Chapter 5

Laser Technology Development in BARC – Quo Vadis?

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5.1 Introduction

Bhabha Atomic Research Centre (BARC), Mumbai, has been pioneering the development of mission-critical lasers in India, over more than half a century. The underlying robust theme guiding the development efforts has been, secure and sustainable empowerment of the nation through deployment of advanced applications of lasers in atomic science and technologies. It is robust, as, time and over, this approach has survived the threat of subjective perceptions and priorities. Thus, in the context of commemorating 75 years of independence of India, it was felt that a historical account of the major laser development efforts that started at BARC would be both appropriate and important. The aim is not just to produce another anecdotal record for the occasional reader, but to stimulate future generations to identify and overcome the pitfalls in new technology development, so that timely, effective and continuing progress can be ensured in future pursuits.

This article briefly narrates some of the important and innovative developments in lasers, optics and instrumentation technologies at BARC, that led to creation of a wide base of expertise, and has enabled self-sustained pursuit of advanced applications for which neither commercial laser systems nor technical knowhow are available.

Besides the focused efforts in development of such specialized laser systems, many laser-based studies were, and are, being carried out in Laser & Plasma Technology Division (L&PTD), and in other groups in BARC, using commercially procured lasers. These extended over a variety of applications, such as high resolution atomic & molecular spectroscopy, non-linear optical processes, laser-based instrumentation development, photochemical process studies, material processing, plasma diagnostics, material processing with ultra-fast pulsed laser, laser based secure communication, and so on. It is not possible to cover the entire list in the detail that would do it justice. Hence, all application developments or studies involving commercial lasers, and also activities that were pursued in other divisions and groups, are kept out of the scope of this article. Thus, for example significant development of optical parametric oscillators within L&PTD was not included, where commercial Nd:YAG lasers and imported crystals were used, although new knowledge and an expertise had been generated. Another important activity that stood out was theoretical and experimental studies on non-linear optical phenomena using indigenously built lasers.

It also needs to be mentioned here, that development of Lasers in BARC was being pursued in the initial phase as a part of Electronics Division, and later in the erstwhile "Laser Section" as well as in "Multi-disciplinary Research Section", as a joint effort, which were later merged together with "Plasma Section" activities thereby forming L&PTD. Migration of activities, equipment and personnel took place again later, particularly to the new centre, Raja Ramanna Centre for Advanced Technology (erstwhile Centre for Advanced Technology), or more commonly refrred to as RRCAT, at Indore, in 1986. This article focuses on providing the historical context to "laser development" related activities which had started and continued as a part of L&PTD, in BARC, Mumbai.

At the end, a roadmap is suggested for harvesting the unique capability that has been created specifically in BARC, towards establishing a global leadership in a wide range of advanced laser based applications in nuclear science and technology, particularly in the core areas of energy, environment, societal use and security.

5.2 The First Light

Although, today laser technology development in India has come to be identified with Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, it all started [68, 69] at Atomic Energy Establishment Trombay (AEET), Mumbai, as early as in 1964-65 with a daring attempt to not only develop a Gallium-Arsenide based semiconductor diode laser, closely on the heels of its invention in 1962, but also to demonstrate its use in communication. AEET, founded by Dr. H. J. Bhabha, in 1954, was renamed as Bhabha Atomic Research Centre, in 1967, after the unfortunate demise of Dr. Bhabha. As recounted by Shri U K Chatterjee, capturing the excitement of the team.

"It was a clear winter night last December. In the dull red glow of the beacon (atop Trombay Hill", one of us was turning the controls, tensely awaiting the response. But the voice through the VHF transreceiver monotonously droned " no signal"—. As the time dragged on, agony mounted on our faces. We had never made such a long run before. The previous trial runs covered only a hundredth part of this distance. Were our calculations wrong? Doubts began to creep into our minds. All of a sudden there was an excited exclamation, "yes, yes, yes, — it is there." The keyed up tension snapped. We had made it. From the Trombay hills a message had reached the TIFR, a distance of about 20 kilometres. Today, a message sent over a distance of twenty kilometres would hardly arouse any interest. But there was something uncommon about the carrier of the message. It was a parallel invisible "light" beam emerging from a crystal chip, the size of a sand grain. It was LASER – the new tool for communications which had just made its advent in India." Continuing, in the words of Shri Chatterjee, *"This was the first such transmission outside the United States of America."*

This work, which took off from a project to develop a mobile, semiconductor diode based thermo-electric refrigerator for making blood plasma available for the forces at the frontier areas, involved a series of modular developments from scratch. It required manufacturing and preparing a laser diode from a virgin Ga-As crystal, a vacuum chamber with a cryogenic finger, building laser beam collimators and concentrators, and the electronics for modulation / demodulation to produce and detect the optical signals.

