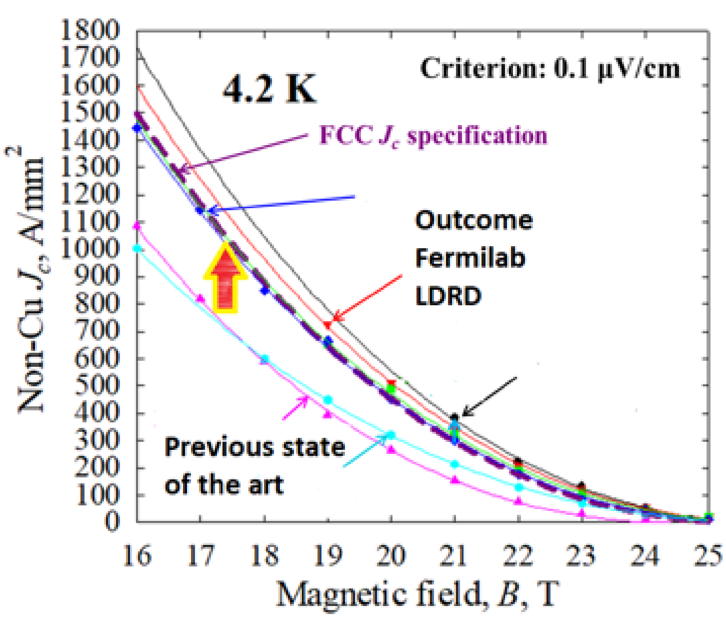
Responses to Recommendations from AAC 2018

compiled by Peter H. Garbincius – October 29, 2019

2. **High Field Magnet Program** – George Velev

- Given the limited resources, new advanced Nb3Sn conductor development deserves the highest priority following the two promising routes already started, (1) increasing engineering current density by using the internal oxidation method for achieving enhancing pinning; (2) include in the matrix high Cp materials (like Gd2O3). Try much higher than the 1% today, investigate i.e. 5 and 10% as well.

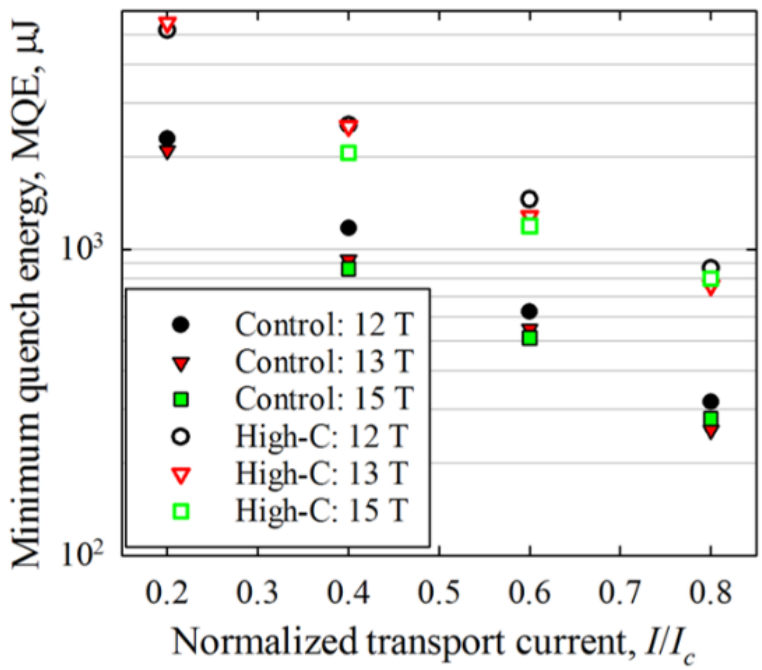
  In FY19, the Nb3Sn R&D was executed with the highest priority. In the past year optimization work in the recipe of the Nb_3Sn conductors based on the artificial pinning center (APC) technology has led to significant improvement in the critical current density (J_c), with non-Cu J_c of most recent APC wires having achieved the challenging FCC conductor specification (see Figure below). Efforts were also made to optimize the design and recipe of Nb_3Sn conductors with high specific heat (C_p) to improve their stability. Particularly, optimization in wire design and recipe is being studied to overcome wire drawing issues. New substances with much higher C_p then Gd_2O_3 at 2-6 K are being studied, which are expected to lead to stronger effect as an alternative to use higher percentage of Gd_2O_3. For APC and high-C_p effort, Xingchen Xu received the prestigious DOE Early Career Award (ECA) for the development of next-generation niobium-tin superconductors for energy frontier circular colliders.



