(Distribution for conference web-site, version 2, 14/4/16)

Minutes of topical discussions at IPAB2016; version 2

These minutes were written by conveners, session chairs and conference chair, and revised by partecipants by emails. Any additional revision is most welcomed.

Some paragraphs without reference [] describe the discussion in general.
Several single paragraphs, where appropriate, try to summarize participants' comments and are referenced to participants in the usual [name] reference form.

Please refer to the web version of these minutes for last updates.

Discussion D1: new concepts and spin-off of fusion injectors
***Quaestio*:** May the large effort in developing powerful ion sources and accelerator produce some spin-off? Which application area? Questions on simulation of multicomponents plasmas (H/D/Cs, 3rd day discussions) and other session topic are also welcomed.
Conveners: P. Veltri, M. Cavenago.
Discussion:
An incomplete list of direct application of the negative ion sources and NBI technology (fusion sources in brief) was considered.

As for satellite application, ion energy is around 1 keV, so H^- source physics is relevant, but 1 MeV technology is not yet relevant [Rafalskyi]. There is a far future prospective for the MeV ion and neutral beam application in inter-stellar missions.

Some application of neutral atom sources to chronology deserves attention [Taccogna].

The large current sources may be useful in industrial applications of plasma processing; moreover understanding sheath physics (which is necessary for the analysis of extraction from a D- source) is important to understand etching of semiconductors [Tsumori]; production of intense H+/H- plasma was cited as a model black holes jets and accretion disks, and deserves attention also in itself.

Stability of source performance is important in application, so fusion source technology is helpful, of course scaled down to few mA range [Poirier].

As a further example[Cavenago], at a previous Accplic workshop at LNL (ABNP2014) A. J. Kreiner (CNEA and UNSAM, Argentina) has shown an electrostatic Tandem accelerator with 0.7 MeV terminal (in construction), aiming to accelerate 3 mA (or more) of deuteron to 1.4 MeV, for an optimized thin target target for BNCT application. In the same field, any current increase up to 10 mA may be very valuable in order to reduce treatment times, provided adequate targets are designed.

Targets for low energy beam, say below 10 MeV, are very difficult to design, since the particle range is very small, so beam is typically stopped inside target, which gives huge power deposition per volumes (1 TW/m^3) even with reasonable power flux density (1 to 10 MW/m^2).

Other medical application of 1 and 2 MeV beams, with 10 mA current should be considered; and silicon wafer treatment with beam energy higher than 600 keV, as application to solar panel implantation, 20 micron deep [Kashiwagi]; since few elements have negative ions, negative ions help in keeping beam impurities low, which is most needed in these cases.

It can be noted that H^- beam give less charging of wafer (since secondary electron emission tend to compensate beam current, while in the case of positive ions, current sum up) [Veltri]

Another aspect that can not be forgotten is that researches for negative ion sources without cesium and improved neutralization methods such as laser photo neutralization are very important for a DEMOmonstration fusion power plant and are actively studied [Kashiwagi].

Finally a source of neutral atom with energy tunable in the hundred of keV order will important for deep implantation of ceramics [Rafalskyi], with spin-off for accelerator physics and fusion source itself [Cavenago, see also Serianni in D6/D7].

As conclusion to this exploratory discussion, V. Antoni offers to prepare a slide with comparative questions on positive and negative ion beams, for next discussions (see D4).

Discussion D2: Poster highlights; free discussion

Quaestio: A space where brief oral summaries of poster may be shown, if desired, as well as other materials for discussion

Conveners: V. Antoni.

Discussions:

Brief highlights of poster P5 (2 slides) and P6 (two slides) are presented [Cavenago]. Since optimization of gas neutralizer conversion η_0 (D^- to D^0) to typically 0.5 requires a large n_g L_n product (with n_g the gas density and L_n the neutralizer length), with the inconvenient of a large D^0 to D^+ conversion [η_1 proportional to $(n_g L_n)^2$ and typically about 0.2], three novel concepts were studied: 1. mutual neutralization of D+ and D- comoving beam, capable of approaching 1.0 conversion efficiency, but typically requiring an unfeasibly huge interaction length ($L_1 \geq 0.3$ km); 2. beam of D^- is recirculated in one storage ring, and D^+ in another one, with a common straight section for mutual neutralization (with length L_1 in the 15 m order, provided number of turn $n > 20$); 3. the beam of D^- is circulated into one storage ring for at least $n > 2$ turns, with a neutralizer cell in one long straight section, with a comparatively low gas density; in this case, η_1 is considerably reduced, while η_0 can reach 0.75, as indicated by a simulation of a two bending magnet storage rings (M=2). For a rectangular lattice with M=4 bending magnet, linear orbit stability is also completed; simulation of large orbit deviation is well in progress.

