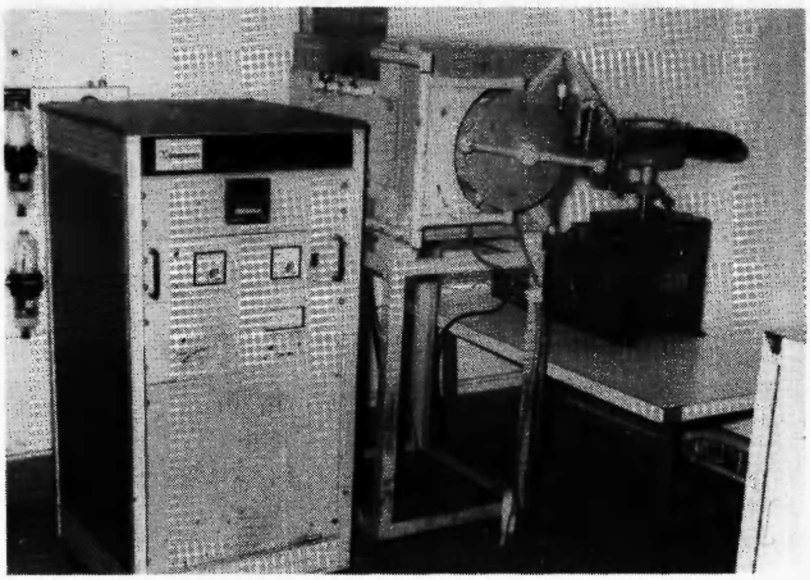

Fig. 10: Stress relieving setup with micro processor based heating and cooling rate controller.

Hot zone	:	150ϕ x 150 mm
Temperature	:	1000 °C (max.)
Accuracy	:	± 1 °C
Atmosphere	:	E-2 torr vacuum

