Experiment Execution Workflows for Alcator C-Mod, DIII-D, and NSTX

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U.S. Burning Plasma Organization working group: Modes of Participation in ITER

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Executive Summary

The U.S. Burning Plasma Organization (BPO) has formed a working group "Modes of Participation in ITER". One main purpose of this group is to work with the IO and provide information on modes of operation and analysis in present day devices, to contribute to the formulation of the strategy for ITER experimental operation procedures and support systems. To this end, the BPO group has engaged in discussions with IO employees, A. Winter and S. Pinches, who are tasked with formulating a proposal for ITER experimentation strategy.

To support this work, this document summarizes the processes and procedures used to prepare, approve, and execute experiments on Alcator C-Mod, DIII-D, and NSTX. An experiment on these devices typically represents a sequence of plasma discharges (often in a single experimental session) aimed at investigating various aspects of a particular plasma phenomenon. A summary of the experiment workflows that highlights their mostly common and occasionally differing approaches is provided below. This is followed by a separate description of the workflows for each device. Finally, a cursory summary of the implied requirements for ITER is provided. These workflows represent the processes used during a single experimental campaign. We use the word campaign in this document to mean the period of experimental operation planned by the processes described here. (This differs from typical use of the term at C-MOD, where planning spans multiple years "campaigns".)

At all US devices, the experimental team is defined by experimentalists at the device host institution together with all collaborators. This typically means researchers supported by their home institution, but can sometimes include unfunded or non-fusion funded scientists having a working relationship with a funded team member. Experimental teams are involved in all aspects of experiment planning, approval, preparation, and conversion of experimental data into scientific knowledge. All programs require that team members sign agreements spelling out data usage policies in order to have access to their data (see example in Appendix).

1. Experiment planning and proposal

Program management at each device defines topical science research groups, which are relatively long-lived entities. Experimental priorities and areas of specific experimental focus in a particular experimental campaign are determined prior to the campaign. In some cases, these are decided primarily by project management with input from an advisory group with select members of the experimental team and in others through discussions involving the various research groups. The choice of foci are heavily influenced by previously negotiated deliverables to the U.S. Dept. of Energy (DoE), to a lesser degree by requests from ITPA and IO, by previously decided long-term objectives of the experimental program, and unique capabilities of the device to provide important contributions. The same influences affect the later detailed planning and scheduling of experiments.

The definition of experiments under the chosen focus areas are sometimes performed within a topical science group and sometimes a separate task force focused on those experiments is formed, e.g., when the topic cuts across topical science areas. Leaders of both the longer-lived research groups and the short-term task forces are chosen by the program managers. Membership in the research groups is typically open to any member of the experimental team and can change from year to year as experimental interests change.

All programs have open forums for proposal of experiments, typically held over 2-3 days. At these forums, any member of team can make presentations of experiment proposals, and remote participation is supported. In some cases, research group leaders may solicit particular relevant experiment proposals. At all three U.S. devices, submission of proposals is a web-based process. For all programs, all information presented at the forum is archived and available on online.

2. Experimental time allocation

In all three programs, definition of priorities and initial allocation of experimental time to research groups is done prior to the open forum, although all three programs have varied the timing of these two events in the past. The initial allocation is defined by program management.

Not all available experimental time is allocated during this initial process. NSTX and D3D reserve a portion of the available run time for contingency, to be allocated later in the campaign based on unmet experiment needs (e.g., due to hardware failures on the day of an experiment) and evidence of promising results seen during the experiment. C-MOD also plans for contingency but manages this time a little differently.

After the open forum, all programs conduct further detailed planning meetings, which are open for remote participation, within the topical groups (and smaller subgroups) and research thrusts to decide on a proposed plan for experimental run days.

The purpose of these meetings is very similar, but not identical across the programs. Their activities include:

- discuss experiment proposals and dependencies on results from other experiments
- integrate or otherwise combine similar proposals
- assign run time and relative priority to merged proposals
- identify proposals that can be accomplished without dedicated run-time ("piggyback") and experiments that will be used to host them
- identify lead authors of detailed experiment proposals, which are typically developed later

During this process, coordination is done both within each research group and across groups.

In determining priority for a particular campaign, several criteria are applied:

- Scientific value, motivation, and novelty
- Technical feasibility and likelihood for success (in particular, must be executable with current capabilities without endangering the facility)
- Relevance to research targets and program milestones
- Potential to contribute to significant publications and/or invited talks at major conferences
- Overall programmatic relevance and priority
- Contributions to joint research, including ITPA/ITER
- Potential for developing new capabilities and/or operational regimes

All three programs make strong attempts to ensure that graduate students are able to get experimental data needed to complete thesis work on schedule.

At all devices, consideration is given to program balance among the many collaborating institutions as well as access for younger scientists (including grad students and postdocs) in assigning run-days and session leaders.

Allocation of time to a particular experiment is typically done in 1/2 or 1 day increments, but smaller increments are also available for specialized purposes.

