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The HIE-ISOLDE project - cost evaluation and implementation plan

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Abstract

This High Intensity and Energy (HIE) ISOLDE project will build on the success of the REX-ISOLDE post accelerator and will focus on an upgrade of the REX facility. Highly charged ions will be provided through an improved low energy stage of REX-ISOLDE and a possible parallel installation of an ECR charge breeder. The top energy of REX-ISOLDE will be increased in two stages with a first upgrade to 5.5 MeV/u and a second to 10 MeV/u. This will be followed by a third stage in which the low energy (1.2 - 3 MeV/u) Normal Conducting (NC) part is replaced with Super Conducting (SC) cavities to increase reliability and enable deceleration to energies below 1.2 MeV/u.

The project also aims to improve the target and front-end part of ISOLDE to fully profit from upgrades of the existing CERN proton injectors, e.g. faster cycling of the PS Booster and LINAC4.

Finally, the beam quality will be much improved for ISOLDE users. The transverse and longitudinal beam emittance will be improved with a new RFQ cooler (ISCOOL). The cooler will permit a tailoring of the beam i.e. de-coupling the radioactive ion beam (RIB) time structure from the proton beam time structure and diffusion-effusion properties of the target and ion source units. A new HRS, based on the latest magnet technology, will have sufficient mass resolution to permit isobaric separation for some isotopes. A renovated Resonant Ionization Laser ion Source (RILIS) will assure full availability of this outstanding system for all users and the construction of a new laser ion source laboratory will permit new ionization schemes to be developed off-line.

The REX-ISOLDE energy and intensity upgrade

The REX-ISOLDE system [1] was initiated in 1993, construction started in 1995 and operation in 2002 and has since then in average delivered some 120 eight hour shifts of physics per year for nuclear physics. The facility has demonstrated that a compact linac combined with a cooler, buncher and charge breeder is a cost efficient and reliable option for the production of radioactive ion beams. The upgrade proposed within HIE-ISOLDE concerns the top energy and the capacity to handle the full intensity and mass range of available ISOLDE isotopes.

International Advisory Panel recommendation for linac technology

During two months in spring 2006 the AB RF group made a study of two possible technologies for the REX energy upgrade; an SC option and a NC option. The two options were presented for an international advisory panel which gave a unanimous recommendation for a super conducting linac. Quoting from the IAP report [2] conclusions: "*Indeed, the inherent flexibility of an SC-linac based on independently phased super-conducting cavities, further allowing at term (conditioned by a new injector) 100% duty factor operation, guarantees a much wider experimental programme. On the longer term, the experimental programme will quest for more precision experiments, intimately linked to high beam quality for which the SC solution has more assets*". The panel also stressed the importance of synergies with other projects at CERN, such as LINAC4 and SPL and other European projects like SPIRAL-2, SPES and EURISOL.

The REX linac upgrade

In order to meet the energy specifications maintaining at the same time the transverse and the longitudinal beam quality we propose here a superconducting linac based on quarter wave resonators which can be installed downstream the present linac and eventually replace some of the existing accelerating structure. The energy upgrade will happen in three stages; in a first stage the maximum energy will be limited to 5.5 MeV/u with energy variability between 2 and 5 MeV/u. In a second stage the final energy will be incremented up to 10 MeV/u, and in a final stage the present low energy section from 1.2 MeV/u will be changed with superconducting cavities. This latter stage will allow to decelerate and to transport the beam to energies lower then 1.2 MeV/u hence increasing the possible use of this machine.

We have chosen two gaps quarter wave resonators as building element of the linac. The reduced numbers of gaps assure a very high flexibility in terms of velocity acceptance and at the same time they assure a small number of different geometry necessary to cover the whole energy range. The energy range between 1.2 MeV/u and 10 MeV/u corresponds to a reduced velocity β between 5.1% and 14.5%. Energy of 5.5 MeV/u corresponds to a reduced velocity $\beta = 10.8\%$.