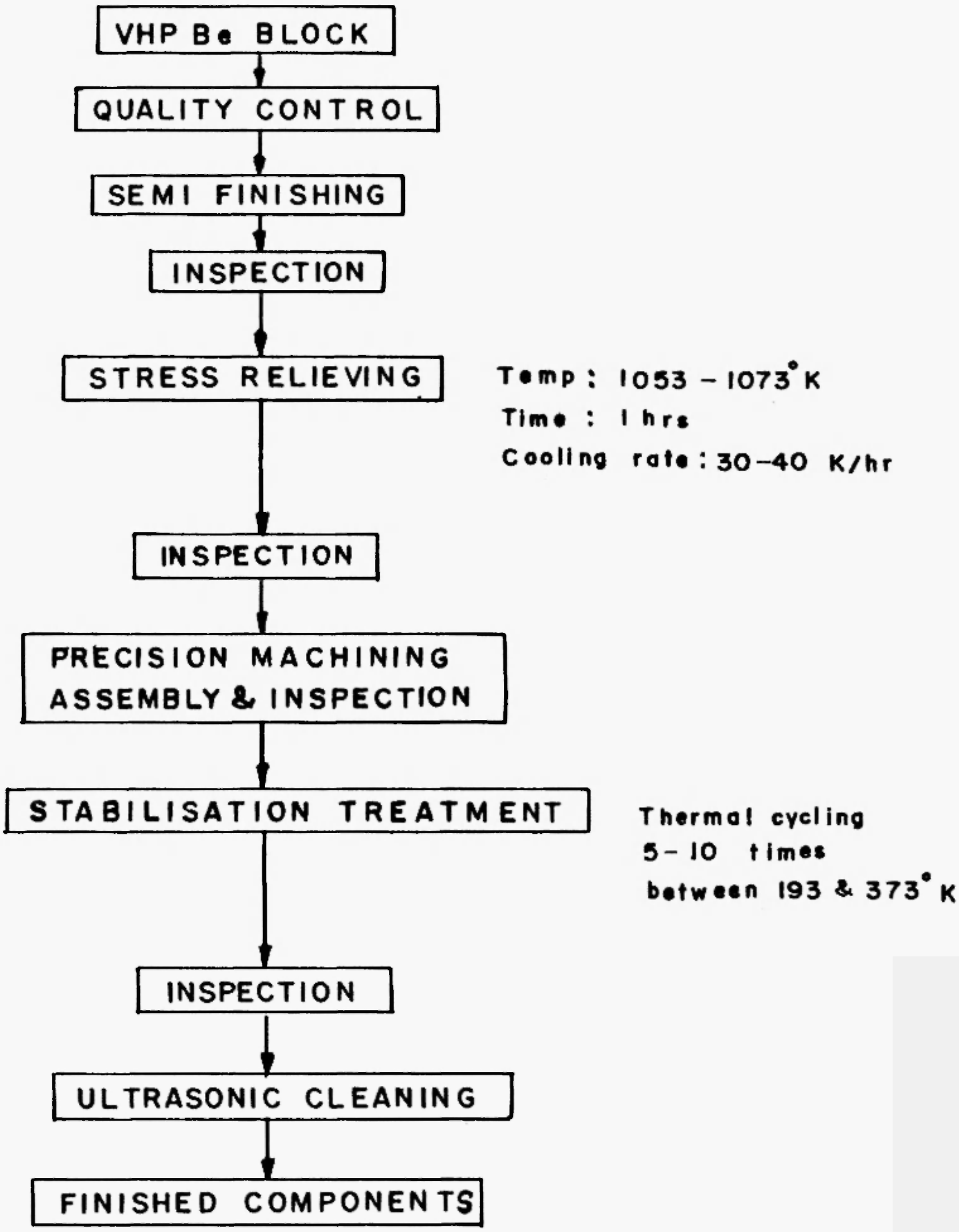

Fig. 11: Flow sheet for the machining of VHP beryllium blocks.

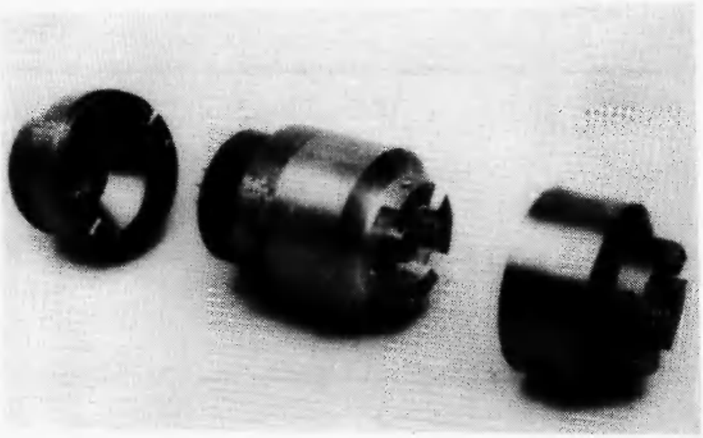

Fig. 12: Beryllium machine parts and assembled gyroscope.

Fig. 13: Prototype electroless nickel coated beryllium mirror.

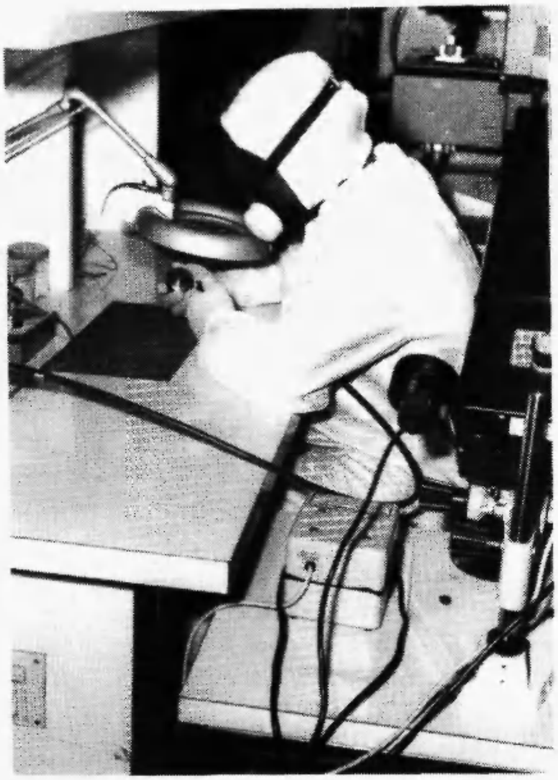

Fig. 14a: Ultrasonic deburring with down draft chip pick-up.

