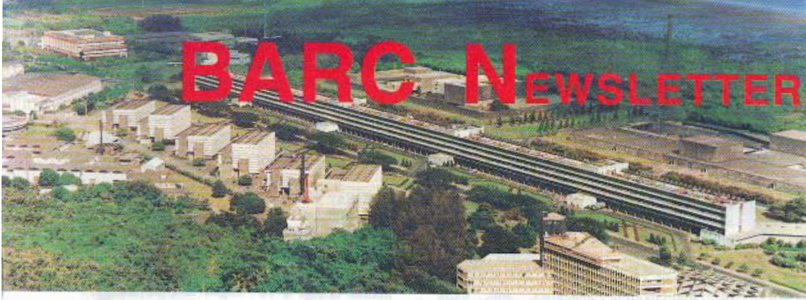

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CYGNUS X-3 : ONE OF THE HIGHLIGHT OBJECTS OF HIGH ENERGY ASTROPHYSIES

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1. Introduction

When we gaze into the night sky even with naked eyes or with ordinary (optical) telescopes, we become amazed by the splendour of the spangled canopy for obvious reasons. What we see in the process are the stars, planets and nebulae in the optical band. For practical purposes they are countless because our own galaxy (Milky Way, henceforth referred to as Galaxy) itself contains approximately 10^{11} stars. But there are many higher order wonders, albeit very few in comparison to ordinary stars, beckoning at us from the sky, which would reveal themselves not necessarily in the optical band, but in other bands such as radio, infrared, X-ray and γ-ray. Many of them are situated at far off distances in the deep space and could be in distant galaxies too. If we measure our degree of wonder with the luminosity and density of our nearest star, the Sun, there would be thousand or even million times more wonder in store for us.

Although some of these esoteric objects were theoretically predicted earlier, their actual study became really possible with the development of technology in the form of Radio, Infrared, X-ray and γ-ray telescopes

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since the sixties.We would like to specifically mention here the case of *Neutron Stars* **(NS)** whose idea was first given by the great Russian physicist Landau in 1932 and *Black Holes* **(BH),** whose idea was given by the French mathematician Laplace in 1799!. Studies of such exotic objects are important (1) in their own right, to understand their genesis and end, if any, (2) to appreciate and adjudge the basic physical theories which predict their existense, (3) to understand the high energy processes responsible for the emission of varied radiations they spew out in mind-boggling quantities, and, more specifically, (4) to undertand the origin of High Energy *Cosmic Rays* bombarding us all the time.

Having made this preamble, we would now explain the title of this article: "Cygnus X-3" stands for the 3rd X-ray source discovered in the direction of the "Cygnus" constellation (in 1967). It is one of the brightest X-ray sources in the Galaxy with bright counterparts found in infrared and radio bands too. In the eighties and early nineties, it was suspected to be the accelerator responsible for the existence of Ultra High Energy (UHE; 10^{14} – 10^{17} eV) galactic cosmic rays and γ-rays. Probably it is this cosmic source for which BARC scientists have carried out enormous amount of theoretical as well as observational research.

As, we proceed, we would go on explaining the new glossary :

- Solar Mass ($M_\odot$) = 2 x 10^{33} gm
- Solar Luminosity ($L_\odot$) = 4 x 10^{33} erg/s
- *Compactness* $C \equiv 2GM/Rc^2$, G = Gravitational constant, M = mass, R = Radius, and c = speed of light.
- **NS** = An extremely dense star (> nuclear density, ρ_{nucl} 2 x 10^{14} g/cm^3) comprising (mostly) *neutrons* where the self-gravity is resisted by the Pauli repulsive force of the neutrons. A typical NS has $M = 1.4\ M_\odot$ and R = 10 km.
- **BH** = It is believed that if a star gets squeezed so much that $C \rightarrow 1$, a stage is reached where even light can not escape and everything collapses to a central point (singularity) where the density becomes infinite. The operational definition for the surface of the BH, called, *event horizon,* has a radius $R_g = 2GM/c^2$. For a 1 $M_\odot$ BH, we have R_g, = 3 km, three times lower than that of a NS.