The RF cavities should give 6 MV/m as effective accelerating gradient (E_0T) with a power dissipation less then 7W. The active lengths are 180 mm for the low beta cavity and 300 mm for the high beta one. This means a total of 1.08 MV and 1.8 MV of voltage gain respectively at the optimum velocity. From the transit time factor curve it is possible to calculate the energy for different masses. Fig. 1 shows the final energy of beams with different A/q as a function of the cavities number.

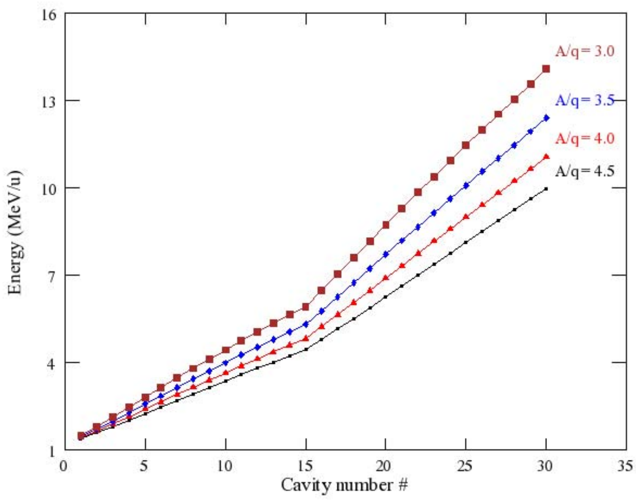

Figure 1: Beam energy as a function of the cavity number for different masses (i.e. A/q)

For the quarter wave cavity there are two different type of technologies that can be used for the production of the cavity itself, bulk niobium technology and sputtered niobium technology. From the RF point of view the performance of the cavities built with the two technologies are very similar [3], high gradient are achievable in both the cases with the only important difference that the mechanical stability and hence the RF stability is much higher in the sputtered cavities. On the other hand, the technologies for building bulk niobium cavities are already available in the industry while the sputtering technology for this kind of geometry only is available in a few research laboratories such as INFN-LNL and CERN.

The superconducting cavities require a Helium liquefier locally at ISOLDE as the total cooling power needed for the full linac is almost 450 W. The total cost for a new cryo-system is 3.35 MCHF. However, there is a suitable system available from the LEP experiment ALEPH. The system will require a complete renovation; in particular, the compressor unit must be replaced. Still, a saving of 1 MCHF can be made compared to a new system.

The new extension hall provides an additional space of around 23 × 17m^2. The magnetic rigidity for a beam of 10 MeV/u with A/q=4.5 is about $B\rho$ = 2 Tm, and in order to optimize the space availability, large bending angles are necessary. Figure 2 shows a layout of the full superconducting linac leaving most of the space in the new extension available for the experiments.

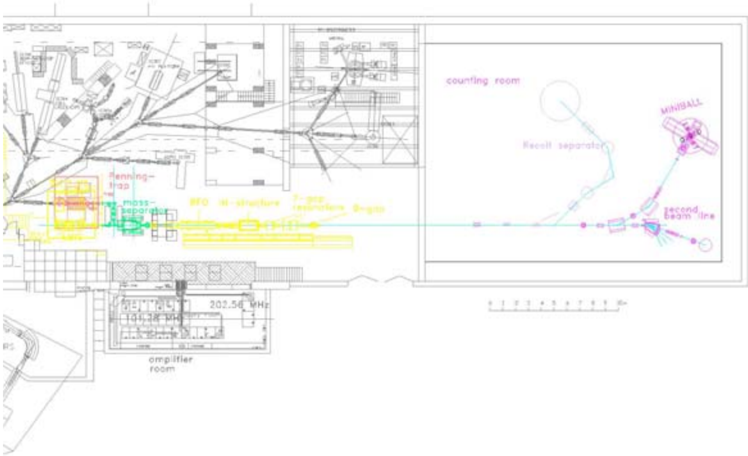

Figure 2: Layout of the new linac with a possible beam line arrangement in the experimental hall.