Gas flow into bending magnet and related parasitic neutral conversion are a possible limit; questions about stability of secondary plasma was also noted [Tsumori], which need careful consideration in third design phase, where also plasma neutralized and open magnet yoke can be considered.

Returning to general application discussion, beam up to 5 MeV of d (or p) are important for neutron production, for security application or a simple neutron source [poster P2, Fagotti].

Other application may include writing on diamond chip, for biological application [Canella]. Systematic discussion of V. Antoni list is postponed to discussion D4.

Discussion D3: application of accelerators

Conveners: A. Faus-Golfe, M. Cavenago

Quaestio:

Which applications of accelerators will benefit from large current? Which perspectives for development? Which new collaboration themes (between participants) can be identified?

Discussion

The relation with industrial world should be careful organized, on specific goals; it should be nice to know which accelerator (or innovation) has to be developed [F. Poirier].

As regards to radioisotope production, the talk of A. Duatti gives an excellent review, which can be taken as hints for starting specific projects; "sociality" aspect is very important, as well emphasized in the UK praxis of technological transfer [A. Faus-Golfe].

Concerning neutron applications, a preferential requirement for the primary accelerator is the capability to operate in pulsed mode, to enable time-of-flight detection (TOF); current up to 70 MeV and 700 microA (Legnaro cyclotron design) looks very interesting for application, as well as ^{236}U targets [Loong].

The beam dynamic losses, especially in cyclotron, should be carefully studied, as well their effect on construction materials; simulations are important [F. Poirier].

The beam diagnostics are not optimized for this kind of uses; R&D on this aspect is crucial [A. Faus-Golfe].

Simulation are of course a keystone of LNL and RFX groups, as well as in other labs (see discussion D6); about radioisotope production, a simple concept to start with may be a very thin target of 99Mo, to be internally placed inside a FFAG cyclotron at 14 MeV where 99mTc production cross section is maximum (or at slightly higher energies), with possible recirculation and reacceleration of protons to the same energy by the FFAG itself; maybe this is a collaboration theme [Cavenago].

For Fixed Field Accelerating Gradient accelerator (FFAG) see D. Bruton presentation.

Another interesting radioisotope target is a sandwich of thin targets, to use one proton beam for several radioisotope productions, ordered for decreasing value of optimal production energy [Duatti].

Diagnostic of neutrons is also important theme; a good monitoring of fusion plasma may be achieved by GEM (Gas Electron Multiplier) based detectors.

Conclusions of discussion D3:

Concerning the radionuclides for medical applications various aspects have to be considered:

- new radionuclides in accordance with medical doctor community have to be investigated
- new modes of production with accelerators for the most used as ^{99}Tc in an efficient and reliable way to avoid the dependences of the reactors.

- the creation of a panel with all the "actors" could be a constructive mode of attacking the problem
- Beam losses has to be taken into account in the process of production
- Beam diagnostics is a niche of investigation, especially for neutral beams
- The industrial transfer aspect is an aspect that we have to take into account in the next future. This aspect if exploited could be a source of future financing for some projects.

Discussion D4: industrial application of intense (negative) ion source

Conveners: M. Cavenago, V. Antoni

Quaestio:

Conclusive discussion on applications shown at the conference. Perspectives of ion sources for hydrogen and deuterium, and other elements (negative ion, and/or positive). Perspective of (new) collaborations.

Discussion

A table of items for the discussion prepared by V.Antoni is shown and is filled and updated as a summary (see Table I below)

About ion application, micrometric lamination by Bragg peak induced defoliation (or exfoliation) is noted; clearly a monochromatic peak at $E=E_1$ in the spectra of the energy/atom E and lack of impurities are most preferable qualities; to this respect, H^+ sources may have H_2^+ and H_3^+ components, with peaks respectively at $E=E_1/2$ and $E=E_1/3$, while neutralization inside accelerator (which give a diffuse lower energy term in the energy spectra) may be larger for H^- sources than for H^+ sources, at some energies; so comparison of H^- and H^+ for this application class depends on energy [Kashiwagi, Fantz].

About emittance, H^- source can reach remarkably low emittance, but this requests a correctly formed extraction meniscus [Kashiwagi, Tsumori] and demands a better effort in theoretical investigation.