2. X-Ray Emission

The peak X-ray luminosity of Cyg X-3 is L_x = 2 x 10^{38} ergs/s ~ $10^5 L_\odot$. This may be compared with the total power consumed by human beings ≤ 10^{23} ergs/s and the energy released in a typical nuclear explosion ~ 10^{22} ergs. To understand the origin of the X-ray output of the X-ray binaries, note that the Compactness parameter gives a measure of the depth of the gravitational potential around an object, and while C_{sun} ~ 4 x 10^{-6} only, the value of C_{NS} ~ 0.25, and $C_{BH} \rightarrow 1$. When such compact objects happen to be located in a close binary with a loosely bound (much less compact) star like Sun, they would try to pull matter from the latter by means of strong gravitational attraction. Such mass transfer may take place directly as indicated in Fig. 1 or indirectly by capturing the wind material from the donor star (Fig. 2).

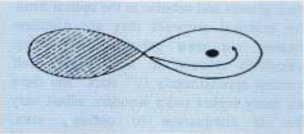

Fig. 1. A compact object pulling mass directly from an evolved and inflated Donor Star

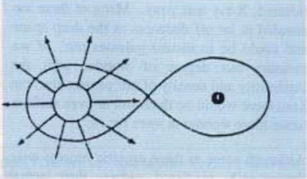

Fig. 2. A compact object accreting mass out of the intrinsic or X-ray induced extrinsic wind

The material captured by the compact object spirals in towards it and may attain enormous speeds:

$$v = \sqrt{\frac{2GM_x}{R_x}} = \sqrt{C}c \qquad (1)$$

which approaches a significant fraction of c for NS-accretion, and approaches *c* exactly for BH-accretion. Here we have used the subscript "*x*" to quantities related to the compact object. The infalling gas particles collide amongst themselves or with the surface material of the NS and get heated upto temperature as high as $\sim 10^7$ K. This results in emission of X-rays by the Bremsstrahlung process. If the mass accretion rate is given by $\dot{M}$, the net accretion luminosity is easily found to be

$$L_x = \frac{GM_x}{R_x} \dot{M} = \frac{C}{2} \dot{M}c^2 \qquad (2)$$

Note that the efficiency, η, for conversion of rest mass into radiation is *C/2* - 10% for a NS. This may be compared with the value of $\eta \sim 0.7\%$ obtained for nuclear fusion process! The emitted X-rays, on the other hand, tries to push the infalling gas away by the *radiation pressure*, and this feedback process limits the luminosity to the so-called Eddington value[1]

$$L_{ed} = 1.26 \times 10^{38} \left(\frac{M_x}{M_\odot} \right) erg/s \qquad (3)$$

And this explains the origin of the X-ray luminosity of Cyg X-3 (and many other binaries). One may now go back to Eq. (2) to infer a corresponding mass accretion rate, called, Eddington rate : $\dot{M}_{ed}$ 10^{18} *g/s* ~ 10^{-8} $M_\odot$*/yr*. However, it does not explain why the accretion rate is so high and many other details of the X-ray spectra whose discussion is beyond the scope of the *article*. Such aspects are partly related to the actual nature of the *compact object* (M_x) and the donor star **O** (M_o). To appreciate such aspects, one has to be guided by some of the basic properties of Cyg X-3. It has an orbital period of P = 4.8 hr, and this relates the length of the semi-major axis a of the binary to P by virtue of Kepler's law:

$$a = G^{1/3}(M_O + M_x)^{1/3} (P/2\pi)^{2/3} = \left(\frac{M_o+M_x}{M_\odot}\right)^{1/3} 10^{11} \text{ cm} \qquad (4)$$

This indicates that the orbit is probably not very wide, and, it is difficult to accommodate a hydrogen burning star (like Sun having a radius $R_\odot = 7 \times 10^{10}$ *cm*) unless it is of modest mass because the R increases in proportion to *M*. And such modest mass H-burning stars have no strong wind, and neither can they expand (evolve) sufficiently fast to pump mass by a direct mode (see Fig. 1). On the other hand, by the time H-burning stars exhaust hydrogen at the core they blow up part of their envelope by radiation pressure and have a fresh lease of life as a more compact ***Helium Star*** when they produce energy by fusing $3He^4 \rightarrow C^{12}$. It was on such considerations that, it was proposed that the donor star in Cyg X-3 is a He-star of $M_o \sim (3-4)\, M_\odot$[2]. However, assuming that the compact object was a canonical NS of mass $M_x \sim 1.4 M_\odot$, the binary dynamics tells that, in case M_o is so large in comparison to M_x the mass transfer process should soon be a *runaway* one inundating the NS. On such grounds, it was argued by us[3,4] that the value of M_o is likely to be considerably lower $\leq 1 M_\odot$. It was also discussed that even though such a compact star may have difficulty in supplying mass for a long time by a direct mode, it may be inflated and artificially evolved by the impingement of the radiation from the compact object[5]. In view of the importance of Cyg X-3, several international observation groups continued their efforts to "see" the donor star in optical or infrared. Such efforts bore fruit in 1992 and a most presitigous collaboration involving astronomers from Univ. California (Santa Barbara, Univ. of Iowa, Astronomy Centre (Hawaii), Univ. of Oxford, Greenwich Observatory, and Astronomical Institute, Amsterdam (in fact its Director) reported in *Nature* the detection of strong helium emission lines in the near infrared I and K band spectra of Cyg X-3[6]. Although this result would in a strict sense imply that the donor star is He-rich, a new twist was added here.