In retrospect, apart from being a truly remarkable feat in those early days, this accomplishment seems to accentuate an underlying commitment at BARC mentioned above – to aim for robust deployment of technologies side by side with excellence in the development itself.

5.3 Early Phase

This early achievement stimulated a strong interest in pursuing major activities in laser development and applications in BARC. Unfortunately, a combination of events slowed down the enthusiasm for some time. This included breakout of war with Pakistan, untimely death of the Prime Minister Shri Lal Bahadur Shastry, followed by that of Dr. Homi J. Bhabha himself, as well as local problems such as resignation of Shri M B Khambatty - the team leader for the laser project. Also, most of the electronics activities started shifting to the newly formed Electronics Corporation of India Limited at Hyderabad. BARC, however, continued to encourage and support the activity in lasers, which soon gained momentum with the induction of Dr. D. D. Bhawalkar from UK to lead the program and gather a team of scientists and engineers to spearhead an activity in this emerging topic, that held wide ranging promises. The unique multi-disciplinary expertise available in BARC even then, and which has continued to grow as a core strength today, facilitated early experimentation with a variety of laser media and laser excitation mechanisms.

By 1970, the team had set up and demonstrated a Ruby laser, a Carbon dioxide laser and a He-Ne laser in the infrared as well. Efforts were also being made to set up a liquid Nd laser, where solution of Selenium Oxy Chloride with Nd ions was used. It required elaborate handling procedures inside a glove box to prepare the laser medium. This early phase initiated the development of a unified science & engineering outlook in a specialized domain, encompassing model based design of lasers addressing the optical gain and loss processes to improve efficiency, in-house design and fabrication of specialized optics and precision opto-mechanical control and test equipment, development of specialized electrical systems, and model driven techniques to control the temporal, spatial and spectral characteristics of the output in order to best exploit the application potential. The seeds of this multi-disciplinary approach unifying various domains of science and engineering has gone a long way in creating diverse activities in lasers and applications in India.

Once long pulse laser output, albeit consisting of repetitive short duration spikes, from Ruby was demonstrated, giant compressed pulses with short duration and high peak powers were produced next, with an immediate application for ranging moving targets especially in hostile battlefield situations. By 1972, BARC had demonstrated a ruby laser range finder, and thereafter, a Nd:YAG laser range finder that was more efficient and hence more suitable for field deployment. During the beginning of the last quarter of the 20th century, two major application drivers for large scale high power laser systems holding great promise for mankind captured the attention of the scientific community, attracting avid interest among several nuclear science and technology establishments in the world. The primary attention was in developing laser driven Inertial Confinement Fusion (ICF) as a potentially superior alternative to existing concepts for controlled generation thermonuclear fusion power, such as the tokamak. The second was laser based enrichment of isotopes of importance in producing nuclear power, as well as, in industrial and medical applications. On the other hand, a more wide-spread active interest was emerging within the commercial industry at large, for laser based machining, lasers in health care, and in communication. It also became increasingly clear that each of these activities would have diverse spin-off benefits with wide ranging frontline applications in both, basic sciences and applied technologies.