About space charge compensation: in negative ion beams, since the compensating specie are heavy ions (and not electrons), the overcompensation (101% or more) is possibile, which is a difference with respect to positive ion beams [Veltri].

About theoretical items to be clarified, we must emphasize coupling of radiofrequency to plasma and the existence of a preferable or optimal heating frequency for ICP (inductively coupled plasmas); of course, as a function of source size [Fantz].

As a matter of fact, for detailed geometries (2D and 3D), a law for the plasma conductivity σ is extrapolated from simplified cases (typically 1D), with many possible options: σ may be a scalar, a tensor, or even a nonlocal operator, may include anomalous heating or field gradient or only gas collision, in a vast range, as a quick browsing of existing literature will make manifest [Cavenago].

A similar situation exists for ECRIS (Electron Cyclotron Resonance Ion Source), and presentations to this conference documented recent results and progresses [Mascali], where frequency is a very sensitive parameter, as verified in experiments.

Also kinetic effects and 3 temperature distributions are important [Gammino].

It is agreed that this frequency question so much deserves further consideration, and can be continued in Wednesday workgroup as scheduled.

To continue the discussion of technology, efficiency and target issues should be clarified [Tsumori].

Interesting result were obtained by cooling target with liquid metals or <metallic foam >, even if activation of target is also an issue; helium gas can considered.

Cooling water is useful in many situations, but a fast flow speed is recommended [Cavenago].

As regards to Hall thrusters, their application to airplane wings for air flow control should be also noted.

Table I: a tentative summary of application features of positive and negative ion accelerators (green means better)

	Negative	Positive	Comments and notes
Power installed (for unit cost)	Small	Large (also by a factor 10)	
Charge deposit on insulated substrate	It may be small (if it compensate SEE)	large	SEE= secondary electron emission
Energy tuning and monochromaticity	Easy (*)	Fairly easy	(*) no other species, but a good vacuum in accelerator is required
Charge compensation for beam transport and optics	Easier	Fairly easy	For negative ion, the compensating species are much heavier than electron, so they accumulate more
Diagnostics and measurements	=	=	R&D is needed, for large current detectors
Source and meniscus modelling	Frequency effect unknown, if any	Frequency effect well known	Negative ion study seems much more challenging
Beam modelling	=	=	Similar issues with space charge and secondary beams
Efficiency of ion source	Many design choices and issues	Comparatively simpler	The electron temperature needs a careful control in negative ion sources (NIS).
Other species beam contamination	Tend to be absent (since few elements	May be avoided with source design	

	make negative ions)	and cleaning	
Beam targets (high power load)	=	=	Similar: Request careful cooling design; target lifetime may be an issued due to deposited H
New concepts (accumulation rings) and injection/ extraction	Accumulation of H- requires phase space stacking . H- beams allows for injection/ extraction by a stripping foil (*)	H+ can be injected by stacking, or by conversion of a H- beam	(*) used in syncrotron injection of spallation source (*) used in cyclotron extraction
AOB	-	-	-

Discussion D5: dissemination of result and/or next workshops
Conveners: M. Cavenago
Quaestio:
Future publication of the conference results can be discussed, as well as ideas for new workshop themes in the Accelerator Application Network of the EUCARD2 project, and general questions.
Closing remarks will follow.

Discussion summary
In conclusion, key items emerged are:
- a collaboration about ideas for developing radioisotope production is generally accepted, well focused on few cases (say up to 3), including ^{99m}Tc. Production target is a challenging item of these projects, whose design principle was reviewed for example in the previous AccApplic/Eucard2 workshop at LNL, ABNP2014.
- comparison of negative and positive ion and relation between plasma and acceleration physics and simulation needs support of a well organized group [Antoni], considering also single aperture ion sources at energy and current typical of applications;
-specialized neutron sources from low energy proton beam were presented [Fagotti], with possible application to security and medicine;
-next LNL and RFX workshops should include not only few MeV or tens of MeV application, but also ion implantation and other very low energy application as well as neutron spallation sources, to avoid micro meetings on too specialized areas.

*Cross links to ABNP2014 documentation (*https://agenda.infn.it/conferenceDisplay.py?confId=7214*), to the AccApplic and to Eucard2 web page will be inserted in IPAB2016 documentation as soon as* *possible. More effort to advertise possible next workshops to neutron diagnostic and medical accelerator community is needed, with the help of workshop participants.*

It is agreed that all presented slides and posters will appear in IPAB2016 web site (unless each single presenter ask explicitly not to show); IPAB2016 will welcome a revised copy of the slides within 3 weeks from conference, otherwise presented copy will be posted.