The REX low energy stage upgrade

The REX low energy stage consists of a Penning trap used for cooling and bunching and an Electron Beam ion source (EBIS) for charge state multiplication. This approach to charge state multiplication was pioneered at REX-ISOLDE and has proven highly successful. The EBIS source operates with UHV vacuum and as a result the extracted ion beam is close to background free with the only source of contaminating ions being the inherent isobaric contamination of the injected radioactive ion beam itself. An upgrade of the REX low energy stage is necessary to enable charge breeding of heavier elements with maintained breeding time (half life limitation) and to handle higher intensities.

To maintain breeding times for heavier ions a higher electron density is required in the EBIS source. The possible upgrades of the present source are limited and in order to meet the requirements we propose to install a new EBIS similar to the BNL TestEBIS [4]. This system has higher electron beam current density and total current so both the breeding time (reachable charge state) and the total space charge capacity can be improved with this system. The BNL EBIS has a total electron beam of 10 A (present EBIS <0.3 A) from a new type of cathode with longer life time and better reliability. The electron density is close to 575 A/cm^2 with electron beam energy of 10-20 keV. The resulting charge capacity is 1 10^{12} charges and if operated in accumulation mode together with the new RFQ cooler (see section of already financed parts of the project) the space charge limit of the existing REX penning trap can be overcome. For lower beam intensities the existing penning trap will continue to be used.

There is also a study in progress within the EURONS and EURISOL DS studies at ISOLDE of an Electron Cyclotron Resonance (ECR) Phoenix charge breeder. This system is of key importance if physics would require continuous (CW) beams from REX-ISOLDE. Such a development would mean that a Phoenix ECR charge breeder is installed in parallel to the present REX low energy stage and it would also need a new low energy acceleration stage. The ECR source can also deliver a pulsed beam in after-glow mode but at a higher A/q compared to the EBIS system. Ions at this higher A/q can only be accelerated at the REX linac after important modifications to the

RFQ and the first IH booster structure. The plan is to review the progress on the ECR towards the end of 2007 to take a final decision on a possible parallel installation of an ECR phoenix charge breeder.

ISOLDE driver and radioactive beam intensity upgrade

Faster cycling of the PS Booster

The approved proton beam based physics programme at PS, SPS and LHC will from 2008 and onwards need a large fraction of the protons delivered by the PS Booster. A continued operation of ISOLDE with the average proton beam intensity (2 microAmps) maintained will require an increase of the number of protons delivered by the PS booster. The PS booster itself can be run (with substantial system upgrades) with a 600 ms cycling with maintained beam quality and intensity but neither the injection lines nor the transfer lines from the booster can cope with this higher rate. During the 2005 run a PS booster cycle of 900 ms was tested with ISOLDE as a single user. Shared operation would require the replacement of some transfer line power supplies. However more machine studies, especially to understand the impact on PS operation are needed before implementation. We propose a rapid implementation of the 900 ms cycling of the PS Booster to assure that ISOLDE physics can continue with a driver beam of at least the present average intensity.

Linac 4

The proposed new injector for the PS Booster, LINAC 4, would result in a doubling of number of protons per pulse from the PS Booster. This will together with the faster cycling of the PS Booster permit an important intensity upgrade at ISOLDE. In average ISOLDE could hope to receive up to 6 microAmps and for limited periods even higher intensities.