5.4 The High Power Lasers – Nd:doped Solid State and Carbon Dioxide Gas Lasers

The team involved in laser development activities in BARC, which later formed the core of L&PTD, also decided to pursue some of these activities after due deliberations on resources, benefits and core mandates of the organization. This was the beginning of a new phase that attracted new talent from the freshly trained resource pool of BARC as well as from other science and engineering groups. It was learnt from theoretical and experimental work in advanced laboratories at that time, that the high laser intensity and energy required for producing the desired interactions with matter would need development of pulsed laser amplifier chains following the oscillator, in order to enhance pulse energy while retaining the temporal characteristics, and without degrading the spatial beam quality. The first major project that was taken up was to develop a 1 kJ pulse energy, 1 nanosec laser chain based upon Nd:Glass oscillator and amplifiers. As early as in 1978, a 4-stage oscillator amplifier chain producing 8 J in 20 nanosecond pulses was developed and used to carry out initial laser matter interaction studies in a specially designed vacuum chamber [70]. By mid 80s the energy was enhanced to 80 J [71, 72]. At the same time, the teams were actively engaged in building various diagnostics, optics, electro-optic switches, synchronized pulse power generators, glass micro balloon fabrication facility to be used as the fusion target after incorporating Deuterium-Tritium mixture [73], theoretical models and simulation codes, to develop the laser facility, as well as elucidate the characteristics of the fusion plasma. Several advantages of the Carbon Dioxide (CO_2) laser over the Solid state Nd laser, viz., higher efficiency, sustained availability of active medium and self-healing of optical damage, and more facile thermal management, prompted the group working on CO_2 lasers to try to develop a short pulse high power CO_2 oscillator-amplifier chain. A Transversely Excited Atmospheric pressure (TEA) CO_2 laser had been built earlier [74]. Hence, an amplifier was developed, with UV pre-ionized discharge to suppress arcing and produce uniform discharge [75]. In order to further increase the transverse dimensions of the amplifier for achieving higher pulse energy, an amplifier was built with transverse excitation discharge sustained by an electron beam produced in an adjacent chamber. When tested as a laser, it could produce 20 J in few microsecond pulses [76]. A significant improvement was achieved by using a Blumlein pulse generator, with the help of colleagues from Accelerator and Pulse Power Division [77, 78]. Further development of the pulsed CO_2 laser amplifier for fusion applications was not pursued, primarily, because of its 10 times longer wavelength, compared to the Nd laser; it was realized, later in the game, that this would substantially reduce energy coupling efficiency from the laser to the plasma produced in the fusion target, because a much lower density plasma produced in the early part of the laser pulse would reflect the rest of the pulse. As has been pointed out by Shri U K Chatterjee, the current concept of laser induced X-ray based fusion drivers, could possibly benefit from using a longer wavelength efficient laser thereby suggesting a review of the use of CO_2 or some other equally advantageous laser. In parallel to pulsed CO_2 laser development, a continuous working (CW) CO_2 laser was an attractive option because when tightly focused to produce high intensity, it could be used for machining, cutting, welding or small brazing applications, with smaller heat affected zones. Power scale-up by increasing input electrical power was limited mainly by gas heating induced laser gain reduction. Fast flow of gas mixture, cooled by recirculation through a heat exchanger to minimize gas loss especially of Helium, was not scalable as it would produce localized discharge streaks. Turbulent gas flow let in at high pressure through side orifices, requiring the use of specialized circulating Roots Blower, produced 500 W from one arm of a 4 arm laser with designed to produce 2 kW [76]. The infra-red pulsed CO_2 laser was also seen as a source for isotope separation making use of isotope shifts in molecular transitions. Towards this application potential, an effort was made to explore generation of 16 micron coherent radiation using CO_2 laser pumped CF_4 gas [79]. Before continuing with the next major development effort that had started taking root in BARC around mid 70's, viz., design and development of monochromatic, wavelength tunable dye lasers, for wide ranging applications in atomic science and technology, we conclude the discussion on the high power solid state and CO_2 laser development efforts with the following observation.

By the mid-80s, the growing realization of the impact of lasers and the rapid advancement of laser-based activities at BARC, as well as the need to develop a synchrotron light source in India, spawned the creation of Centre for Advanced Technology, renamed later as Raja Ramanna Centre for Advanced Technology (RRCAT), at Indore, with a dedicated mandate for developing laser and accelerator technology in the country. Many of the laser development and application activities shifted to RRCAT. A few niche areas of activity continued in BARC, one of which has sustained the test of time and grown into a unique, versatile and enabling capability in the country for diverse applications in nuclear science and technology, with a strong back-end synergistic partnership with RRCAT.

5.5 The Multi-colour Tunable Dye Laser Facilities

As mentioned earlier, development of high-power tunable dye lasers and their applications had been an actively pursued activity of many advanced nuclear establishments such as LLNL (Lawrence Livermore National Labs), US, CEA (French Alternative Energies and Atomic Energy Commission) in France, JAERI (Japan Atomic Energy Research Institute) in Japan, and frontline scientific institutions in the world, such as Institute of Spectroscopy Troitsk-Russia, and CERN (European Council for Nuclear Research), Geneva. L&PTD also took up the task of developing a functional capability in tunable lasers for diverse potential applications in ultratrace detection and analysis of isotopes and elements, isotope separation for nuclear energy & healthcare sectors, and, for spectroscopic applications in frontier basic sciences, as and when a need would arise. At the beginning, home-made Nitrogen gas discharge lasers producing short duration UV pulsed output at few Hz pulse repetition rate were used to excite the laser dye molecules dissolved in an organic solvent that was placed in a fused silica cuvette [80]. The first copper vapour laser producing a visible pulsed laser beam with an output power of 15 W at a pulse repetition frequency of 5 kHz was also developed in the early 80s, and immediately put to use for pumping a narrowband dye laser by using a flow-through dye cell available from a commercial laser, and a gear pump based fast circulation system for high speed flow of the dye solution through the pump excitation region [71].

