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**M E M O R A N D U M**

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*Concerne/Subject*: **Status of the RILIS laser setup and perspectives of its upgrading.**

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*This document is intended to describe briefly the evolution of the RILIS laser setup from the phase of feasibility stand to the CERN operated machine, to outline current status with emphasis on weak points and to overview ways of future developments in short-, medium- and long-term scales.*

The proposal IP50 “Development of a laser ion source” has been approved by the ISOLDE Committee in 1988. The collaboration consisting of the University of Mainz, Institute of Spectroscopy (Troitsk, USSR) and the ISOLDE Collaboration proposed to use the ISOLDE off-line separator for tests of appropriate target ion source configuration with respect to efficiency and purity. At that time collaborators from the Institute of Spectroscopy already had imported a set of copper vapor lasers (CVL) and dye lasers for the approved earlier experiment IS82 “Multiphoton ionization detection in collinear laser spectroscopy”. The off-line tests were performed in 1989. Following on-line test experiments at the SC ISOLDE-3 (1990-1991) successfully demonstrated that resonant multi-photon excitation and final ionization by pulsed lasers is an efficient tool for the production of isobarically pure ion beams.

During the migration of ISOLDE facility to the PS-Booster the laser setup was shipped to Germany, where the RILIS technique has been applied for study of short-lived Sn isotopes at GSI Darmstadt.

The installation of a permanent laser ion-source at the PS-BOOSTER ISOLDE was proposed in 1993 by the CERN-Daresbury-Leuven-Mainz-Oslo-Troitzk Collaboration as “Request for implementation and further development of the ISOLDE laser ion-source” (ISC/P47). The laser equipment was supplied from Troitsk as their contribution to the ISOLDE programme. It included three CVL operating in the Master Oscillator – Power Amplifier (MOPA) mode, three dye lasers, a set of optical and mechanical components for laser beam control and focusing. The market cost for equivalent commercial equipment was estimated as 971 kDM at that time.

First physics run with the use of RILIS has been carried out in 1994 (IS333: “Neutron-rich silver isotopes produced by a chemically selective laser ion-source: test of the r-process "Waiting-Point" concept”). The development program of RILIS was defined by the approval of the experiments proposed for the laser ion source. It consisted of testing the ionization scheme of the requested element as well as determination of the ionization efficiency, the selectivity and other operational parameters in an off-line mode. Ion beams of 20 chemical elements have been produced with RILIS at ISOLDE in the period of 1994-2002. During that time the output MOPA power increased from 40 W up to 80 W, the wavelength tuning range was extended due to an implementation of new dyes as well as by generating the second and third harmonics beams (a simplified schemes of the RILIS laser setup is given in the Appendix). The laser ion source became the most requested type of the ion source within ISOLDE community. Table 1 represents data on the evolution of the RILIS annual operation time together with the indication of ionized elements and experiment designation.

Table 1. Involvement of RILIS in the ISOLDE program.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** |
| **Laser setup operation time, hours** | 490 | 348 | 486 | 1679 | 1267 | 547 | 1203 | 1429 | 1787 |
| **Ionized elements** | AgNi | Ag | AgMn | BeCdCuNiMnZn | AgBeCdCuNiMgMnSn | AgBeCuMnPbSn | AgAlBeBiCaCoCuGaMnPb SnTl | AgBeBiCdCuGaInMgPbTbTlYYbZn | AgBeBiCdCuGaMgMnPbSnTlZn |
| **Experiments** | IS333 IS335 | IS333 IS335 IS345 | IS335 IS359 | IS304 IS333 IS335 IS345 IS353 IS358 IS359  | IS333 IS335 IS345 IS358 IS359 IS365 IS366 | IS335 IS345 IS358 IS359 IS364 IS368 IS369  | IS333 IS335 IS345 IS358 IS359 IS365 IS368 IS369 IS374 IS378 IS387 | IS333 IS335 IS363 IS368 IS369 IS373 IS374 IS387 IS393 IS403 IS406 I33 | IS302 IS333 IS343 IS345 IS359 IS360 IS368 IS369 IS378 IS381 IS387 IS390 IS391 IS393 IS396 IS401 IS403 IS404 IS406 IS410 |

The development and operation of the RILIS was provided exclusively by resources of ISOLDE Collaboration until 01.04.2000. After the transfer of the technical part of ISOLDE to PS division, the RILIS system became a CERN operated setup. Running the laser ion source requires a particular expertise, consequently, a new post of applied engineer was open, which implied 33% of working time for ISOLDE RILIS. For the round-the-clock operation of RILIS much more manpower is needed. During the physics runs on-shift service of one external specialist usually was supported by ISOLDE Collaboration.

Technically the RILIS laser system is quite old. Although it was constantly improving over the past years, the basic equipment – CVL and dye lasers – were manufactured 15 years ago. The CVL power supplies are not equipped with the voltage stabilization circuits, its cooling systems suffer from the accumulation of water electrolysis products, thyratron misfiring events randomly interrupt the RILIS operation. An electromagnetic noise produced by the CVL discharge circuits interferes in the performance of sensitive electronics of ISOLDE experiments. The dye lasers perform well, but due to the presence of high pressure dye pumps a risk of dye leak always exists.