- Include in the new Nb3Sn conductor development program also cable development using the new strands, and prove enhanced cable stability by performing relevant Minimum

Quench Energy (MQE) versus normalized critical current (I/Ic) studies at 15T level to demonstrate superior behavior (or not); followed by a small demonstrator coil.

Such a conductor development program for characterization of the new APC and High-C_p strands exists and it is progressing well. We characterized the latest APC strands from Hypertech Inc. and obtained results are presented in several conferences and workshops. Specifically, for high-C_p, we tested strands with Gd_2O_3 and 2.5 times increase of the Minimum Quench Energy (MQE) comparing to the control samples without Gd_2O_3 additives was achieved. The plot below shows the result of these studies. The next step in this R&D is making small coils, following the AAC recommendation. Unfortunately, up to now we do not have enough high-C_p conductor to make a cable and consequently a small coil.



- Develop further and set priorities in the new in-house magnet development program, still in coherence with the US Magnet Development Program, but supporting a main research line towards the next one or two magnet demonstrators, featuring new technology and not more of the same.

  Fermilab SC magnet R&D program is an integral part of MDP. MDP is in the process of rewriting the roadmap for the next 3-4 years. Fermilab group actively participates in this planning process. As today, the process is not finalized, we are discussing the proposals internally (inside MDP) and externally (with DOE). Currently the Fermilab SC magnet R&D group is proposing the following topics of R&D to the MDP management:

  - Superconducting wire and cable R&D that includes Nb_3Sn APC and high-C_p directions
  - High Field Accelerator Model Magnets, leveraging our achievement in 15T demonstrator

- Developing HTS coils based on CORC (REBCO HTS) cable for possible insert in the 15 T structure
- Developing HTS iron dominated magnets for linacs
- Technology development:
    - Training and Diagnostics (e.g. Quench Current Boosting Device)
    - Instrumentation and protection (e.g. New High-Resolutions Quench Antennas, Optical Fiber Sensors for quench characterization and protection)
    - Material studies (e.g. Insulation Systems, Epoxies and Resins Test)

- Ensure that financial resources are sought to sustain the in-house Magnet Development Program, in order to preserve the lab's skills and expertise for participating in frontline magnet projects.

  The SC magnet R&D management pays close attention to the R&D budget. Unfortunately, the standard GARD funding for SC magnet R&D continues to be flat through the recent years. We are working with the MDP management asking DOE for an increase of the R&D funds. Additionally, we are using any opportunity to obtain additional non-GARD funds. We regularly apply for Early Career Awards (ECA, DOE) and Laboratory Directed Research and Development (LDRD) awards (Fermilab). Currently, we have one ECA (Xu) and two LDRDs (Stoynev and Kashikhin). For example, this year we proposed six LDRD topics related to magnet R&D, three of them are progressing to the second evaluation round.

3. **FAST & IOTA**

- Quantify the error tolerance in implementing McMillan lens with the electron beam.

Giuilio Stancari responds: Quantification of tolerances is definitely an important aspect of the IOTA electron lens design and we thank the committee for pointing it out. In 2018, a post-doctoral research associate position dedicated to the electron lens was opened. The post-doc joined Fermilab in April 2019. The first task is to design the McMillan electron gun. The design is based on previous electron-lens and electron-cooler experience (from Fermilab, Brookhaven, CERN and Budker Institute) and on particle-in-cell simulations of space-charge-limited emission. Once built, the electron gun will be tested and characterized in the Fermilab Electron-Lens Test Stand. In parallel, a tracking simulation project was started to assess the effects on beam dynamics of imperfections in the electron beam shape. This work is currently in progress.