Upgrade of the ISOLDE facility

To enable ISOLDE to receive the higher proton beam intensities from LINAC 4 a number of modifications of the targets and front-ends has to be done. The SC has already made a first study of the safety aspects [5] and the most costly of the required modifications is the construction of gallery above the existing ISOLDE target area in order to provide shielded access to the infrastructure and minimize the radiation dose received during routine operation and maintenance of the facility. In addition, the present target handling system has to be replaced, the front-ends which connect the targets to the separators have to be re-designed and replaced, the shielding must be improved and the targets has to be modified for the very high instantaneous proton beam intensity. The development of new targets and target materials are profiting from the on-going EURISOL [6] design study in which CERN plays a key role for target development.

ISOLDE beam quality improvements

A new high resolution separator and highly charged ions

The high resolution separator at ISOLDE has never been running with a mass resolution better than $R=m/\Delta m$ of approximately 3500 in standard operation. The reason for this is the limited higher order multi pole correction power available from the surface mounted correction coils inside the analyzing magnets. We propose to remove the correction coils and the existing flat magnet pole faces and replace them with new shaped pole faces for passive correction. We also propose an improvement of the instrumentation at the HRS with compact emittance meters to enable simple setting-up and tuning of the separator. In a longer time perspective we propose a re-configuration of the magnets with the first magnet being used as pre-separator feeding an RFQ cooler for transverse and longitudinal cooling so that isobars can be resolved with a second magnet following the cooler. We also propose the installation of an EBIT down streams in the experimental hall to provide highly charged ions for implantation at a HV platform and for mass measurements.

The RFQ cooler (ISCOOL)

The requirements of the Users on the beam quality delivered by the facility are more and more stringent. Experiments ask for better beams, with higher intensity, smaller transverse emittances or bunched beams with small longitudinal emittance (energy spread and bunch width). The device best suited to tailor low energy beams transversally and longitudinally is an RFQ cooler which delivers a small transverse emittance beam with the freedom to adapt the time structure and energy spread of the beam to meet specific user requirements. A general purpose RFQ cooler (ISCOOL) with many new features compared similar systems operating at e.g. the ISOLDE mass experiments and in Jyväskylä at the cyclotron lab has recently been developed at ISOLDE.

The RILIS and LARIS laboratories

The Resonant Ionization Laser Ion Source (RILIS) at ISOLDE is the first ion source of its type to be in standard operation at a RIB facility. It is the most requested ion source system and the stable performance of the RILIS setup is of great importance for the ISOLDE facility.

The RILIS system is based on Copper Vapor Lasers (CVL) pumping dye lasers with non-linear crystals for frequency doubling and tripling. The dye lasers can be pumped by Solid State Lasers (SSL) instead of CVL. Since the wavelength of the second harmonic generation of a Nd:YAG laser (532 nm) is close to the wavelength of CVL (511 nm), most of the currently used ionization schemes can be used after such a replacement. In addition, a broader choice of ionization schemes will be possible through the SSL fundamental frequency, third and forth harmonics beams. Regarding operation and maintenance, SSLs are better: they do not require long-time preheating, the power supply control is relatively simple, and the level of electromagnetic noise is much lower compared to CVLs. In the long term the dye lasers can probably be replaced by emerging state-of the-art wavelength-tunable solid state lasers improving further the reliability of operation.

The development of new ionization schemes and the R&D to improve existing schemes is very time consuming and as it today exclusively can be done at the on-line facility only a very limited number of hours are available each year for this work. We are presently constructing an off-line LAser Resonance Ionization Spectroscopy laboratory (LARIS) for all R&D work.

Resources and planning

Additional resources required

The resources required for the HIE-ISOLDE project has been studied by the AB department and are summarized in Table 1, Figure 4 and Figure 5. A possible implementation plan is given in Figure 3 assuming that the project starts in 2007.

Already financed activities

A proposal in the UK to finance the construction and installation of an RFQ cooler for general use at the high resolution separator at ISOLDE was successful and with additional support from the ISOLDE collaboration, LMU-Munich, the University of Mainz, the university of Jyvaeskylae. LPC in CAEN and CSNSM in Orsay it should be possible to install it on-line in the shutdown 2006-2007.