Following these group meetings, the experimental plans are typically reviewed on a program-wide basis. There is often some minor modification of the proposed plans.

3. Experiment preparation

All programs assign a member of the scientific staff to serve as a run coordinator (RC), who is responsible for the scheduling of experimental sessions, or “runs”. Experiments are scheduled according to constraints defined by expected machine readiness and availability of key personnel. There is usually some flexibility retained in the schedule to deal with unforeseen events, typically issues of machine readiness. In those cases, the RC is responsible for modifying the schedule within the prevailing set of constraints.

A detailed experimental proposal must be written by the person or persons who will lead the experiment and then approved by program representative(s) before the experiment is allowed to run. Required content for these proposals is similar between the programs and are typically reviewed by the relevant topical science group or research thrust and by device operators before submission. At all three devices, these are linked to an online database.

At C-MOD, the experiment proposal is evaluated and approved by an Experimental Program Committee (EPC, consisting of (1) lab and project managers, (2) leaders of topical science areas, thrusts and task forces and (3) representatives of major collaborating institutions) through its regular meetings. At NSTX, there is a formal review meeting, chaired by the RC and with open attendance and a “review committee” consisting of two to three physicists (to ensure adequate review). At D3D, it is reviewed and approved by the topical group leader, the chief physics operator (see definitions in Section 4 below), and the RC.

The exact time the detailed experiment proposal is required in relation to the scheduled experiment day varies between programs, from a day or two before to two weeks before execution.

4. Experiment execution

Execution of experiments is performed similarly at all three devices. There are five key roles:

- Session leader: the physicist in charge of the experiment
- Physics operator: responsible for obtaining the experimental conditions requested by the session leader, e.g. by programming of the plasma control system
- Lead engineering support: responsible for resolving device technical problems and ensuring device safety
- Diagnosticians: responsible for obtaining data requested by the session leader
- Analysts: responsible for running between shot analysis codes synthesizing data from several sources (for data validation and to aid with experiment execution).

In the experiment itself, it is typical to have some deviation from the written plan due to device conditions and results of prior discharges, although such variations are sometimes considered a priori via listed decision points. After each discharge, the key people involved in the experiment make comments in an electronic logbook. At the end of the day, one or more summaries of the experiment are also written. Short presentations to the experimental team are expected shortly after the day of the experiment.

5. Experiment data analysis

There are multiple phases of experimental data processing; see e.g. "Sample Data Analysis Workflows from Alcator C-Mod, DIII-D, and NSTX" produced by the group that generated the present document. In the initial phase, automated processes (1) acquire and store data, (2) convert data to physical units and apply calibration factors and (3) carry out low level analysis tasks. Full data acquisition can take several minutes to complete. Software 'event' signals are sent as each step is completed. As soon as the required data are available (determined by these 'events'), automatic post-discharge analysis begins. Software events may also be set when these jobs complete; in many cases one process (e.g., EFIT reconstruction) must be completed before another (e.g., radial profile mapping) should begin.

Details of execution of a discharge often depend on results obtained in a prior discharge, so the interval between plasma discharges (and therefore number of experimental discharges in a fixed-length day) depends on timely availability of data and speed of automated analysis processes. Issues of data dependence imply that the order with which data becomes available also matters.

In the next phase of data processing, interactive tools are used for higher-level analysis and manual data review. This is typically in cases where assessment and decisions by experts are required; analysis routines may be run manually, e.g. by the diagnostician. The speed of this analysis depends on the urgency with which data are needed. It may be needed between discharges or needed later in the experimental day. In these cases, it is understood that control room data, while as reliable as is feasible, may not be 100% accurate. Either hardware or physics issues are often discovered later which may require reprocessing of data, or in some cases mean it cannot be used.

After an experiment, more extensive analysis extends over weeks, or months, and sometimes years. It is usually coordinated by the session leader or team leading the experiment. In most cases, the results of this analysis are written back to the MDSplus data tree, where they become available to all users. Later detailed analysis, especially for publication, requires knowledge of error bars, and may result in replacement of previously analyzed data, since knowledge of these error bars sometimes evolves after data is taken and/or analyzed. Extending the analyzed data set on a given discharge may continue indefinitely.

For conference presentations and publications to journals, it is expected that all who have contributed in a significant way to the results will be able to obtain publications or be included as co-authors on publications and given ample opportunity for input. Typically, the session leader has first priority on the major results of the experiment, but others who participate or support an experiment typically write papers describing certain details of the experiment and their analysis. Coordination of this process is overseen and approved by program management. Informal team participation in preparation is encouraged to ensure coordination of publications and to obtain useful feedback. Formal review is required for actual publication or public presentation.