- Develop the required beam diagnostic instruments and techniques for measuring the impact of electron lens on the space change effect.

Sasha Valishev responds: The IOTA team pays close attention to the beam instrumentation and thanks the committee for recognizing the importance of this aspect. The efficiency of space charge compensation using electron lens or other techniques will be evaluated on the basis of the following diagnostics:

a) Beam intensity. IOTA is equipped with a wall-current monitor and with a DCCT for precise measurement of the beam current;

b) Transverse beam profile. The key measurable will be the amount of beam in the tails and halo dynamics. The IOTA team has been working in collaboration with the researchers at Northern Illinois University to develop a beam diagnostics instrument for the high-dynamic-range beam profile measurement. The prototype gas-jet profile monitor for IOTA has been built and the first tests with 2-MeV proton beam are expected in early 2020 at UC Davis' Cyclotron;

c) Particle losses. Diamond-based loss monitors suitable for detecting low-energy protons have been under development at Fermilab for a number of years. A prototype device is being designed with a possible test at PI2IT.

4. **SRF R&D Progress and Research Program**

Responses (interspersed with recommendations) by Sam Posen, October 18, 2019

- This problem with shipping cryomodules to SLAC has been a difficult issue. Consider how to strengthen your expertise in CM mechanical design and revisit your quality programs.

Fortunately, the shipping problem has now been resolved for LCLS-II. The solution involved special restraints to fix the movement of the coupler bellows as well as a modification of the shipping frame to have fewer spring elements. Since the implementation of these fixes, 14 cryomodules have been delivered to SLAC without incident.

After the shipping problems with LCLS-II cryomodules, quality assurance for future transportation has been treated with extreme importance at Fermilab. This is true not just of SRF cryomodules but of all relevant delicate scientific components with high value. To this end, a small team was assembled to review the current practices associated with transportation activities and their associated design, risk, and QA/QC elements and to evaluate the degree to which the relevant laboratory manuals and policies offer a clear and thorough description of the required processes, roles, and responsibilities. The summary report from this team is attached. Based on their recommendations, Fermilab's Chief Engineer is commissioning a working group to create a new chapter in the Fermilab Environment, Safety and Health Manual (FESHM - https://eshq.fnal.gov/manuals/feshm/) dedicated to transportation.

For PIP-II, there will be many types of cryomodules, built at many different labs, and shipped not just over land, but also across the ocean. Therefore, PIP-II established that a detailed transportation plan would be developed for each type of cryomodule, and that each type of cryomodule would have its own Transportation Readiness Review. Details can be found in Section 9.8 of the PIP-II Technical Review Plan (Fermilab document number ED0008163). The first of these reviews was held in April for the SSR1 cryomodule, with presentations that can be found here: https://indico.fnal.gov/event/20124/ .