The new RILIS system and the LARIS laboratory have been fully funded by a generous grant from the Wallenberg foundation in Sweden. The lasers for the LARIS laboratory have been inherited from the SILVA project at CEA Saclay. The work to upgrade the RILIS system and to construct the LARIS laboratory is done in collaboration with the Royal Institute of Technology in Stockholm and the CEA Saclay participates in the work with the LARIS laboratory.

References

[1] Nuclear Physics and Astrophysics at CERN and beyond 2005, Edited by L.M.Fraile, CERN-INTC-2005-035

[2] International Advisory Board for the REX-ISOLDE LINAC energy upgrade, A.C.Mueller (IN2P3,Chair), R.Laxdal(TRIUMF) and O. Kester (GSI), CERN, May 9, 2006

[3] Low and Medium Beta SC Cavities, A. Facco, Proc. EPAC 2004 Paris, France.

[4] TestEBIS

[5] SC-RP report as part of accepted CERN report “HIE-ISOLDE – The technical options”, to be published 2006, draft available at http://isolde-upgrade.web.cern.ch/isolde-upgrade/HIE-ISOLDE.htm

[6] http://eurisol.org

Table 1: Summary of resources required for the project

WP	Requested budget			Received External funding	
	Staff		Material		
	Staff	Visitors	kCHF	kCHF	Source
1a. Linac prottyping and cryo design	5.5	0	425		
1b. Linac 3.0-5.5 MeV/u	25.5	0	6888		
1c. Linac 5.5-10 MeV/u	19.0	0	3350		
1d. Linac lower energies	9.5	0	1325		
1e. Beam lines for experimental area	1.0	0	500		
2. REX trap and charge breeder	12.1	3	2238		
3. TS consolidation	0.0	0	2000		
REX upgrade:	72.6	3	**16726**		
4. Targets & Front-ends	25.8	0	8100		
5. PSB 900 ms	9.0	1	2000		
Proton driver beam :	34.8	1	**10100**		
6. RFQ cooler	0.0	0	0	500	EPSCR (UK), Mains U. (DE), Orsay (FR) and ISC
7. RILIS upgrade	0.0	0	0	2400	KAW, SE
8. High charge state beams	1.1	0	800		
9. New HRS	0.8	1	1100		
Beam quality:	1.9	1	**1900**	**2900**	
10. Radiation protection consolidation	1.0	0	750		
11. Vacuum consolidation	8.5	0	1658		
Consolidation:	9.5	0	**2408**		
12. Experiment	0.0	0	0		
Total:	**119**	**5**	**31134**	**2900**	

ID	Task Name
1	**LINAC upgrade**
2	Review of linac technology
3	Decision on TDR by RB
4	Prototyping and design
5	Stage1: 3.0-5.5 MeV/A
6	Stage1b: 5.5-7 MeV/A
7	Stage2: 5.5-10 MeV/A
8	Stage3: lower energy capacity
9	**REX trap and chargebreeder**
10	Start
11	Tests of Phoenix set-up completed
12	Review of chargebreeding technology
13	REX trap and chargebreeder upgraded
14	**RFQ cooler**
15	Start
16	Commisioning completed
17	First beam into central beam-line
18	**High charge beamline**
19	Start
20	First beam to central beam-line
21	**New HRS**
22	Decisionon TDR by RB
23	Decision by ABM on final design
24	New HRS operational
25	**Targetry for linac 4**
26	Decision on TDR by RB
27	Decision by ABMB on lay-out
28	New target area operational
29	**Fast cycling PSB**
30	Start study
31	PSB at 900 ms
32	**RILIS upgrade**
33	Grant received from KWF
34	Replacement for CV lasers operational
35	LARIS operational
36	Replacement of Dye-lasers operational
37	**TS infrastructure**
38	Start
39	New transformer operational
40	New cooling water stage operational
41	New ventilation system operational
42	**AT/VAC consolidation**
43	Start
44	All roughing pumps moved from hall
45	Vaccum consolidation