The individual experimentation workflow sections from each device are given in the following three sections. From these, a common set of implied requirements for ITER is given below:

- Open access to all data for all members of experimental team.
- Remote participation tools for widely distributed experiment team members to participate in experimental planning process.
- Web-based tools to support the experimental proposal and planning process.
- Clear definition of evaluation criteria for experimental proposals.
- Electronic entry of discharge logs and experiment summaries.
- Policies requiring entry of discharge information and written summaries.
- Remote access to all data related to a discharge.
- Methods that enable data analysts to evaluate quality of data.
- Permanent archiving of both raw and analyzed data from experiments.
- Archiving of varying quantities of analyzed data.
- Archiving of analyzed data not previously archived.
- Clear policies defining responsibility and authority for allocating and approving publications based on experimental data.

Experiment Execution Workflow for Alcator C-Mod

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0. Organizing Principles

Alcator C-Mod experimental research is driven by a workflow that is continuous in time, but may be broken down into experimental cycles of 1—2 years in length. The program is typically organized into several *Topical Science* areas and high-level *Research Thrusts*. The identification of these areas, and assignment of group leaders for each is performed by the project manager. Group leaders are responsible for performing coordination of the experimental program both within their thematic area and with the leaders of other groups. In some cycles, additional *Task Forces* are formed to provide special coverage to cross-cutting program themes, where extra coordination is needed to address particularly timely problems. The exact groupings are subject to change from one cycle to another, but past examples include:

Topical Science Areas	Operations, Diagnostic Development. Basic Science, Transport, Pedestal, MHD, Divertor/Edge, ICRF, Lower Hybrid
Research Thrust Areas	H-mode Baseline, Advanced Integrated Scenarios, Alternative Operational Regimes
Task Force Areas	I-mode studies, FES Joint Research Targets

An *Experimental Program Committee* (EPC) performs primary coordination of the C-Mod research program. The EPC consists of (1) lab and project managers, (2) leaders of topical science areas, thrusts and task forces and (3) representatives of major collaborating institutions. The EPC sets overall research priorities and run-time allocations, reviews experimental proposals (MPs) and provides input to the engineering group to help coordinate facility activities. The EPC also appoints a *Run Coordinator* (RC). The RC is a member of the scientific staff responsible for the scheduling of experimental sessions, or runs.

Because of the relatively small size of the C-Mod facility, a substantial fraction of the full-time scientific staff serves in leadership roles, including being on the EPC. These group leaders in turn have a steady influence on decisions that are the responsibility of the program manager. Research management decisions therefore tend to have broad support within the C-Mod team.

The stages of the experimental workflow are roughly as follows:

1. Pre-plan based on run time guidance, facility schedule and capabilities
2. Hold Ideas Forum to air wide range of possible experiments
3. Set initial run time allocations for each research area

4. Hold topical group meetings to organize and prioritize proposals
5. Call for new, high-priority MPs
6. Schedule experimental run time
7. Execute experiments
8. Acquire and analyze data
9. Present and publish results

Each of these stages will be discussed in some detail below.

1. Pre-planning

An extensive run planning process is a key component of the Alcator C-Mod experimental work flow. This process is structured to allow for efficient use of available run time, while striking a balance between predictability and flexibility. By necessity, we must balance a large set of program drivers and constraints, including the active support for graduate student research.

As an initial step, the program manager disseminates the run time guidance for the upcoming fiscal years, which comprises both the amount of run time available per year (provided by DoE) and how the blocks are likely to be arranged on the calendar (provided by project management). The arrangement of run time accounts for specific facility issues, e.g. planned upgrades, anticipated outages. Depending on, the experimental planning cycle may encompass either one or two years of run campaigns. With current staffing levels, the C-Mod facility could run a maximum of 25 weeks year, but in practice the number of run weeks supported by DoE has typically fallen in the 10—20 range.

2. Ideas Forum

Proposals for C-Mod research typically begin as submissions to the Ideas Forum (IF), an open, relatively informal, two-day meeting held following the pre-planning phase. At the IF, the expected facility capabilities and schedule for the upcoming planning period are presented. This is followed by an extensive schedule of presentations of individual ideas. Ideas can range from highly conceptual to well-fleshed-out, but every idea is allowed a presentation of five minutes (plus two minutes for questions and constructive discussion). Presenters are asked to describe (a) the motivation and goals of their proposals and b) the general plan of execution (MP-level details are not required). Resubmitting ideas which were previously reviewed is discouraged, as older ideas and MPs are tabulated and considered in the subsequent planning process, on equal footing with newer ideas.

Participation in the IF is encouraged of students engaged in fusion research, and typically around 30% of IF submissions come from students, both at MIT and from collaborating universities. Outreach is made to all collaborating institutions, both domestic and international, and, at least in recent years, the entire meeting has been made available for remote participation. All IF information and presentations become archived on the web, at http://www.psfc.mit.edu/research/alcator/program/index.html

Submitting an idea to the IF is an informal process, handled via a simple web form or email to the organizers. A submitter provides (1) a presenter's name, (2) a title and (3) a primary and secondary research area (see table above) to which the Idea is relevant. Over 100 ideas were presented at recent Ideas Fora. These ideas typically request more than one run day. Organizers sort the submitted Ideas into sessions (mostly) according to theme, and tagged with their author-identified topics. Leaders of the various research areas present thematic summaries of their sessions at the close of the IF.