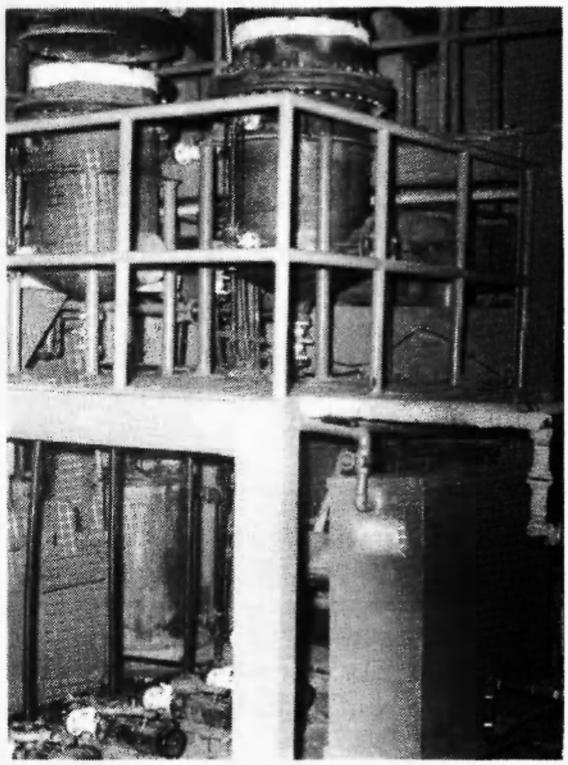

Fig. 14b: Section converting $Be(OH)_2$ to $(NH_4)_2BeF_4$. All beryllium handling equipment are exhaust ventilated.

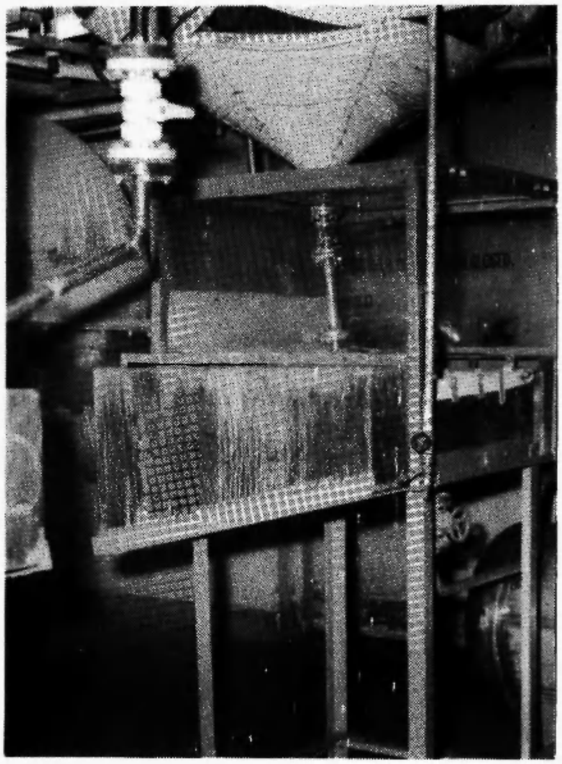

Fig. 15: Beryllium hydroxide precipitation.

An "acid egg" pan filter combination has been employed to ensure leak-free transportation of beryllium solutions.

fumes/dust are conducted in carefully engineered fume hoods/glove boxes. Use of personal safety gear is mandatory. Airborne beryllium contamination is determined regularly by the Health Physics Unit at each work station. The virtually leak-free transfer of large volumes of beryllium-bearing solutions is done by using "acid eggs" (Fig. 15) and magnetically coupled centrifugal pumps (Fig. 14b).

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