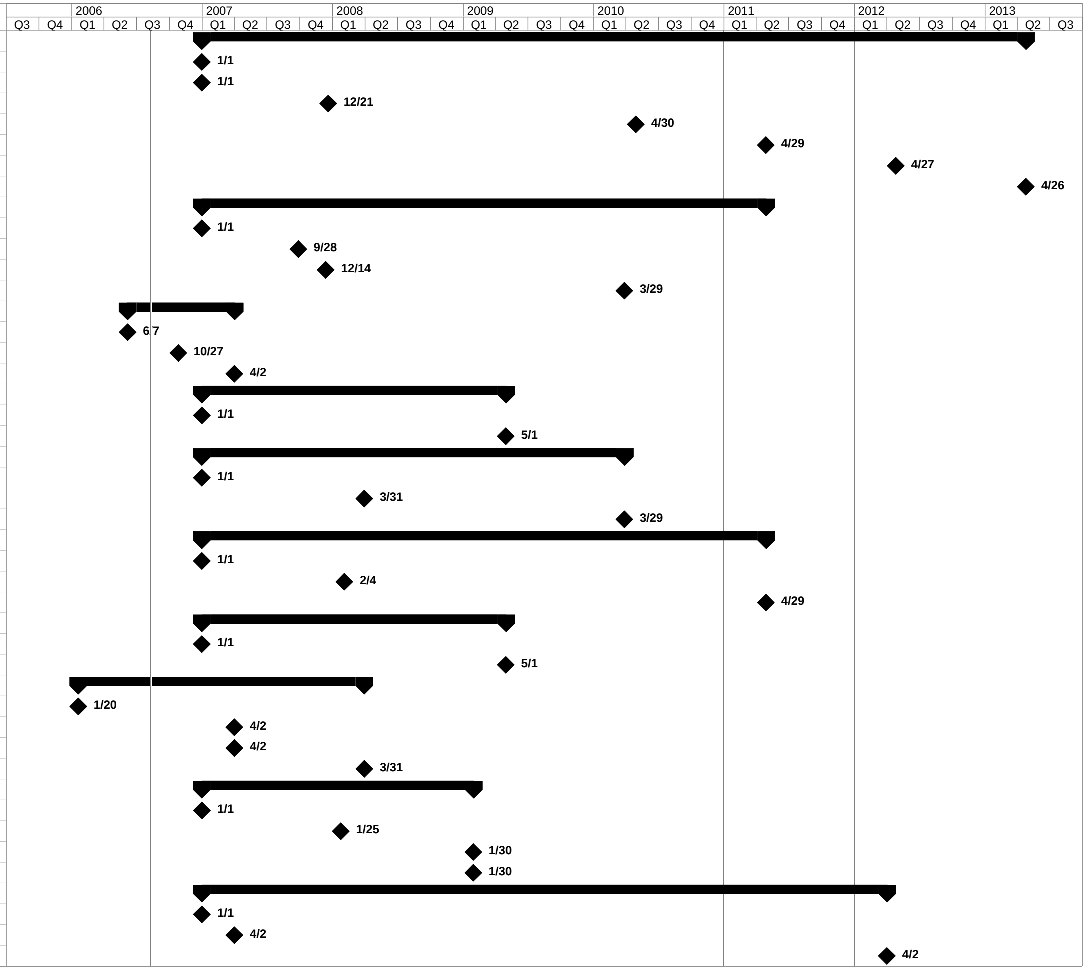

Figure 3: Implementation plan