3. Run-time allocation

Shortly after the Ideas Forum, a follow-up process begins to refine plans for the coming run campaign(s), defining a set of priority experiments for the next 1—2 years. This process takes into account the initial run-time allocations assigned to each research area in Stage 1 by the program manager. These approximate numbers are based on total run-time guidance and relative weight of each area, and are always far less than the ideal amount requested for all proposals.

4. Research group meetings

Following the IF, leaders of each research area call open breakout meetings, often with remote attendance capability to support collaborators in the areas, to review proposals and define priorities. The organizational goals include:

- Enumeration of new ideas, ideas from previous IFs and existing MPs
- Discuss and define important themes
- Consolidate ideas as appropriate (sometimes across groups)
- Attempt to fit proposed research within initial run-time allocation for area

Large task force areas may optionally organize into sub-topical areas for more efficient use of meeting time. For example, the Transport area might comprise over 25% of the submitted ideas in a given cycle, and require sub-division into Core, Pedestal, Rotation, etc.

Both within each research area and across areas, agreement is reached on how to assign run time to each proposal. The process often involves consolidation of ideas, and the identification of proposals that can be accomplished without dedicated run-time ("piggyback"), and which experiments will be used to support them ("pigs"). Prioritization is determined based on a set of standard criteria (in no particular order):

- Technical feasibility (i.e. must be 'doable' with current capabilities and without endangering the C-Mod facility)
- Relevance to targets/program milestones
- Potential to contribute to significant publications and/or invited talks
- Relevance to student research and theses

- Overall programmatic relevance
- Contributions to joint research, including ITPA/ITER
- Uniqueness of C-Mod contributions
- Potential for developing new capabilities and/or operational regimes

During this stage, tentative authors of MPs are identified, as well as high-priority run time allotments for each MP. While the amount of requested run time is very large, the actual number of scientists and students making proposals is such that most participants in the process have the opportunity to become first-author on an MP, if they wish. In the case where there are overlapping interests in a particular experiment, efforts are made to give the responsibility of MP writing to students and other young scientists, as well as collaborators from other institutions.

The results of this stage of planning are reported to the EPC. Based on the details of the group reports, the initial run-time allocation provided in Stage 3 may be revised slightly by the program manager.

5. Submit new Mini-Proposals

As the campaign planning process concludes, and prior to the start of the run campaign, the EPC issues a call for new MPs. An MP is a relatively brief document, containing enough information to allow the EPC to evaluate the readiness of the experiment to go forward on C-Mod. Sections include:

1. *Purpose of experiments* --- general description; can include justification in terms of scientific/programmatic goals
2. *Background* --- key information to motivate experiment, documenting the physics basis
3. *Approach* --- what are the main experimental methods and analytical/interpretive techniques to be used?
4. *Resources* --- includes range of machine parameters, wall conditioning, necessary/desired auxiliary systems and diagnostics
5. *Experimental Plan* --- run time required to complete MP; a detailed plan of shot sequence, and for multi-session experiments, the run sequence needed; decision trees and contingency shots can be described here in anticipation of in-run discoveries.
6. *Anticipated Results* --- how will the results contribute to physics program, operation of the machine, programmatic milestones, etc?; how will results be disseminated (e.g. journal articles, international databases)?

These are submitted to an online database, for review by the EPC: http://www.psfc.mit.edu/research/alcator/program/cmod_runs.php?miniproposals&sort=id&dir=desc

For each MP under review, the EPC considers feasibility and likelihood of success of the run plan, and often offers criticism intended to improve the experimental plan. Commonly, MPs are accepted upon their initial submission with minor recommendations for improvement. The EPC requests significant changes to a few percent of MPs, which then get revised and resubmitted for consideration.

Approval by the EPC does not automatically qualify an MP for run time; only high priority proposals (as determined in Stage 4 of this process) may be scheduled. When approving an MP, the EPC does not generally consider its priority level as determined by the Research Groups. This ensures that a significant number of medium-priority experiments are ready to receive run time in the event that higher priority experiments have to be cancelled, or new run time becomes available. In this circumstance, the authors of a lower priority MP may request that their Research Group upgrade its priority. Group leaders may make these reassignments, although if this results in a particular area extending beyond its run-time allocation, EPC approval for the run-time re-balancing must be sought.

Prior to plasma startup, and approximately every two weeks as the run campaign proceeds, the EPC meets, typically on Mondays, to review MPs. In order to be considered by the EPC, an MP must be submitted by a pre-determined deadline, e.g. noon on Friday prior to the EPC meeting. Once approved by the EPC, any MP on the *high priority* list may be scheduled by the RC.

6. Run scheduling

C-Mod operation is nominally 4 days per week, 8 hours per day, usually with a target of 30—35 discharges per day. Experiments are most often designed to use one run day, but it is also common to request multiples of half-days. The RC accounts for this by allowing for an AM run and a PM run on a given day. When it is desirable (often at the beginning or end of a campaign), finer fragmentation of run days is done, sometimes with 3—4 sessions scheduled back to back and each receiving a few plasma shots. There is no prescribed minimum length to a session.