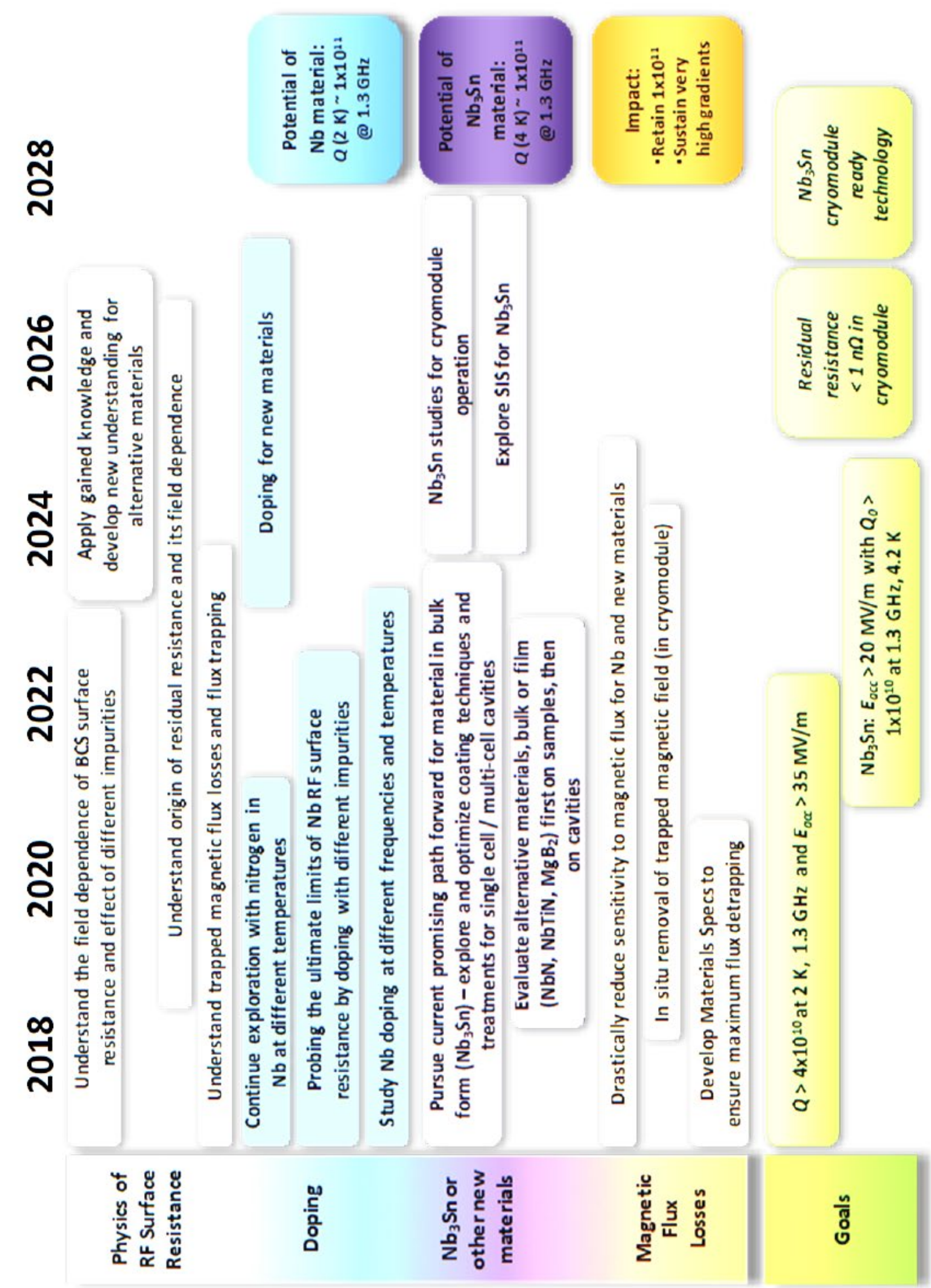
In addition, in May 2019, APS-TD established a new functional Transportation Engineering subgroup to facilitate collaboration for transportation issues.

See also 04a – Review of Transportation Practices and Policies for Project Deliverables, August 26, 2019, to be found under Material at top of https://indico.fnal.gov/event/21604/