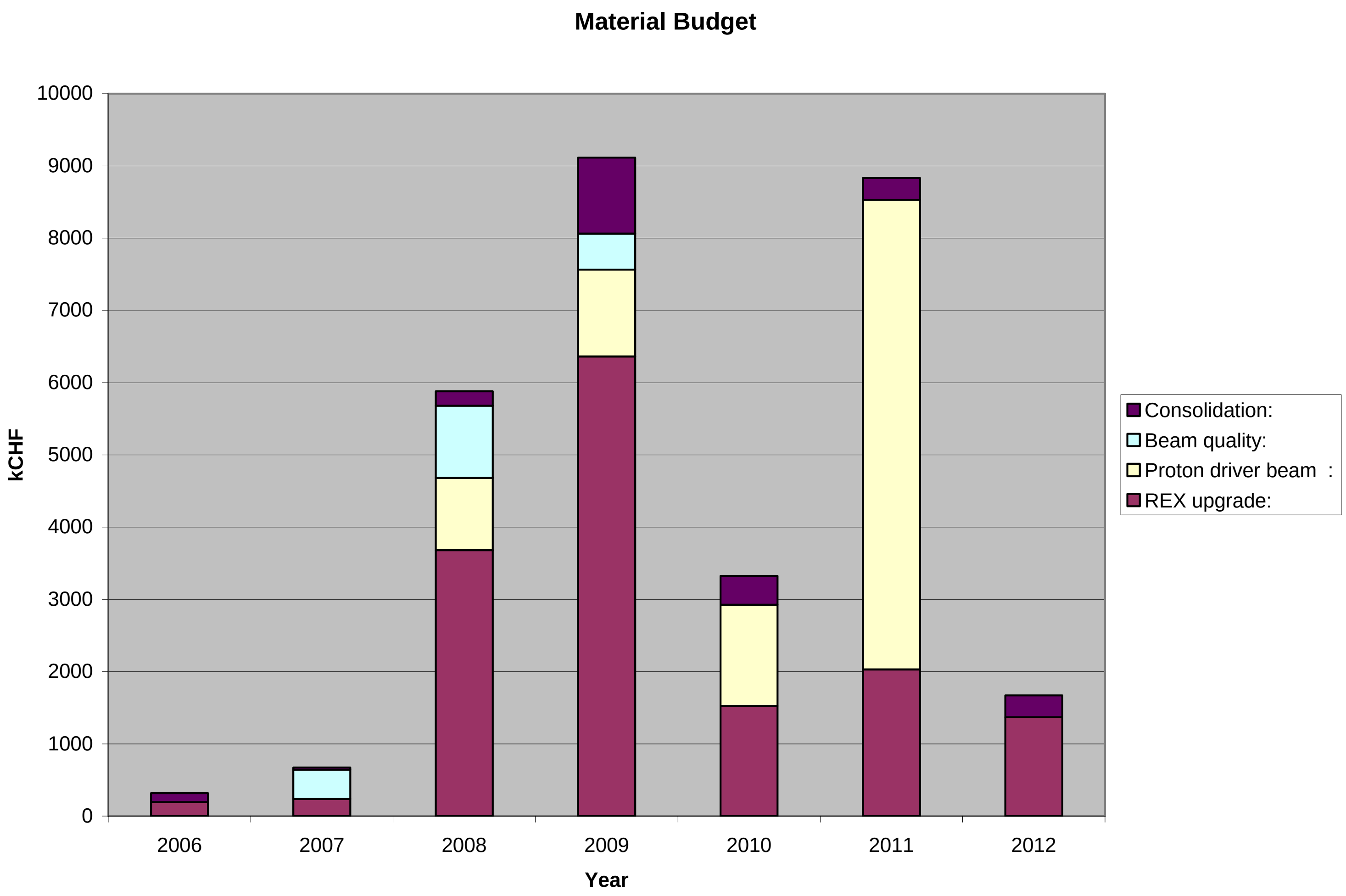

Figure 4: Spending profile for material budget in kCHF