There is a kind of hot massive, (10 – 40) $M_\odot$ and exotic stars, called *Wolf-Rayet* Stars (in the name of their discoverers) which emit very strong radiation driven winds $\dot{M} \sim 10^{-5}$ $M_\odot$/yr. These stars too exhibit strong He-line emission suggesting that they too are He-rich. Astronomers have so far failed to detect any Wolf-Rayet star as a member of a bright binary, and the above mentioned collaboration found it tempting to announce that they had discovered this link in the form of Cyg X-3. In other words, they claimed that the companion of Cyg X-3 is a massive (> $10M_\odot$ Wolf-Rayet star[6]. This explanation suffered from many anomalies as noted in the News & Views section of *Nature*[7]; the first being that it is difficult to squeeze such a massive star in the narrow orbit. To further appreciate the difficulties, consider the following fact.

The period of Cyg X-3 is increasing at a fairly high rate, and in principle such a period increase might be due to the gravitational pull by a nearby massive star. If we rule out such rare possibilities, the most natural explanation for such period increase would be due to loss of mass from the binary. In the wind mode of mass transfer, there is clearly loss of mass from the system. In the direct mode too, the compact object may eject part of the mass initially captured by it, say, by radiation pressure. By using Kepler's laws and energy momentum conservation laws, (and after several simplifications) the rate of increase of period may be related to the *mass loss* rate:

$$\frac{\dot{P}}{P} = 2.2 \times 10^{-6}\ yr^{-1} \sim \frac{\dot{M}_o}{M_o} \qquad (5)$$

Therefore a value of $M_o = 10M_\odot$ would indeed demand a huge mass loss rate of few $10^{-5}\ M_\odot\ \mathrm{yr}^{-1}$. We undertook a detailed project to verify from all possible angles what the effect of this thick wind would be on the emergent X-rays. And, we confirmed that, the soft X-rays (2- 10 KeV) would be completely absorbed even if the wind was less stronger by two order (in a partially ionized cosmic gas, 2 KeV X-rays get attenuated by < lg/cm^2 of matter)[8]. This ruled out the Wolf-Rayet hypothesis. Nevertheless, the Doppler broadening of the emission lines in the Cyg X-3 IR spectra indeed suggested their origin in a wind having speed ~ 1200 Km/s. All such facts can be accommodated in a scenario in which the wind (from the donor or the accretion disc) is due to heating induced by X-rays or other radiation from the compact object and not *intrinsic to the donor.*

A detailed numerical and theoretical analysis of the problem involving the actual form of Eq.(5) (which is far more complicated) eliminated a considerable amount of the parameter space, and it followed that, for Cyg X-3, one should have $M_o << M_x$[8]. But what is the value of M_x really? If it is a NS, it is expected that $M_x \sim 1 - 2M_\odot$. On the other hand, if the compact object is a BH, no prior limit can be put on the value of M_x. Several international groups have been vying with each other to find evidence for existence for BHs in X-ray binaries (BHs in isolation can hardly be detected) and the underlying philosophy there is to infer a value of $M_x > 3M_\odot$, the upper mass limit of NSs. In fact, somewhat recently, a claim was made by another international collaboration (though a smaller one), on the basis of IR observations, that Cyg X-3 harbours a BH of mass $17M_\odot$[9]! To understand the basis of their claim, first consider the binary to consist of idealized point masses. If the spectral line is emitted by the point mass M_o the projected orbital velocity amplitude of M_o along the line of sight would be :

$$v_l = \left(\frac{2\pi}{P}\right) a_1 \sin i \qquad (6)$$

where a_1 is the distance of O from the common centre of mass (CM) and i is the angle of inclination. On the other hand, the definition of CM implies

$$a = \frac{M_o + M_x}{M_x} a_1 \quad (7)$$

Now by combining Eqs.(4), (6) and (7), we may define the so-called *mass* function of the binary:

$$f(M) \equiv \frac{(M_x \sin i)^3}{(M_o + M_x)^2} = \frac{P v_l^3}{2\pi G} \quad (8)$$