Maintenance weeks are scheduled as needed, especially for configuration changes (ICRF frequency, field reversal, etc). Runs are historically scheduled 1 to 2 weeks in advance. Modifications of schedule are common, although for collaborators travelling to MIT, we make every effort to hold to scheduled times. In recent years, collaborators have successfully led experiments from remote locations.

Since execution of an approved MP requires a defined set of auxiliary systems and diagnostics, the RC must take system availability into account when scheduling runs. To facilitate this, we employ an electronic availability table, available on the web site. Following a login, responsible individuals can toggle the status of their system on/off, and also supply an explanatory comment (e.g. current functionality, timeline for improved capabilities). While the availability table provides guidance, it is best to verify its accuracy by confirming with the key personnel responsible for each critical system, prior to scheduling a run.

The RC uses a web-based calendar service to schedule experiments. It is convenient to maintain a private scratch calendar for tracking prospective system availability and personnel presence, thus providing a framework for doing the initial alignment of MPs to experimental run days. Typically two weeks in advance of a given run week, the draft experimental schedule is copied to a second calendar, which is shared with (and password-restricted to) the entire C-Mod team.

The EPC meets approximately every two weeks during campaigns, to approve new MPs as described above and to monitor the development of the research program. This affords the C-Mod experimental program significant flexibility. Experimental priorities are revisited throughout each campaign, with good new ideas seriously entertained at any time. At times it becomes necessary to re-balance program elements based on changing circumstances, and the EPC has the power to do so. Therefore, the organization of each research area tends to include contingency based on results, evolving capabilities or unforeseen opportunities, and each group is expected to prepare MPs for more run days than available in initial allocations.

7. Experimental Execution

Once experiments are approved and scheduled, their preparation and execution begins. To support run planning and execution, a set of web pages provides researchers with information on all past runs. This information includes descriptions of each day's experiments with links to experimental proposals, run plans, run summaries, logbook entries and data summaries. In general this approach is extensible to any additional information that is organized along similar lines. The web pages are driven from a set of relational database tables that are loaded as part of run execution.

Many people are involved in this phase. Leadership responsibilities are:

Session Leader (SL): Overall scientific responsibility for deciding the plan of the experiment, before and on the day (eg, parameters, order of scans…). Usually the lead author of the MP – a scientist or student. Usually on-site, but we have had off-site collaborators successfully lead experiments using remote participation tools. Most often for an entire run day, but there may be several shorter experiments, with different session leaders, during a day.

Physics Operator (PO): One of a group of physicists with special training in operating the tokamak. This person actually programs the settings and waveforms requested by the session leader (first assuring they are feasible). Always on site; requires communication with engineering operators. Generally serves for a full run day, on a rotating schedule.

Engineering Operator (EO): A senior engineer, who oversees the operation of engineering systems (magnets, vacuum, cryogenics etc), and resolves any technical problems on the day. The EO is responsible for ensuring proper cooling of magnets and nominal power supply behavior, and for enforcing programmed hardware limits, e.g. on power supply currents, which could be otherwise violated by an imperfect PO. On site, EO shifts may change during a run day.

1—3 days before the run:

- Session Leader and Physics Operator consult on, and post shot plans. The electronic SQL-based Logbook utility makes these openly available. Session leader informs leaders of key heating systems and diagnostics requirements, makes sure they will be available. If not, rescheduling or modification of run plan may be needed.

- Physics Operator preprograms waveforms for at least the starting discharges for the experiment, in some cases multiple discharges.

On the run day:

- Physicists responsible for diagnostics set up for expected conditions. Access to instruments in the test cell or diagnostic labs during a run is restricted, but not impossible if changes are needed during an experiment.

- Physicists and engineers responsible for heating and auxiliary systems set up for required input, prepare waveforms.

- Discharges are run with typically 15 minute repetition rate (set mainly by TF cooling, but also vacuum, and time to look at data between shots). Following each shot, session leader and physics operator look at data, decide whether it ran as desired, and whether it should be repeated or changed. Rapid (<5 minutes) access to calibrated diagnostic data and some between-shot analysis is critical here (see below). The session leader is ultimately responsible for deciding the next step (subject to feasibility), with the physics operator programming the waveforms. Modifications to the shot plan, depending on actual results, are common.

- Following each shot, both session leader and physics operator post short comments in the electronic Logbook, on what happened, and plans/changes for the next step. This helps keep all involved in the experiment informed. Individuals responsible for heating systems and diagnostics are also encouraged to post comments – for example any problems noticed in a diagnostic, or interesting observations. It is not uncommon to have dozens of comments per discharge, particularly useful for our offsite collaborators but also for the majority of participants who are in the control room, and for those doing post-run analysis.

- Typical run day is 9am-5pm (set by personnel; C-Mod does not have the key people for diagnostics and other systems to run two shifts). Extended days are run on occasion, though rarely lasting longer than 10 hours.