In the frame of the ISOLDE Consolidation Project (ICP) an amount of 220 kCHF is allocated for an improvement of the RILIS. It mainly concerns improving the safety conditions and implementation of modern tools of laser beam control. Currently 97 kCHF are committed and the following milestones of the project are defined:

* Laser hut extension – done, 2001
* Remote controlled beam tuning – done, 2002
* Laser beam diagnostics – mid 2003
* CVL beam guidance (screening of the laser beams) – mid 2003
* Automated beam positioning – mid 2004
* Automated laser power monitoring – mid 2004

The reliability of the RILIS operation is reducing with the age of the lasers. A new CVL system from Russia has been ordered by the Collaboration in 1999. The quoted price for three lasers was 80000 USD. Unfortunately, the lasers were not manufactured in due time and the order is cancelled by the CERN purchasing department.

The stable performance of the RILIS setup is of great importance for ISOLDE facility, therefore all possibilities for upgrading the RILIS lasers are to be considered in order to define an optimal way. Several scenarios for that are under discussions among the experts in the field of laser techniques:

1. **Improvements in the existing CVL-dye laser system.**

The CVL power supplies can be replaced by contemporary electronic devices with the voltage and power stabilization and automatic recovering of misfiring events. The power supplies are developed and manufactured in Russia in the course of the above mentioned order. According to the recent quotation (December 2002) the price for such supply is equal to 11700 USD[[1]](#footnote-1)\*. These units can be supplied with all necessary documentation including principal schemes. Their implementation would improve the stability of RILIS operation, the effective CVL power will increase due to better timing of the laser oscillator-amplifier system.

A new designed CVL oscillator is available from the same Russian supplier for 14800 USD\*. With respect to the currently used open CVL tube it produces much less electromagnetic noise because the discharge circuit and the laser tube are incorporated in a single well screened case.

Cooling of the CVL is provided by “softened” water which, however, contains a substantial amount of dissolved bicarbonates. Since the water passes through high voltage elements an electrolytic mass transfer produces deposition of solid materials inside the cooling system. A preventive cleaning of the laser cooling system is required after about 100 hours of laser operation. This type of maintenance can be eliminated by the use of demineralized water or oil cooling system. A commercial laser chiller unit can be purchased for this purpose.

1. **Replacement of the old CVL by new CVL available on the market.**

There are very few producers of copper vapor lasers in the world. We have contacted with “Oxford Lasers ltd.”, manufacturer of CVL systems for industrial applications. The discussions of RILIS requirements with the managing director of this company were followed by the “Proposal for a high power master oscillator, power amplifier laser system” accompanied by the commercial offer. The quoted price is 246 k₤[[2]](#footnote-2)\* (app. 550 kCHF) including a starting set of spare parts and 1 year subscription to 24 hour support service. The net price of lasers is 222 k₤. The average output power of this system is specified to 80 W at the pulse repetition rate of 10 kHZ, which corresponds to the current CVL system. Its maintenance seems less time consuming and the beam quality (divergence) is better. But the pulse duration is by a factor of 1.4 longer (25 ns vs. 18 ns), which means less peak power of the laser pulses. Consequently, the efficiency of UV light generation in non-linear crystals will be reduced. Assuming a reproduction of the dye laser efficiency and an absence of the saturation in the frequency multiplication process, the expected power reduction factors are 2 for frequency doubling and 2.8 for frequency tripling processes. The ionization efficiency of some elements is directly proportional to the power of frequency-doubled UV beam (Be, Cu). Thus, for these elements such CVL replacement is not favorable. On the other hand, the ionization efficiency for many other elements probably will gain as far as more CVL power can be delivered to the ion source cavity due to the lower laser beam divergence.

1. **Replacement of the CVL by solid-state lasers.**

The dye lasers can be pumped by the solid state lasers (SSL) instead of CVL. Since the wavelengths of second harmonic generation of a Nd:YAG laser (532 nm) or Nd:YLF laser (524 nm) are close to the wavelength 511 nm of CVL, most of the currently used ionization schemes can be applied after such replacement. In addition, a much broader choice of ionization schemes will be provided by making use of the SSL fundamental frequency, third and forth harmonics beams.

In the aspects of operation and maintenance SSL would be preferential as well: they do not require long-time preheating, the power supply control is relatively simple, the level of electromagnetic noise is much lower with respect to CVL, the life-time of active elements can exceed 20000 hours.

Presently the world laser market is dominated by the SSL (24310 units sold in 2002[[3]](#footnote-3)), in particular due to the growing applications for materials processing and medical therapeutics. The SSL technology is developing and its average pricing is reducing. Still most commercially available SSL have either too low repetition rates, too long pulse duration or too low average power.