These authors estimated $f(M) = 2.3 M_\odot$ by measuring $v_l = 480$ Km/s, and then estimated $M_x = 17 M_\odot$ by considering $i = 50^\circ$ and $M = 13 M_\odot$. Again, we pointed out that there are several anomalies in the above analysis. First, assuming that $F(M) = 2.3 M_\odot$ indeed, our previous result $M_\odot << M_x$ when applied to Eq.(8) would yield $M_x < 2.7 M_\odot$ for $i \leq 70^\circ$! More importantly, when the spectral lines are emitted by a wind (with speed $>> v_l$) and not from a region close to the centre of O, this interpretation of v_l in terms of a *point mass* model is completely improper. From such considerations, it follows that the value of M_x is indeed modest, and, hence, it is *much more likely to be a NS.* If we now consider our result that in order that the X-rays can come out unattenuated $\dot{M} \sim 10^{-8} M_\odot \, yr^{-1}$ and feed this fact back into Eq.(5), it follows that the mass of the donor star is *extremely small* : $M_o \sim 0.01 M_\odot$. Few years back astronomers discovered a close binary, *PSR*1957 + 20 (here PSR stands for "pulsar" and the rest indicates the angular coordinates in the sky) containing a *radio pulsar* and a dwarf star of mass $\sim 0.01 M_\odot$ where the radiation from the pulsar is seen to excite a wind off the dwarf, which in turn has become inflated by this heating process[10].

So, in summary, our work[10] has shown that though Cyg X-3 contains an usual NS but its companion is a most unusual dwarf, and that Cyg X-3 could be an immediate predecessor for another unusual system like *PSR*1957 + 20. In fact, the value of $M_o \sim 0.01 M_\odot$ suggests that the donor star in Cyg X-3 could be a sort of *brown dwarf,* stars which can not ignite their nuclear fuel because of insufficient gravity. Only recently astronomers have been able to discover few isolated brown dwarfs.

3. UHE Gamma Rays From Cyg X-3 ?

The report of detection[11] of PeV (10^{15} eV) gamma rays, so to say suddenly electrified the world of High Energy Astrophysics in 1983. And various groups vyed one another to stake claim for detection of either UHE or VHE ($10^{11\text{-}13}$ eV) gamma rays from Cyg X-3 and many other X-ray binaries. These were explained by assuming the X-ray pulsar to accelerate protons/ions to energy as high as few 10 *PeV*, and which were then assumed to interact with the "atmosphere" of the donor star. In the process, one would produce neutral pions and which would decay to give gamma-rays : $p + p \rightarrow \pi^0 \rightarrow 2\gamma$. The reported fluxes were in general high and it seemed that a single Cyg X-3 type source can more than meet the entire UHE cosmic ray budget ($\sim 10^{39}$ erg/s) of the Galaxy and one could find hundreds of papers published in journals like *Nature, Phys. Rev. Lett., Astrophys. J.* and others either reporting such detections or their tantalizing physical implications or new models. However, even in this state of euphoria, we systematically argued that most of these reported flux values were unlikely to be true because, it would very difficult to justify them in the framework of any reasonable model[12]. And we further pointed out that the UHE gamma rays from Cyg X-3, if they are there, are much more likely to be produced by means of the *photo meson* process where the high energy protons interact with the dense X-ray field of Cyg X-3 to produce the gamma rays: p + *X photon* $\rightarrow \pi^0 \rightarrow 2\gamma$[13-18]. In fact this was one of the early occasions when the *importance of the photomeson process in High Energy Astrophysics* was highlighted. And now, ten years since then, it is common to invoke the photomeson process with γ-ray production in diverse astrophysical situations. Our model of UHE γ-ray production even in its optimal form yielded fluxes, two orders of magnitude lower than most of the early reports[18]. In fact, strictly, speaking, the first claim of UHE gamma-ray detection (and with highest flux) was due to the Gulmarg experimental group[19]. It was remarkable that they reported such high fluxes from Cyg X-3 (and other sources too) by using a simple device, essentially, containing two wide angle photomultipliers with associated electronics. However, all claims of detection of UHE/VHE gamma rays from Cyg X-3 either by Gulmarg telescope or relatively more sophisticated experiments the world over *could not be reproduced by next generation highly sensitive telescopes.* And, the same is true for all other X-ray binaries or Active Galaxies too. And it is practically certain now that most of the apparent "detections" made in the eighties or early nineties were nothing but *statistical fluctualations* of the night sky or of the cosmic ray back ground!