Over the years since the inception of this activity, L&PTD had developed advanced facilities that now produce high average power, high-repetition-rate precisely synchronized pulses of multicolour dye laser beams using master-oscillator-power-amplifier (MOPA) chains, which are accurately tunable, and, spatially, temporally and spectrally stable. Each dye laser MOPA is excited or 'pumped' by a separate set of Copper Vapour Lasers (CVL), and later in combination with Nd:YAG solid state green lasers, both of which were obtained from RRCAT, and thereafter modified and arranged in optimized CVL-MOPA chains at L&PTD. Several units of CVLs and dye lasers are operated in the facility with a plant level robustness and reliability in batch operation over hundred hours. In achieving this performance, a specific challenge was monitoring and controlling the timing of the individual laser pulses, as well as that of the pulsed electrical discharges for the CVL units, at each oscillator and amplifier stage of both CVL and Dye laser MOPA, with nanosecond precision and stability. This was doubly important for the CVL MOPA, as temporal evolution of the dye laser pulses and hence its characteristics are strongly dependent on the CVL or DPSSL pulse shape and timing on nanosecond time scales.

The dye lasers developed at L&PTD exhibited a robust long-term spectral linewidth of 2

GHz (< 5 ppm), which can be accurately tuned with a precision of a fraction of the linewidth, from the central control, on to the atomic absorption line of interest while effectively ignoring unwanted atomic absorptions in the spectral domain. The spectrum of these lasers when observed with high resolution instrumentation, exhibited a few longitudinal modes or resonant frequencies of the laser resonator, each with a spectral width of about 100 MHz and with individual intensities fluctuating from pulse to pulse, but producing a stable comb like spectrum on a 100 pulse average. While this was not ideally suited for many applications, such as to excite atomic transitions that are in-homogeneously broadened over few GHz by hyperfine splitting, it served the purpose on average, albeit less effectively. In contrast, LLNL (US), and JAERI (Japan), CEA (France) developed single longitudinal mode (SLM) laser oscillators with specialized phase modulation techniques to tailor the laser spectrum for a more efficient coverage of the absorption spectrum for each pulse, thereby significantly improving the excitation efficiency. On the other hand, a single mode dye laser is essential for efficient excitation when the absorption line is not split up, for ensuring ultra-trace selective detection of isotopes with ultralow abundance, using techniques such as Resonance Ionization Mass Spectrometry (RIMS).

Many designs of single longitudinal mode SLM pulsed dye lasers were tried in L&PTD. A few of these designs based upon the classical Grazing Incidence Grating (GIG) or the longitudinally pumped Littrow Grating short cavity design exhibited SLM operation under highly controlled conditions on the lab bench, but the performances were too vulnerable to normal variations in pump laser power or pump pulse shape, and could not be deployed usefully for any real application. It is hoped that these design drawbacks would result in useful lessons learnt in designing complex precision devices. On a positive note, while these otherwise well-engineered SLM dye laser units, that had been productionized in numbers in anticipation, had to be abandoned in favour of regular existing designs of the dye laser, the teams came to learn of other ways of achieving excitation selectivity using cross-polarized laser beams. Having analyzed that continuing with the existing dye laser design that used a grating in grazing incidence to reduce output linewidth, would not be well suited for reliable and robust single longitudinal mode operation, it was decided to use the classic Hansch cavity with an intra-cavity interferometer, or etalon, that would make the performance much less sensitive to various perturbations. Methods to actively stabilize and tune the output frequency using phase locked etalon dither techniques were identified. *It is expected that these design changes together with new ones introduced by the designers in charge today, have borne fruit producing robust SLM operation.* Some of the key innovations in lasers, laser dyes and solvents, and custom instrumentation that were crucial in achieving a 24x7 world class plant level functionality of the facility, are briefly narrated below.