- Immediately following the session, Session Leader and Physics Operator both post short (~ 1 page) summaries of the day using the logbook. The former focuses on the plasmas run and initial assessment of results, identifying some key shots for further analysis, and the latter focuses on technical issues – what operational techniques worked well, any issues identified. Both can be very helpful to the team preparing later experiments. Summaries can be modified or extended later.

- In the week following an experiment, a short presentation on the progress and preliminary results is expected at the C-Mod Science meeting. Offsite collaborations participate, and may present, remotely.

8. Data Acquisition and Analysis

As noted in the complementary document on data analysis workflows, there exists an initial phase of data processing, in which automated processes (1) acquire and store data, (2) convert data to physical units and apply calibration factors and (3) carry out low level analysis tasks.

Many data acquisition settings (eg, sampling speeds, triggers), are programmed using MDSPlus prior to each plasma shot. All data, raw and processed, for each C-Mod discharge are stored in an MDSPlus 'tree'. The general principle is that ALL information required to understand, and if need be reprocess, data should be stored along with a shot. This includes for example calibration factors, frequency/wavelength settings, gains, attenuations etc. All setup information in the discharge "model" tree can be manipulated by individuals with assigned privileges, up until the beginning phase of the shot cycle. Before the shot is taken, the model trees are copied to pulse files identified by the shot number, and subsequent acquisition, analysis and retroactive changes to settings such as calibration factors must take place in the new pulse files.

Signals are acquired using CAMAC highway for older systems, with many now converted to CPCI. Raw data are archived immediately after a discharge, with the order predetermined taking account the urgency with which they are needed for between shot decisions or analysis. Full data acquisition can take several minutes to complete. Software 'event' signals are sent as each step is completed.

As soon as the required data are available (determined by these 'events'), automatic post-shot analysis begins. These include for example applying calibration factors to raw data to derive physical units, computing viewing and mapping viewing locations vs time, inversions of arrays. Processed data, with units and where possible uncertainties, are written to the MDSPlus tree where they are accessible to any user. Software events may be set when these jobs complete; in many cases one process (eg, EFIT reconstruction) must be completed before another (eg, radial mapping) should begin. Most of the routine post-shot analysis is complete within approximately five minutes, though some more complex systems with large data requirements (eg multi-MHz fluctuation analysis) may take longer.

In a second phase of data processing, interactive tools are used for higher level analysis and manual data review. This is typically in cases where assessment and decisions by experts are required; analysis routines may be run manually, eg by the diagnostician. In this case speed depends on the urgency with which data are needed; it will ideally be between shots, but may be later in the day. In any case, it is understood that control room data, while as reliable as is feasible, may not be 100% accurate. Either hardware or physics issues are often discovered later which may require reprocessing of data, or in some cases mean it cannot be used. For example, ECE cannot give electron temperature in periods where emission was cut off, or dominated by non-thermals. For this reason, good communication with people running diagnostics, before extensive post-shot analysis, is important.

Depending on the experiment, more sophisticated between shot analysis may be run to guide the run planning. Examples include linear GYRO analysis for transport experiments, described in a separate document, or ray tracing/Focker-Planck calculations to assess wave deposition during an RF experiment.

After an experiment, more extensive analysis can extend over days, or months. It is usually coordinated by the session leader or team who led the experiment. But, any member of the C-Mod team, inclusive of collaborators, is free to analyse any data of interest without restriction. The first step is to identify the discharges and time periods which appear useful for the goals of the experiment. Analysts are expected to communicate with operators of key diagnostics, to ensure that data have been validated. This has generally been informal and done in person or by email. A system was recently set up online to help set priorities, allocate resources, and track analysis requests and results, which could be helpful for a large and distributed group such as ITER, but it has not yet been widely used. If need be, calibrations may be adjusted, and any post-shot analysis deriving from these parameters should be rerun.

The type of post-run analysis will vary widely depending on the goals of an experiment. Examples include:

- Computing the power deposition profiles with sophisticated RF codes,
- Inferring local transport coefficients, inversion of radiation profiles and determination of impurity species from spectroscopy.
- Determination of MHD mode spectra.
- Pedestal profiles of not only Te and ne but Ti, rotations and Er.
- Cross-correlation of channels to derive core Te turbulence.
- Simulating turbulence or heating with large numerical codes and comparing synthetic diagnostics to measurements.

In most cases, the results of analysis are written back to the data Tree, where they become available to all users Data trees are highly extensible and, though they are securely backed up, they are never “frozen” Therefore extending the analyzed data set on a given discharge may continue indefinitely.