BARC's new generation VHE γ-ray telescope TACTIC, when calibrated and fully operational is also likely to study some of these exotic sources in a meaningful way. Nevertheless, to be realistic it must be admitted that the overall prospect of VHE/UHE γ-ray astronomy has belied its initial optimism (*a la* Cyg X-3). Because, starting from 1990, so far several new generation VHE γ-ray telescopes, despite their best efforts (and huge investments), have been able to detect *only six point* sources : 3 Supernova Remnants: Crab, Vela, and SN1006, 2 nearby Active Galactic Nuclei; Mrk 421 and Mrk 501, and 1 Radio Pulsar. PSR 1706-44. And there are unconfirmed reports of detection of VHE gamma-rays from one X-ray binary, Centaurus X-3. And in the UHE band, *not a single point source* has been detected. In contrast in the GeV region, satellite based (single) experiment EGRET has detected 157 point sources so far. In particular, the upper limit on Cyg X-3 UHE flux is much lower than what was predicted in our model , even though our model predicted a flux two orders lower than the highest reported flux! Clearly, our optimal model overestimated the gamma-ray yield and we had, in fact, pointed out the UHE gamma ray flux may be severely degraded by "magnetic pair production". Given this scenario, it is unlikely that any new VHE/UHE experiment will be rewarded with rich dividends, and, on the other hand, the satellite based (international) experiment GLAST to be launched in the next few years to probe the (10~100) GeV region is almost certain to reap a rich harvest of knowledge. Talking about satellite borne experiments, in the last few years, two experiments BATSE and BeppoSAX have revolutionized the studies of Cosmic Gamma Ray Bursts (GRBs), which, towards the end of this century (and millenium) is considered as the most outstanding and unsolved mystery of High Energy Astrophysics. GRBs are the biggest explosions in the cosmos if we exlcude the Big Bang, which might have created the Universe. The GRB of Januray 23, 1999, is estimated to have radiated 2.3×10^{54} ergs of γ-rays in a matter of few seconds, as if the entire mass of Sun has somehow been converted in pure energy in a flash!! And it is interesting to note that BARC is the only institute in India where indepth theoretical research on GRBs is being pursued 10[20-23]

Coming back to Cyg X-3, there is renewed interest in a different aspect of this source: its radio emission. Cyg X-3 has a quiescent radio luminosity of $\sim 10^{32}$ erg/s; but, intermittently it flares up with luminosities larger by thousand times! A remarkable feature about the radio flares is that they are emitted in broad twin-jet like patterns with jet speed $\sim 10^5$ km/s, roughly 1/3rd of the speed of light. We really do not understand how such jets are collimated. In summary, although we do not, as yet, understand the details of the functioning of this cosmic machine, we probably know its basic constituents: A helium rich low mass dwarf is generating a strong wind in response to the radiation emitted by the compact object of stellar mass. Although the modest mass of the compact object would suggest that it is a

NS and not a BH, is there any way we may absolutely rule out the existence of a BH not only in Cyg X-3 but anywhere?

This foregoing question is *relevant* because, so far nobody has been able to analytically solve the General Relativistic (Einstein) equations for collapse for any realistic Equation of State of the collapsing matter, and the idea of BHs, in a strict sense, remains one of the greatest hypotheses of modern science. Could there be any clue or any global property of these equations which would tell us what really happens at the end of gravitational collapse? A BH or something else? Such questions (too) are currently being pursued in the Theoretical Physics Division of BARC.

Acknowledgement: Much of the work mentioned here actually germinated in NRL, BARC, under the leadership of Dr H. Razdan. The author thanks him for providing considerable amount of academic freedom and selfless encouragement.