1. **CVL design modification – enhancing efficiency of CVL & Dye laser MOPA:** L&PTD modified the CVLs obtained from RRCAT to incorporate large size intra-cavity linear polarizers in the oscillators, and introduced Brewster's windows in CVL amplifiers to remove the large unacceptable window reflection losses especially at the higher power stages. At the same time, the polarized CVL pump beams produced substantially higher efficiency in each stage of Dye laser MOPA, and enabled devising a very facile online control for optimizing CVL power distribution in various dye laser MOPA units, using polarization rotation plates. This gives the facility a critical advantage in maintaining optimal operation of the dye laser MOPA chains with minimal downtime. In short this was a win-win-win design modification. Several other modifications were carried out on the CVLs based upon vulnerability analysis, that enabled reliable long term operation.

2. **Compensating thermal gradient and enhancing efficiency in dye lasers:** The most serious challenge to the performance of high average power liquid dye lasers is the severe thermally induced optical disturbance in the intensely excited laser active region.

High speed circulation of dye solution through specially designed optical cells maintains optical uniformity in the bulk of the gain region. However, the thermal gradient in the slowly moving boundary layers persists and seriously affects performance. The design developed in L&PTD, initially by Dr. L. G. Nair, who had pioneered the dye laser activity, overcomes the adverse effects of the thermo-optic gradient in the boundary layer by reflecting the dye laser radiation at the interface, which compensates the effect to first order. *Simultaneously*, this approach improves the efficiency as the dye laser radiation interacts with the highest gain residing closest to the pump window, and causes the output beam to be directed away from the broadband amplified spontaneous emission (ASE) inevitably generated from the gain region, thus improving the spectral purity of the output.

3. **A differential wavemeter** – that robustly measures both laser spectrum and small changes in laser frequency with high precision was developed and deployed to provide an online qualification of the spectra of multiple lasers that was essential for long term applications [81, 82].

4. **Closed-loop, fast-feedback wavelength stabilization**, and in-lock control of the output wavelength of the dye lasers, both with a precision of a fraction of the linewidth, was devised and deployed, operating 24x7, without which experiments on laser spectroscopy in L&PTD by several groups using the dye lasers over a period of three decades would not have been possible [83].

5. **Efficiency enhancement by polarization control:** which uses an optical polarization rotating plate innovatively inside the dye laser oscillator significantly enhancing the efficiency.

6. **Optimizing MOPA design:** wherein, an analytical model of dye laser amplifiers developed in L&PTD brought out for the first time that increasing the signal beam intensity to saturate the amplifier gain and maximize the efficiency, as prescribed by the then prevalent Lawrence Livermore model, would actually reduce the efficiency due to a nonlinear loss mechanism arising from excited state absorption which was not visualized in the earlier model [84, 85]. Also, a time dependent numerical model for the dye laser oscillator was developed [86], successfully reproducing dye laser pulse evolution and efficiency for the first time, thereby enabling virtual optimization of dye laser MOPA performance saving many man-machine hours. In principle, this generic model can be developed to serve as a virtual lab for optinizing development of lasers.

7. **Sustainable long-term operation of dye lasers – availability, stability, and safety**: Major limitations hindering industrial application of high power dye lasers are availability of high purity laser grade dyes, power deterioration due to photo-chemical degradation of laser dyes, and use of large circulating quantities of toxic and hazardous alcoholic solutions.

L&PTD has made major progress in these areas based upon extensive scientific studies and engineered testing. Indigenous bulk manufacture of several laser dyes was established in collaboration with Institute of Chemical Technology (ICT), Mumbai, securing large scale availability in face of import restrictions [86, 87]. Photo-chemical degradation of laser dyes and optical damage of dye cells used to limit high power operation to a couple of hours. These obstacles were very effectively overcome by first analyzing the underlying mechanisms, and then using a case-wise optimized solvent management, such as, chemical additives to disrupt the degradation, water solvent with novel supra-molecular additives that simultaneously prevent dye molecule dimerization and degradation, nitrogen purging of dye solution to reduce free oxygen, and periodic top-up of dye solution. Also, in comparison to conventional ethanol solvent, water provided major additional benefits as it was determined to have an order of magnitude higher thermo-optic figure of merit making thermal management much simpler, and obviated fire hazard control requirements [88]. Before moving on to the last section of this article, it would be pertinent to take note of the auxiliary developments.