There is an unmet need for end-to-end tracking of data workflow. Neither the infrastructure nor a set of tools that automatically create, discover, display or explore the relationships of complex data from experiments and computer simulations currently exists. To meet these needs a collaboration between MIT, GA and LBNL has begun work to develop a system that would document workflow and data provenance for scientific domains like fusion energy. The project will allow traceability of workflows from data acquisition through all processing steps that lead to all intermediate and "final products" (for example exportable data bases or publications). The system will support rich metadata, enabling researchers to answer the questions "who, what, when, how and why" for each data element; provide information about the connections and dependences between the data elements and allow human or automatic annotation for any data element. By systematically documenting the activities that transform one piece of data into another, the system will enhance data validation – that is a user could check the validity of a data element by checking the validity of all inputs and outputs through the entire processing chain.

9. Publication and Presentation

As analysis of an experiment matures, it is appropriate and important to present results to the wider community, and to publish in refereed journals.

A typical first step is to present results at an internal meeting, usually the C-Mod Science meeting or in some cases a topical group discussion. This helps to identify any erroneous data or interpretation at an early stage, and is generally helpful in keeping the team informed.

Periodic discussions of analysis and publication plans, within topical groups, are common and helpful in ensuring all key results are covered, and avoiding duplication of effort or later conflict. Proposals for presentation are typically discussed by the entire C-Mod team in advance of major conferences such as APS or IAEA, and a list of speakers identified. Selections generally are made to attempt to raise the profile of particular programmatic aspects of C-Mod research and also to increase the exposure of students and young scientists on the team. Given the relatively small size of the team, there are rarely conflicts about who should present results.

For presentations outside C-Mod, some form of 'dry run' is expected. This varies from circulating slides to contributors for an informal presentation such as an ITPA meeting, to a full practice talk or poster layout for a major conference. For large conference, reviewers are assigned for different topical areas.

For publications to journals, it is expected that all who have contributed in a significant way to the results will be included as authors, and given ample opportunity for input. This includes the people responsible for key measurements, an important way to ensure no erroneous data are published. Draft papers are then submitted for approval to a designated C-Mod scientist, who checks the content for correctness, and also that authorship is appropriate. External collaborators sign an agreement that they understand these policies. (see http://www.psfc.mit.edu/research/alcator/program/collab_agree_2.pdf). For our small group, we do not use an official tracking document, and the approval process usually only takes a few days; there have been no complaints that publications have been prevented or held up.

Experiment Execution Workflow for DIII-D

G. McKee, M. Van Zeeland, D. Thomas

(0) High level research goals established by DIII-D management in accord with DOE, informed by:

- DIII-D 5-year research plan
- Specific milestones
- Annual plan consistent with run-time budget allocation
- Joint Research Targets, DOE Milestones, ITPA and IO requests influence priorities
    - JRTs organized by DOE to jointly address current pressing issues via 3 US exps.
  - Establish High priority Research Thrusts (that change year-to-year)
  - Examples: 3D/RMP/ELM-suppression physics, Disruption physics
  - Research Council provides advice and input
  - Initial runtime guidance from DIII-D Director (run days in research areas, thrusts)
    - 20% contingency time for hardware failures (based on experience)
    - several days of Director's Reserve time allocated each year, decided during year
      - high priority, high value experimental topics get specific run time

(1) Individual researchers submit proposal to DIII-D Research Opportunity Forum (ROF, ~1 page with background, motivation, goals, basic experimental requirements)

- Annual process at DIII-D, typically in November-January time frame (post-APS)
- Web-based process: any and all collaborators and scientists in fusion-plasma field are invited to submit experiment proposals; submission accounts establish for any who request (must be approved by D3D managers)
- topical group leaders may solicit particular relevant experiment proposals

- consider novelty, scientific value, practicality (is it doable?)
- submit to specific research area (e.g., Transport, H/CD, Steady-state, research thrusts)
    - research groups organized by 3 long-term topical areas on D3D as defined by Program and Experimental Director: Burning Plasma Physics, Dynamics and Control, and Boundary and Pedestal Physics, each led by a D3D scientist; Thrusts vary from year-to-year based on high-priority topics for ITER or other program interests
    - each topical area divided into smaller topics (e.g., transport and turbulence, energetic particles, ELM control, etc. to facilitate organization)
- Keep in mind: typically about 10 ROF proposals/run-day-equivalent, run-time in extremely high demand

(2) Attend post-ROF "breakout" meetings in relevant research topical area to organize experimental plan during few weeks after ROF

- organized by subgroup area leaders
- consider various ROF proposals, integrate like proposals, consider programmatic goals, management priorities, etc., invited talks, IAEA-FEC presentations, graduate student theses
- decide on proposed plan (experiments, run days)
- Decisions based on scientific value and motivation, program priorities, novelty, likelihood for success; group discussions and prioritization; topical area leaders make first cut decisions

(3) Research Council reviews plans for research areas, provides advice

- proposed plan may evolve in response to discussion

(4) Management decides on run days/research group

- research areas adjust run days, priorities, but typically follows topical group allocations
- typically follows allocation defined by topical groups
- decide on Session Leaders that organize scientific goals for experiments and run experiment
    - topical area or thrust leader usually decides on session leaders