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INTERNATIONAL DAY FOR BIOLOGICAL DIVERSITY

On 29th December 1998 the 'Taman Nature Club' organised the International Day for Biological Diversity. Mr A. K. Anand, Group Director Reactor Projects, Technical Coordination and International Relations Group, BARC, was the Guest of Honour. He visited the site of Taman plant and appreciated the care taken. He inaugurated the Exhibition on the Biological Diversity and interacted with students, appreciating their exhibits. It was followed by presentations of the projects on Taman, Neem, Tulsi, etc. Statewise parade of the 108 species; as per recommendation by Prof. T.N. Khoshoo in consultation with Botanical Survey of India, Zoological Survey of India, National Botanical Research Institute and National Bureau of Plant Genetic Resources; as state Mammal, Bird, Wild Flower and Tree based on the nativity/endemicity and general importance for conservation by each state of India; was unique and most impressive. For the first time in India this methodology was used to sensitise and involve students in International Day for Biological Diversity celebration. Mr A. K. Anand addressed the students and appreciated their efforts.

On 23rd October 1998 students of Dnyan Pushpa Vidyaniketan, Swami Vivekanand Nagar, C.B.D. Belapur, Navi Mumbai, had visited BARC to see the trees of *Lagerstroemia speciosa* called Taman in Marathi. One seedling of Taman was handed over by Mr. A. K. Anand, to Mrs Leelavathi Vaidyanathan, Principal of the school. Taman has been recommended for conservation as 'Wild Flower of Maharashtra' by Prof. T. N. Khoshoo, Distinguished Scientist (CSIR), Tata Energy Research Institute, New Delhi, in his Presidential Address "Environmental Priorities in India and Sustainable Development" at the 73rd session of the Indian Science Congress, 1986.

On 1st November 1998 the Taman seedling was transplanted at the garden of the school. Students of the school have started 'Taman Nature Club' registered with the World Wide Fund for Nature-India.

Mr A. K. Anand, Group Director, Reactor Projects, Technical Coordination and International Relations Group, BARC, addressing at the International Day for Biological Diversity celebration.

AN MOU BETWEEN BARC AND DIAMOND & GEM DEVELOPMENT CORPORATION

A Memorandum of Understanding has been signed on January 25, 1999 between Bhabha Atomic Research Centre and Diamond & Gem Development Corporation, Mumbai for Technology Development of Diamond Polishing Scaives.

Scaives are used for polishing natural diamonds and consist of a steel disc having a groove filled with a sintered metal bonded diamond powder formulation. This formulation is used for cutting facets on the diamond gems by mounting this scaife on a polishing table with the shaft supported on bearings. The scaife is allowed to rotate at high rpm with the help of an electric motor. Presently, the diamond polishing industry largely depends on the imported scaives.

BARC will develop the technology and handover the technology package which would consist of details of system of production as well as product itself including full composition of the materials involved, their technique and propotion of mixtures, technique of mixing, grinding processing and related information. This technology will be a spin off the activities currently being pursued by Power Metallurgy Division of BARC.

CATALYTIC REDUCTION OF U(VI) TO U(IV) WITH HYDROGEN

In Purex processing of spent uranium fuel, uranium and plutonium and co-extracted in solvent TBP, leaving bulk of the fission products in the aqueous waste stream. Earlier, ferrous sulphamate was used as a partitioning agent for the reductive stripping of Pu ans Pu(III) from the co-extracted U-Pu mixture in 30% TBP.

The Trombay reprocessing plant currently employs electrolytically generated U(IV) as a substitute for ferrous sulphamate as the latter is corrosive and enhances the iron contamination of the product and salt content of the waste stream. Generally, U(IV) is generated by an electrolytic reduction process. As this method has many drawbacks, an alternate technique for the conversion of U(VI) to U(IV) in nitric acid medium by passing hydrogen gas in presence of platinum as catalyst has been evolved by Fuel Reprocessing Division in collaboration with Fuel Chemistry Division. The conditions for efficient reduction has been optimized with respect to various parameters like acidity, uranium concentration, hydrazine content, hydrogen gas flow rate, etc. Near quantitative conversion to U(IV) at 100 g/L level has been achieved. Further engineering development is in progress for large scale production of UIV) as input to Purex process.

WORKSHOP ON SAFETY LEGISLATION FOR SAFETY CO-ORDINATORS

A workshop on provisions of Atomic Energy (Factories) Rules, 1996 was conducted by Industrial Hygiene and Safety Section, Radiation Safety Systems Division, for the Safety Co-ordinators of this Centre during December 23-24, 1998.