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Before closing the general session of the conference the chairman thanks all the speakers, the participants and the conference committees for their collaboration to the success of the meeting, and asks audience to give another thanks to the laboratory personnel which have so much helped in meeting organization, in particular Daniela Zane and Maria Crista Buoso.

Discussion D6: Workgroup on simulations: plasmas vs high current beams.

Conveners: F. Taccogna, M. Cavenago.

Quaestio:

Free discussion.

Discussion

We discuss actions (possible in the short term) for a better simulation of rf coupling in Inductively Coupled Plasma. Broadly speaking, self-consistent fluid simulation (FMS) and self-consistent PIC have the electromagnetic field E simulation module in common, while they differ in the way current j and density n are calculated. In FMS, a conductivity law as

$j = \sigma_1 (Te , B)\, n\, E$

is assumed where σ_1 is conductivity per unit density (a scalar, tensor or an operator, depending from model); *n* is calculated by ionization balance [Cavenago, Veltri]. In PIC ionization amplifies the existing density *n*, and *j* is computed by average on randomly selected particles histories [Taccogna, Veltri]; so we avoid the need to choose a plausible σ_1, at the price of computation time and numerical error. Both approaches are complementary, and inclusion of electromagnetic module in the Bari PIC is well progressing [Taccogna]. Also some extraction PIC validation is going on from NIBS2014 conference [Taccogna].

Let z be ion source axis, say of ion source NIO1 for a first example. Trajectories were simply computed in the Ez=0, $\sigma = \sigma_1 n = 0$ assumptions [Cavenago], showing several complexities.

So we plan three actions (as simple as possible in order to allow a rapid completion):

1) Fluid solutions with σ_1 taken as adjustable parameter (and n similarly) can be prepared [Cavenago, Veltri];

2) Bari PIC code will be installed also at LNL and RFX;

3) New module writing will be subdivided. In particular three methods (FEM/finite difference and boundary integration) can be compared for electromagnetic field.

About physical content, the use of 1 or 2 MHz frequency was discussed [Serianni]. In the transformer circuital model of ICP, operation on broad range of frequency seems possible [Cavenago]. Even if PIC model will confirm this lack of a clear preference, this result will be valuable. Note that experimentally changing frequency in ICP sources requires to change rf generator and matching box, so that cost can be justified only if a prediction of some effect exists, say for a factor 2 of frequency change.

In the case of ECRIS frequency effect are well known [see Mascali's slides].

A word of caution should be added on ICP optimization: source performance does not necessarily increase with electron temperature, while performances seem to improve with plasma density and wall condition. So hotter plasma (over 5 eV) does not necessarily give a better H^- source, which make optimization goal difficult to establish.

Effect of Faraday screen can be added in a second instance [Cavenago, Serianni].

Cesium effect needs also to be addressed now [Chitarin], so we begin discussion D7 in the morning.

Discussion D7: cesium in simulations; new concepts.

Conveners: F. Taccogna, M. Cavenago, P. Veltri.

Quaestio:

Free discussion.

Discussion

Cesium coverage allow improved operation both for H and D, and oven tuning suitable for long term operation for H were tested with reasonable success. Dynamic of cesium redistribution was studied at IPP in 3D, and physics of these processes is discussed [all].

A proposal to verify result against a 0D model with Cs plasma content given by spectroscopic measurement is raised [Cavenago].

About deuterium, its greater sputtering effect will probably request more cesium.

Implantation of Cs underneath a Mo surface (few tens of nm deep), to be used as cladding of source walls, was also considered in some laboratory [Serianni].

Another question of cesium is practical operation. RFX and INFN-LNL are joining effort on that theme. The baseline cesium evaporator is a liquid metal oven, to be protected and sealed by a bakeable all metal valve during source air venting (for maintenance), as designed in NIO1 oven prototype. A very promising technology is the solid pellet evaporator; a different prototype was designed for NIO1, optimized for working in the 700-900 K range [Cavenago], with minimal impact on NIO1.

Inside the PRIMA/MITICA building, a test facility for cesium manipulation is being installed [Serianni, De Muri] and oven development for SPIDER and MITICA is also in progress.

A potential advantage of pellet technology is simplicity of usage, useful for most tandem accelerator sources and application. In conclusion both liquid and solid pellet oven development are recommended.

Session continues over lunch and ends at 14.10

End of minutes of topical discussions at conference IPAB2016