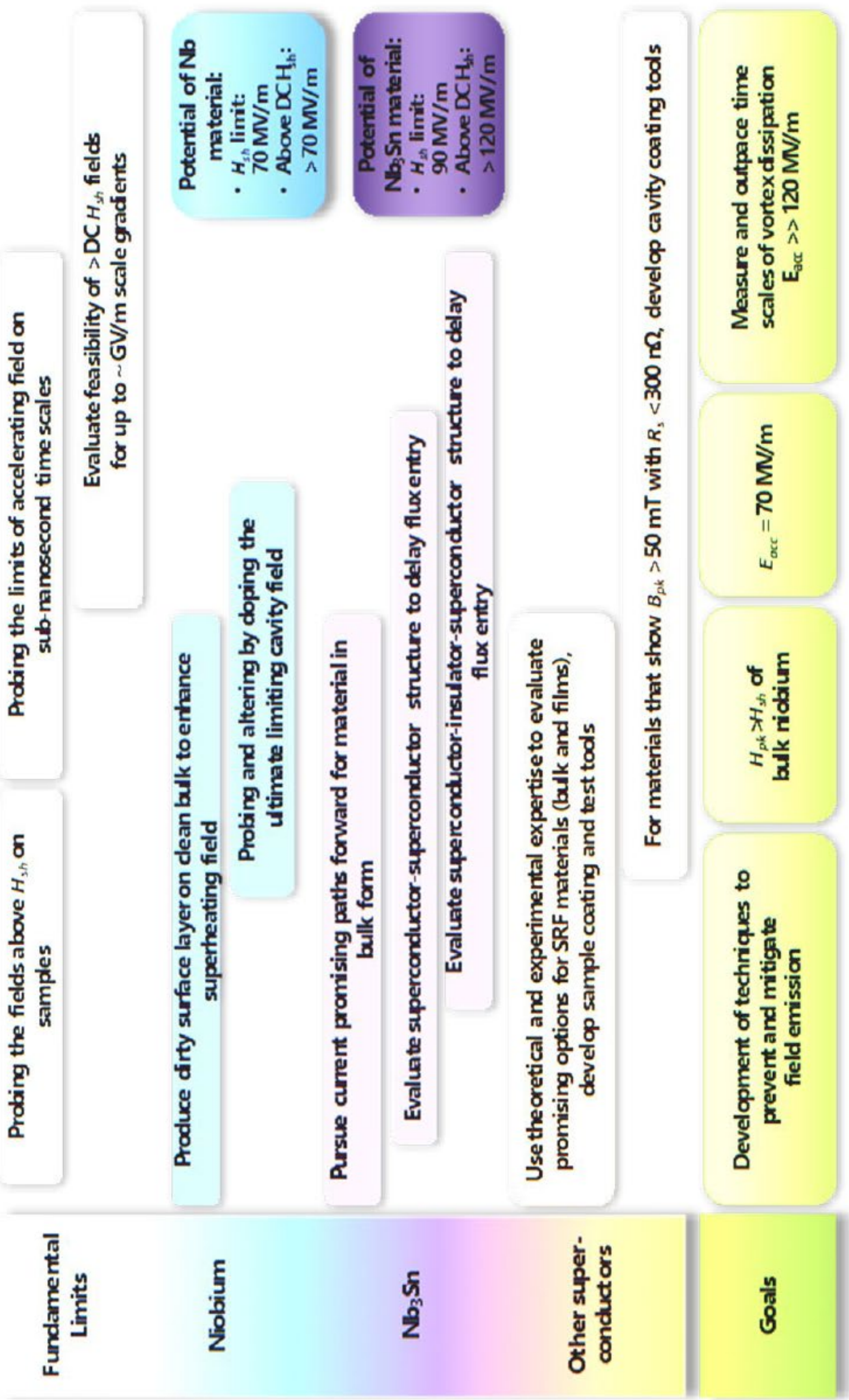
- Fermilab's SRF groups have made impressive contributions to projects around the country and the goals generally aligned with future machines. Develop a multi-year FNAL SRF technology development plan that aligns with the HEP roadmaps and includes FNAL priorities and QIS initiatives. This will help to clarify your priorities internally and externally.

Currently, our program follows the GARD-SRF Roadmap, which was developed with substantial contributions from Fermilab. Fermilab also hosted the GARD-SRF Roadmap Workshop in 2017 that brought in SRF researchers from US labs and around the world to help develop the most promising research directions for the next decade: https://indico.fnal.gov/event/13606/ . The roadmaps for the High Q_0 and High Gradient Frontiers are reproduced below.

In addition, the Fermilab Technology Committee (https://news.fnal.gov/2018/10/technology-committee-launches/), which is chaired by the CTO, is developing a strategy document for all technologies at Fermilab, including both SRF and QIS. By incorporating all Fermilab technologies, this technology strategy document will aim to refine development plans in the broader Fermilab context. The document will be finalized by the end of this year and can be presented at the next AAC meeting (Nov 2020).



GARD-SRF Roadmap: High Q_0 Frontier



GARD-SRF Roadmap: High Gradient Frontier

5. **Accelerator Facility Upgrades**

- Consider prioritizing the list of Booster studies that has been presented, starting with the most impactful on future operations getting highest weight. Consider to distribute the studies over several years.