Therefore, we have sent an inquiry concerning the capability to produce a laser source specified for ISOLDE RILIS to 10 leading SSL producers. By present time four replies are received. An interest to working on this project has been expressed by Spectron Lasers Systems ltd. and by Thales Laser S.A. Main characteristics and pricing for currently available lasers **PowerGator PG532-15** of Lambda Physics AG (155 kEuro\*) and **Q201-SM-E** of Lightwave Electronics Corp. (72 kUSD[[4]](#footnote-4)\*) have been received recently. These Nd:YAG lasers provide TEM00 beams at 532 nm with the pulse repetition rate of 10 kHz and the pulse duration of 15-25 ns, which is in good correspondence with CVL pulse structure. However, the average power of about 15 W is far below of the required 80 W.

1. **Creating a new fully solid-state laser system.**

It is now possible to construct all solid state tunable laser systems, which will access the wavelengths of interest. Such a system would comprise a SSL laser followed by a number of OPOs or Ti:sapphire lasers which would then be frequency multiplied to the desired wavelength. This is an attractive long-term option. However in the short to medium term there are a number of major problems with this route that make it very unattractive for the ISOLDE facility at this time. These include:

* + The need for very high powers compared to the state of the art for these types of laser.
	+ The need to generate high powers in the UV which will require frequency multiplication from the IR.
	+ The reliability of such a system would be questionable given the powers required and the number of state of the art units used.
	+ The use of lasers of this type would probably require the ionization routes to be re-optimized as it is unlikely that the attractive wavelengths for the all solid state system would correspond to those currently obtained from the dye system.

The combined requirement for laser development and spectroscopic studies mean that a tremendous amount of R&D work needs to be undertaken before such a source could be fitted to a facility on which so much other work relies. To some extent the R&D work on the development of all solid state laser system for RILIS application is included into the program of the EU joint research project “**LAS**er techniques for **E**xotic nuclei **R**esearch” (**LASER**).

**Conclusion**

 The conditions of the actual RILIS laser system do not provide its reliable operation: lasers are old, spare parts and technical documentation are not available. The use of old laser system is risky for ISOLDE experimental program. Therefore, a laser upgrading is needed.

In the long term perspective we suppose an evolution of the setup to the full solid state laser system. The upgrading scenario has to be compatible with this direction. The investments into the RILIS setup made in the frame of ICP are important and usable for all ways of laser upgrading because of being devoted mainly to improvement of the security, laser beam monitoring and transport. As to the laser setup, we are considering following three stages:

1. Short term – improvement of the actual setup in order to provide as far as possible the conditions for reliable RILIS operation (2003).
2. Middle term – supporting the installation in reliable operational conditions until the appropriate solid state lasers will become available on the market (2004-2006).
3. Long term – replacement the laser setup by the new system which will be delivered in a result of the R&D in the frame of JRP LASER (2006-2008).

The direct replacement of the actual CVL system by the new generation CVL (Oxford Lasers solution) covers the middle term stage, but is not possible in the short term. The advantages of this option are questionable and need to be clarified in practice. In addition, this way is not compatible with the R&D required for the long term task because its high price will not probably allow to make investments in the RILIS during some following years.

The direct replacement of the actual CVL by the SSL is not possible in the short term because no commercial SSL is technically specified to the RILIS requirements.

Therefore, to cover the short term and partially the middle term stages we propose to improve the present laser setup. For this we request to purchase following equipment:

* Three new CVL power supplies, while the old ones can be left in place as spares.
* CVL – oscillator head, keeping the old oscillator for spare.

These measures will increase the stability of the laser power, reliability of RILIS operation and decrease the level of electromagnetic noise. The total cost of this equipment is about 70 kCHF.

 In the middle term we propose to buy a solid state laser those parameters are approaching the CVL ones. This laser can be used to replace the CVL beam in the last step for elements which are ionized via continuum. A gain in the ionization efficiency will be achieved due to the better focusing of the SSL beam. Thus, one CVL amplifier can be released and used either for spare or for increasing the dye laser power. By adding the SSL a supplementary power needed for further development of the RILIS (ionization of Hg, Ge etc.) will be obtained.

 The availability of the SSL at ISOLDE RILIS setup will provide a possibility to apply it for pumping the dye lasers as well as for OPO and Ti:saphire lasers and smoothly implement the all solid state laser technology. Thus, the basic equipment for the relevant R&D program will be available already at the middle term stage. The investments can be made in several steps of about 100-200 kCHF distributed over years. The total cost for the CVL replacement by SSL is difficult to evaluate in present time, but it will not probably exceed the value of 600 kCHF. The important advantage of this way is that the equipment would be entirely reused at the long term configuration.

Appendix 1. Simplified scheme of the ISOLDE RILIS laser setup.

1. \* Confidential information [↑](#footnote-ref-1)
2. \* Confidential information [↑](#footnote-ref-2)
3. K. Kincade and S.G. Anderson, Laser Focus World, 39, No.1, p.143 (2003). [↑](#footnote-ref-3)
4. \* Confidential information [↑](#footnote-ref-4)