The Workshop was inaugurated by Dr Anil Kakodkar, Director, BARC. In his inaugural address, the Director stated that safety considerations have always been of primary importance in the Centre and all the Rules which augur well for safe operations have been adopted by the Centre. Stating that many of these Rules have originated from vast experience, both in our country and countries abroad, and hence have acquired a status of universal applicability in all workplaces, he cited, as an example, the mandatory testing of equipment like cranes and pressure vessels. These equipment, if not tested and maintained in sound condition, can cause heavy damage and can even cost human lives. It would therefore be very sensible that all the workplaces where these equipment are employed should strictly comply with the mandatory testing requirements. In BARC, all the Divisions that employ these equipment may not have the testing facilities nor the expertise. In such cases, the available expertise and facilities in the Centre can be pooled together to meet the requirements, thus benefiting all. Director, BARC further pointed out that safety is not a stagnant field and with the advancement in technology and application of newer working procedures, corresponding safety measures have to be adopted. This calls for an ongoing review of the safety norms and adoption of the relevant provisions of the statutes and, where needed, developing and adopting new norms. He further said that this policy has paid rich dividends by way of excellent safety record all these years and hoped that the Centre would keep improving this record. He appealed to all Safety Co-ordinators to apply themselves in this direction. Dr Kakodkar urged the Safety Co-ordinators to be alert in their new role and wherever they find any unsafe act or unsafe condition, to get it immediately corrected, as otherwise they can cause serious injuries and losses. He advised that the unusual incidents that do not give rise to injuries should also be reviewed as they point to potentially hazardous situations.

Dr U.C. Mishra, Director, Health, Safety and Environment Group mentioned that the Safety Co-ordinator forms an important link between Division and Industrial Hygiene and Safety Section in the safety programme. He briefly described our efforts in accident prevention and stressed the need for constant vigilance to sustain the good safety performance of the Centre. Dr A.M. Bhagwat, Head, Radiation Safety Systems Division, gave the background of the workshop and discussed the expected actions from the Safety Co-ordinators. The inaugural function ended with a vote of thanks by Mr S. Narayan, Head, Industrial Hygiene and Safety Section.

BARC AND HMT SIGN YET ANOTHER MOU!

As a sequel to the conclusion of the earlier MoU for collaboration for the development and supply of upgraded Bilateral Master Slave Servomanipulators, BARC and M/s HMT Limited Bangalore have entered into a fresh Memorandum of Understanding (MoU) for the manufacture and supply of Rugged Duty Mechanical Master Slave Manipulators based on BARC technology.

Mr M.S. Ramakumar, Director, Automation & Manufacturing Group, BARC, Dr Anil Kakodkar, Director, BARC and Mr N. Ramanuja, Chairman & Managing Director, HMT after the MoU.

The MoU was signed by Dr Anil Kakodkar, Director, BARC and Mr N. Ramanuja, Chairman and Managing Director, M/s HMT Limited at Bangalore on 27th January, 1999. Mr M.S. Ramakumar, Director, Automation and Manufacturing Group, BARC, Mr B.C. Pal, Head, Manufacturing and Assembly Section, Division of Remote Handling and Robotics, BARC and Senior Executives of M/s HMT Limited, Bangalore were present on the occasion.

While the explicit and immediate purpose of the MoU is to launch a cost effective and timebound programme for the manufacture and supply of Rugged Duty Manipulators to meet certain in-house requirements in the near future, the MoU, when implemented, will also establish a competent party in the Public Sector for commercialising our technologies for other varieties of Master Slave Manipulators as well as to cater to the long range requirements of various sectors where potential for deployment of such strategic systems exists.

BARC and HMT have already initiated on schedule the activities envisaged in the MoU.

ION ASSISTED DEPOSITION OF REFRACTORY OXIDE THIN FILM COATINGS FOR IMPROVED OPTICAL AND STRUCTURAL PROPERTIES

Ion assisted deposition technique (IAD) has emerged as a powerful tool to control the optical and structural properties of thin film coatings. Keeping in view the complexity of the interaction of ions with the films being deposited, Spectroscopy Division has developed sophisticated ion sources that cater to the need of modern optical coatings with stringent spectral and environmental specifications. In the present work, the results of ion assisted deposition (IAD) of two commonly used refractory oxides, namely TiO_2 and ZrO_2, using cold cathode ion source (CC-102R) are presented. Through successive feedback and calibration techniques, various ion beams as well as deposition parameters have been optimized to achieve the best optical and structural film properties in the prevalent deposition geometry of the coating system. It has been possible to eliminate the unwanted optical and structural inhomogeneities from these films using an optimized set of process parameters. Interference mudulated Spectrophotometric and phase modulated Ellipsometric techniques have been very successfully utilized to analyze the optical and structural parameters of the films. Several precision multilayer coatings have been developed and are being used for laser and spectroscopic applications. (BARC/1999/E/001)