Responses from CY Tan (Fermilab) and Frank Schmidt (CERN) 16oct2019:

The proposed Booster space charge summer studies was successfully carried out from 17 June to 3 July. It consisted of 2 weeks of parasitic studies and then 1 week of dedicated studies in the Booster. The preliminary results of all the studies can be found here:

http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=7522

and a NAPAC19 talk and poster:

NAPAC talk: https://napac2019.vrws.de/talks/thzba1_talk.pdf
NAPAC poster: https://napac2019.vrws.de/posters/thzba1_poster.pdf

In fact, the response from our CERN colleagues have been very positive. See aide de memoire from Frank Schmidt that is also attached.

These studies have been very useful for us as well. We plan to continue looking at the 1/2 integer resonances and convective instabilities.

We would like to have another round of studies with CERN at the end of May.

Regular studies of 1 shift per month have also been implemented. These consist of Linac/PreAcc studies, Booster studies that include RF capture, flat injection, LLRF, paraphrasing etc.

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Aide de Memoire from Frank Schmidt (CERN) (email dated 07 Aug 2019)

Hi guys,

I would like to summarize about the this year's experiment and to plan for the coming year:

- I think we all agree that the 2019 studies have been a success in many ways.

- For the follow-up of the 2019 Booster experiments it would be important that the key players for the analysis of the various experiments are identified. Just one example is the ripple experiment where one should check if one finds emittance blow-up due to tune modulation. This may happen although no particle loss is found. Many IPM dataset are available.

- I agree with Tan that publication in any form is essential to "proof" importance and relevance of the experimental results. Personally, I do not care much about conference papers and I very much prefer internal reports and even more so publications in learned journals.

- I think indeed that it is now time that the Booster operations team takes over in defining the continuation of the Booster experiments.

- I also think that to reduce the number of tasks to just 3 topics is an excellent idea!

- From the start it has been important for me and also our group that this shall be a two way collaboration! Therefore, we would strongly appreciate if you could send 2 people to help us in our
LIU commissioning starting ~summer 2020. We fully understand that this will have to be out of phase with your own re-commissioning.

Exact timing and length of visit can be discussed in due time. As usual the standard CERN-Fermilab agreement shall be applied which specifies that the sending laboratory pays for the flight while receiving Lab pays for the local costs.

- Most essential are the 3 candidates as topics for further studies:

A) "Flat Optics" or fully optimized optics

In my view this will be the most promising approach to make progress in the long run. To this end one should take a fresh look at the lattice and take advantage of all modern tools available.

Since one would need to build it from ground up this will need a considerable effort on all fronts. I would believe that this task should have priority over anything else.

B) From my experience with our CERN Booster next thing in line is the correction of the half integer resonance. One has to understand that the plain resonance correction, albeit very important, may not
be sufficient. For the CERN PSB one had to fully understand all components like quadrupole variations around the ring and also misalignments to be fully successful.

C) The IPM has been a star at this experimental session. Apparently, there are a number of intensity related effects that skews the calculated emittances. Hopefully, this can be controlled with adequate
benchmarking. Moreover, there remain operational issues to improve the usefulness of this instrument. This is of particular interest for our CERN colleagues.

I hope the recollection of my memory might be useful!

Cheers, Frank

- For the 900 kW booster related upgrade calculate the impact of the machine impedance on injection and transition.

Response by CY Tan:
We wanted to perform impedance measurements of Booster so that good parameters can be used as input for our calculations/simulations for 900 kW operations. The latest impedance measurements done just before shutdown can be found here:

http://beamdocs.fnal.gov/AD/DocDB/0075/007522/002/Biancacci%20TransverseImpedance.pptx
These measurements will have to be repeated after Booster comes out of shutdown because only the vertical plane gave good results at injection while the horizontal plane requires improvement.

- For the proposed Booster experiments consider installing a quadrupole pickup and look into correcting IPM profiles for the beam space charge.