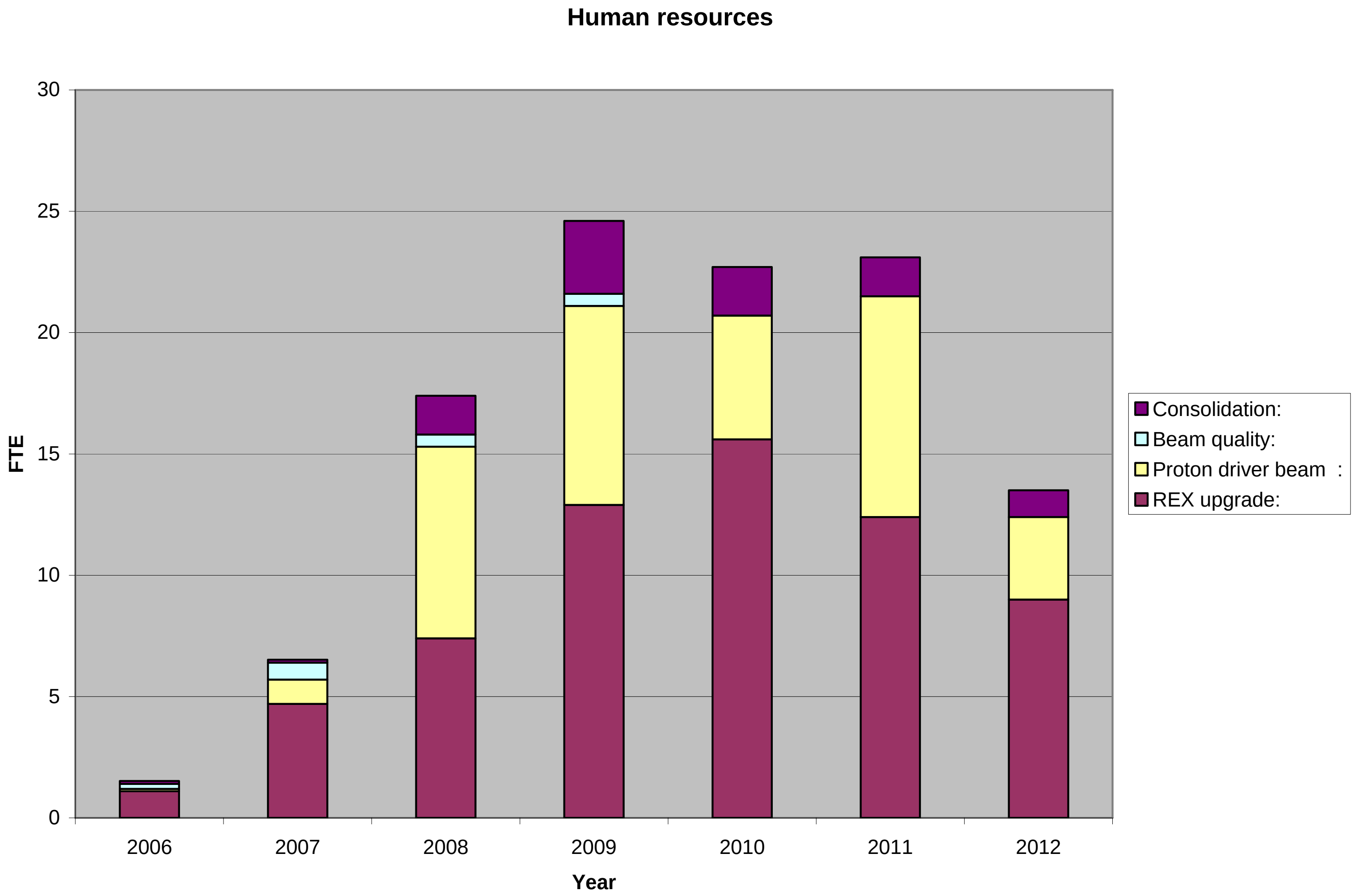

Figure 5: The requested manpower profile in FTE-years