In order to be able to sustain these device and application development activities, it was necessary to generate the capability to make a large number of critical components, support infrastructure, and instrumentation that would be needed to build, operate and control robust lasers with the desired characteristics for useful applications. At the same time, it was necessary to develop precision diagnostics to test and qualify the lasers as well. To meet these requirements, some other groups in BARC were assigned the responsibility to take up development of laser grade optics and highly reflective or anti-reflection optical coatings, large size optical crystals for nonlinear conversion of the output frequency, flashlamps for excitation of solid state and dye lasers, and custom-made electrical pulsed power supplies for driving designer gas discharge processes in the gas and metal vapour lasers. Vendor development, both in private and Government sector, were taken up to ensure secured availability of a large number of critical components under threat of technology denial, such as development of laser grade Nd:Glass materials (for the high power solid state laser amplifiers) at Central Glass & Ceramic Research Centre, Kolkata; High power switches at CEERI, Pilani; and, bulk synthesis of high purity laser dyes and other dyes in collaboration with Institute of Chemical Technology, Mumbai.

5.6 Future Directions in Development and Application of High Power Tunable Dye Lasers in DAE

There are two primary improvements for the pulsed, high repetition rate, dye lasers developed by L&PTD that would make these far superior to other tunable lasers such as the Ti:Sapphire, Optical Parametric Oscillator, Semiconductor diode lasers and other competitors, and make it a highly sought after equipment for the global scientific community for a large variety of applications. This would of course require suitable pump lasers for which technology is largely available in the country. In turn, the pump lasers also stand to gain substantially from design improvements that make the overall equipment more versatile.

The first is achieving a well-controlled, SLM operation with highly precise frequency tuning, for which work is expected to be in progress. The second would be incorporating phase modulation on the dye laser output to broaden the linewidth in a controlled manner. This had also been designed and initiated in L&PTD. Engineering improvements already in place may also be improved further where necessary for 24x7 hands off operation. These advancements would also help in applications such as laser guide-star based adaptive optical astronomy. On the other hand, there is also good scope for improving the solid state tunable lasers such as Ti: Sapphire lasers and optical parametric oscillators to meet the spectral, temporal, wavelength coverage, pulse repetition frequency and average power capability of dye lasers, which, however, would take substantially more work to test existing design concepts. Even, only the SLM dye lasers would be ideally suited for all the applications of Resonance Ionization Mass Spectrometry, known more commonly as RIMS, wherein a high resolution mass spectrometer (also made in L&PTD / BARC) is included as a means of isotope specific detection of ions selectively produced by the resonance ionization process. Among many other applications, these include measuring nuclear properties of exotic short-lived nuclei for testing basic science understanding, rapid ultratrace isotope analysis in Nuclear Forensics for special nuclear materials, Failed Fuel Detection and Location in nuclear power plants by tag-gas analysis, monitoring activities at nuclear reprocessing facilities, isotope abundance anomalies in planetary science and cosmo-chemistry, qualification of geological disposal containment for long lived radioactive waste, bio-medical application, and production of medial radio-isotopes of interest.

A natural question to ask would be that if advanced laboratories, such as LLNL, are attempting these applications with commercial and less sophisticated tunable lasers, where is the need for the advanced dye lasers being recommended here?

The answer lies in the current limitations of the RIMS techniques with existing lasers in simultaneously achieving desired higher degree of accuracy, high isotopic selectivity needed to push down the limit of isotopic abundance, and higher efficiency to push down the limit of detection sensitivity. The fine structure in the laser spectrum and dynamics of laser excitation processes significantly influence the resonance ionization process in ways that affect measurement efficacy. Further discussion to elucidate this aspect is beyond the scope of this article.

Considering the foreseeable impact of RIMS with advanced SLM tunable lasers, in nuclear science and technology, it is worth examining the possibility of setting up a comprehensive Advanced Tunable Laser based RIMS (**ATL-RIMS**) facility, say at GCNEP, that would attract partnership from IAEA, nuclear energy establishments of various countries, as well as CERN and other agencies interested in using RIMS for studies in exotic nuclei. In turn, given the expertise that has been developed in L&PTD, it would provide an excellent channel to lead the world in the RIMS application areas through dissemination of knowledge, equipment and expertise.

5.7 Concluding Remarks

It would be good to share a couple of important generic lessons that has been learnt during the decades of being associated with a developmental project in a new area from scratch. First, we refer to a subjective view of the organizational, or even national mandate if you like, expressed at the beginning. We rephrase it here – that the guiding mandate for new development efforts should be secure and sustainable empowerment of our nation through deployment of advanced enabling applications. And we asserted that it is robust as it seems to survive course diversions and deflections caused by subjective perceptions and priorities.