Response by CY Tan:
We did not have the money and resources for installing a quadrupole pickup in the time required for the proposed Booster experiments. However, as can be read from Frank Schmidt's note above, the IPM worked very well for the studies, but can be improved. The IPM is of great interest at CERN and we will be collaborating with CERN to improve the IPM measurements. Valery Kapin (Fermilab, AD/PS) the resident expert of the IPM is working with CERN to simulate the behavior of the IPM with space charge effects. The end goal is to have a model to correct for the effects of space charge on the measured emittance.

- Seriously consider adding regular beam studies to the operation schedule.

Response by CY Tan:

Regular studies of 1 shift per month have also been implemented. These consist of Linac/PreAcc studies, Booster studies that include RF capture, flat injection, LLRF, paraphrasing etc. with the goal of improving overall beam transmission efficiencies. Furthermore, we are in the process of improving the lattice and operating points for current beam intensity as well as increased intensities by identifying loss mechanism and finding solutions for mitigating the loss. All the studies schedules for 2019 can be found here:
http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=7763

6. **NuMI 1-MW Target System Design** – NO RECOMMENDATIONS!

7. **Modernization Program – Accelerator Controls Upgrade**

Responses (interspersed with recommendations) by Jim Patrick, October 18, 2019

- The controls infrastructure choices are critical and have far reaching consequences. Due time should be given to carefully evaluating the options and making sure that the chosen solution(s) fully meet the present and future needs of the complex.

  Fermilab's accelerator control system is central to operations of the present accelerator complex and future upgrades to the complex, such as the Proton Improvement Plan-II (PIP-II). Careful evaluation of interfaces between existing components and future upgrades is one of the key aspects in making decisions for the future. The PIP-II control system will be based on EPICS. Fermilab has had a unified control system for the entire complex since the start of Tevatron operations and this is the goal for the PIP-II era as well. A common system provides reduced development, operations and maintenance costs and greater flexibility with personnel. A strategy that is being considered is to put EPICS front-ends under ACNET control, thereby creating a hybrid system that will be transitioned to EPICS for PIP-II operations. An initial version of this hybrid may be operational as a prototype for the PIP2IT run beginning in April, 2020. The experience that will be obtained from the prototype will be used to develop a phased migration plan for the existing complex for both hardware and software in the context of what will likely become a DOE-funded Accelerator Control Modernization project.

- Requirements must be clearly established. To this end, (re)establish operation models and the required functionality for the existing complex and PIP-II.

  Requirements have been established for the PIP-II control system. Requirements for the existing accelerator complex and interfaces to PIP-II still need to be developed. This will happen early in the context of the Accelerator Controls Modernization project that is currently being considered by DOE.

- Carefully evaluate EPICS functionality given the requirements of operations across the complex and evaluate solutions other than EPICS deployed elsewhere, preferable coupled with visits and discussions with the labs concerned.

  We have evaluated EPICS functionality through discussions with personnel at other accelerator laboratories and by working with consultants from OspreyDCS and Cosylab. For example, we have discussed control systems with personnel at Brookhaven National Lab (BNL), such as their existing control system for the Relativistic Heavy Ion Collider (RHIC). Moreover, BNL is in the early planning phase for a possible electron-ion collider and is evaluating control system architectures. Similar to Fermilab, BNL has an older accelerator complex with a custom non-EPICS control system and faces similar issues regarding interfaces with a new electron source that may end up using EPICS. A visit to BNL is tentatively scheduled in December for more extensive discussions. A visit to SLAC is planned in early November, and a visit to SNS has been discussed but not yet scheduled. Working with consultants, we have investigated EPICS functionality and support for key features in ACNET that are currently not provided by EPICS, such as data requests or a particular beam cycle type. Although this functionality is not supported in EPICS, the EPICS core development team is receptive to having Fermilab contribute to implementation of required features.

- Start to develop a resource loaded schedule for the consolidation/upgrade deployment and establish an obsolete hardware eradication plan.

  Fermilab presented a proposal to DOE/HEP in August for an upgrade of the accelerator control system. The project is referred to as the Accelerator Controls Modernization (ACM) project and was presented as part of a Mission Validation Independent Review (MVIR). The presentation included a very preliminary assessment of hardware and software costs.