ANALYSIS OF URANIUM AND URANIUM METAL LATTICES USING DIFFERENT MULTI-GROUP SECTION SETS IN WIMS-D/4 FORMAT

Thermal reactor design calculations are being performed in India using the WIMS/D-4 multi group cross section library, obtained in late 60's, reflecting the status of the basic nuclear data and processing technology then available. Significant improvements in basic evaluated data files as ENDF/B-IV to VI and JEF data files etc have been made in the past four decades and the multigroup libraries have been updated world over using improved and comprehensive nuclear data processing code systems. A few of such updated multigroup cross sections in WIMS/D-4 format are available from KAERI and NEA databank sources. Theoretical Physics Division has carried out the analysis of a set of enriched UO_2 and U-metal uniform critical lattice experiments. These include TRX (4), BAPL (3) and B&W (17) lattices, 64 enriched UO_2 lattices compiled in NEACRP-U-190 report, 56 enriched UO_2 lattices and 61 U-metal lattices which were used for validating theWIMKAL-1988 library. Calculated reaction rate values from the participants of WIMS library update project (WLUP) are available for TRX, BAPL lattices. Integral data measured in the lattices of TRX, BAPL, B&W and NEACRP compliations are available in the open literature. Different calculational methods like $J^{\pm}$ and P_{ij}, and resonance interpolation schemes were examined in the theoretical analysis. Possible shortcomings of the WIMS-D/4 multigroup cross section library currently being used are also identified. (BARC/1999/E/002).

LIQUID ANION EXCHANGERS (LAE) AS NOVEL RECEPTORS FOR PLUTONIUM PERTRACTION ACROSS POLYMER IMMOBILIZED LIQUID MEMBRANES

The diffusion-limited and amine-facilitated Pu^{4+} cation permeation in nitric acid media across a polymer immobilized membrane (PILM) has been inavestigated by PREFRE Plant to quantify the membrane carrier type effects on its transport. Primene JM-T (JMT) as primary, Amberlite LA-2 (Amb LA-2) as secondary, trilaurylamine (TLA) and triiso-octyl amine (TIOA) as tertiary and Adogen-464) and Aliquart-336 (Ali-336) as quaternary amines as typical examples of nitrogen containing basic extractants are tested as the carriers. After suitable dilutions, the receptors areimmobilized on a microporous polymeric support which are held within the pores by capillary forces. Both the composition of the organic membrane solvents and type of amine carriers exert a marked effect on plutonium permeation. Recovery of Pu steadily increases from primary to quaternary amines; its permeability across PILM roughly follows the order: quaaternary > atertiary > secondary > primary; similar to that generally observed in liquid-liquid distribution experiments. More than 95% pertraction of Pu(IV) is easily accomplished using tertiary or quaternary amine as ionophores across PILM in single run employing a feed solution containing about 5 mg dm^{-3} Pu in 4 M nitric acid solution while the receiving phase is 0.1M $NH_2OH.HCl$ prepared in 0.3M HNO_3 under similar experimental conditions using other types of amines as carriers namely primary amine, Pri JM-T afforded only 19% and 49% by Amb LA-2 in 6-7h runs. Results of the detailed study to evaluate the effect of other contaminants on Pu transport are also discussed. (BARC/1999/E/003)

BARC SCIENTISTS HONOURED

Paper entitled "Tritium in Water Monitor for Measurement of Tritium Activity in the Process Water" by M. Rathnakaran, R.M. Ravetkar, M.C. Abani and S.K. Mehta of Radiation Safety Systems Division, Bhabha Atomic Researcg Centre, presented at the 24th IARP Annual Conference held at KAPS, Kakrapar during January 20-22, 1989, was one of the two papers which were selected for the best paper award.

Paper entitled "Characterisation and Evaluation of Airborne Dust Associated with Mining Operations" presented at the International Conference on Occupational Health held at Mumbai during February 4-8, 1998 by D.K. Ghosh of Radiation Safety Systems Division, Bhabha Atomic Research Centre was selected for the "Britannia Award 1998" for the best paper. This award was presented at the 49th Annual Conference of Occupational Health, held at Hyderabad during February 5-7, 1999.

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