The proposal was viewed favorably by the review committee. A more detailed plan is being developed in response to recommendations from the review. A project manager has been identified for ACM, and work on a resource loaded schedule will begin as soon as Fermilab receives CD-0 approval from DOE.

- At an appropriate point, organize an external review of the upgrade strategy.

  An external review of the accelerator controls upgrade strategy will be held after receiving CD-0 approval and before a CD-1 review.

8. IARC – R&D to Commercialize Fermilab Technology

Responses by Charles Thangaraj – November 1, 2019

- C**on**duct a SWOT (Strengths, Weaknesses, Opportunities, and Threats) study for the 10-MeV point design, including both the commercial/federal market and the competition from commercial devices such as the IBA Rhodotron.

  Executive summary: We did not conduct a stand-alone SWOT study of the 10-MeV design during the past year. We have, however, spent a significant amount of effort to better understand the potential market applications for high-power machines (the opportunity part of the analysis), especially in the wastewater treatment and medical device sterilization markets. With regard to medical device sterilization, we hosted a workshop in September 2019, which included both medical device manufacturers and equipment providers, including IBA. This workshop provided significant insights into the strengths, weaknesses, and threats with regard to this particular opportunity space. We have since been funded by NNSA to conduct a formal evaluation of the IARC concept accelerator versus existing commercial technology platforms, for the purpose of identifying the best path forward for advancing the use of accelerator-based technologies for medical device sterilization.

  Details: The primary distinguishing strength of the IARC 10-MeV SRF electron beam accelerator is the CW, high power (> 1-MW) beam production and its compactness. The rhodotron is currently not offered at MW at 10 MeV. The demonstration of high power, CW magnetron source driving a multi-cell high-Q SRF cavity needs continued R&D. The MW capability of the compact SRF unlocks opportunities in wastewater treatment, pavement applications, and emergy X-ray medical device sterilization applications that demand high power electron sources. One possible threat could be from smaller and cheaper copper linacs which could replace one big MW SRF machine with multiple smaller kW Cu machines. However, it is unclear whether all applications are suitable for this multiple redundant linac configuration.

- Identify a broader set of accelerator technologies Fermilab developed for its core mission that can address technology gaps for federal sponsor mission areas.

  Following last year's meeting, we launched a strategic planning effort to identify additional technologies (not just accelerator technologies) that could be developed for application to other federal missions. We are working with PPD to expand our portfolio into high-speed imaging, and detectors that could address mission areas for both federal sponsors industrial applications. We are also engaged in the DOE-wide quantum and AI efforts, including support of the X-Lab summits for AI and quantum. We are also starting to support the proof of concept for some interesting technologies that are coming out of the accelerator division. We want to emphasis that, on the flipside, supporting federal sponsor mission areas such as the road pavement application work with the compact SRF accelerator for the U.S. Army Corps of Engineers has helped expedite R&D work on thin-film coating (Nb3Sn) techniques at 650 MHz which may not have occurred otherwise.

- Evaluate the benefits/threats to partnering with a commercial entity.

  The benefit of partnering with a commercial entity for the first article of the compact SRF could be commercial entities are generally good at thinking in scale and force us to simplify our design for ease of operations. Commercial entities are also familiar with the customer's need and application needs which we might not be privy to. However, the threat is that the technologies in the compact SRF involved are fairly new for a single commercial entity and lack of infrastructure needed for the first article might slow us down if we partner. There are also sensitivities of people and IP involved in such commercialization activities that we need to be alert to. We believe separating the development of technologies from the integration is one way to solve this issue. For instance, commercial entities are typically interested in developing a single component (RF sources, cathodes, cavity, etc..) and other larger engineering firms bring strength in integrating complex technologies into the first article. Most recently, we have been successful in attracting stewardship partners such as General Atomics through the HEP Stewardship grant. Our goal for the next two years in this grant is to bring their expertise in assisting us with reaching a cost-target for the conduction cooling structure. Here is an example of how we develop and de-risk the technology (conduction cooling) but then bring on-board other commercial entities with a specific focus on reaching the cost of the system ($3/W in this case).