- consider program balance in deciding run-days and session leaders: D3D consists of scientists from GA, national labs (PPPL, ORNL, LLNL), big and small university collaborators (UCLA, UCSD, UW, MIT, UCI, UCD, U. Toronto, W&M…), younger and more senior scientists, grad students, postdocs: run-time and session leaders may be decided partially based on program balance to insure that interests of all collaborating parties are adequately addressed, particularly over a multi-year time scale

- run time is usually allocated in 1 day increments; 1/2-day experiments may be defined for specific topics that integrate well scientifically; 2-hour segments set aside for specific operational development work (e.g., PCS testing and improvements)

(5) Organize experiment

- hold meeting of relevant parties, topical area

- draft initial shot plans, determine experimental requirements (hardware, diagnostics)

(6) Write experiment Miniproposal (MP) that documents specifics

- process is led by session leader who heads experiment design and execution

- goals, background, shot plan defined

- experimental requirements (define critical vs. desirable requirements)

    - beams, ECH, error field correction

    - identify desired, important and essential diagnostics

    - coordinate with diagnostic leads as appropriate for special requirements

    - if critical systems and/or diagnostics are not available experiment will be rescheduled

- define target shots

- theoretical input on modeling & simulation: theory and computational colleagues are often solicited to provide input to experiments, parameter scans of most value, etc. to define high-level goals for experiment

- realistic experiment goals for one-day experiment (~20-25 good shots)

    - key decision points, prioritization

- work with run coordinator to schedule experiment

(7) Perform experiment on scheduled run day

- organize run plan execution with all interested parties in advance
- Key players
    - Session leader: physicist in charge of experiment, makes key decisions
    - Assistant session leaders: key advises to the session leader who assist with decision making, control room analysis
    - Physics operator: determines machine parameters and waveforms based on session leaders requests
    - Chief operator: coordinates with various engineering groups to insure systems performing as needed
    - Others: Neutral beam timer, ECH physicist, diagnostics coordinator, diagnosticians
- present run plan to technical and physics group (8:05 meeting)
- bring donuts and plenty of coffee to control room!
- run day decision points may be specified in run plan and based on control-room level results obtained, as well as possible hardware systems performance (is ECH and/or Neutral beams and diagnostics performing as required?)
- record shot characteristics, good shots, bad shots, trouble reports
- Present short summary at following day 8:05 am meeting (few slides, what was accomplished, what wasn't, hardware notes, problems)

(8) Evaluate whether contingency time required

- were goals accomplished, necessary data acquired, hardware problems?
- work with Run Coordinator, who organizes schedule for year in consultation with management, if and as necessary

(9) Organize analysis tasks (typically, session leader leads this effort; could be others)

- equilibrium reconstruction
- profiles

- transport/stability/RF/fast ion analysis
- kinetic equilibrium reconstruction
- fluctuation analysis

(10) Specialized analysis tasks

- TRANSP, ONETWO, TGLF, GYRO, GEM, GENE, ELITE, BOUT++, MARS, M3D-C1, TRIP3D, FIDASYM, ORBIT, UEDGE, DIVSOL, B2-EIRENE, TORAY, …
- Hold meetings as necessary to discuss results
- Friday Science meetings: summarize experiment, main findings (superficial)

(11) Write and submit abstracts to relevant conferences and workshops

- (e.g., APS-DPP, IAEA-FEC, TTF, PSI, HTPD, ITPA…)
- approval within DIII-D Program management (research area, experimental director, program director)
- Abstract and publication are requested by individual scientists, with approval from management to avoid overlap; typically a session leader has priority on initial presentations and publications
- publications group for proper formatting and submission

(12) Prepare and submit manuscripts, as appropriate

- May be associated with conferences
- approval within DIII-D Program management (research area, experimental director, program director)
- publications group for proper formatting and submission
- Respond to referees, work with journal, publish, declare victory and celebrate mightily

(13) Consider new experiment ideas based on these and other previous results, and results from other experiments (and back to Step 1)

Experiment Execution Workflow for NSTX

S. Kaye

1. Development of Programmatic Goals, areas of focus
    a. During year prior to operating period
    b. Topical Science Groups (TSGs)* formulate two to three topical research goals based on availability of hardware, other capabilities, ITPA, Joint Research Target (JRT) influences
    c. Three to four goals cross-cutting among the various TSGs are identified as over-arching Programmatic Research Goals (PRGs)
        i. Initial ideas for these PRGs generated by Team Members* or management
        ii. Reviewed and discussed by Team
            1. Three to four topics chosen
            2. Scopes modified; may include content of topics not chosen
        iii. Participating TSG representatives work together to draft goal language
        iv. Reviewed and accepted by TSGs and Program Management
    d. Initial allocation of run days for each TSG made by management prior to the Research Forum
        i. Based on PRG, TSG goal, JRT, ITPA priorities
        ii. Some contingency (20%) is identified, to be used by TSGs to finish experimenal proposals (XPs) that may need another portion of a run day
        iii. Additional allocation given after Mid-Run Review
            1. Remainder of contingency allocated
            2. Progress reports on results, additional needs by each TSG
2. Research Forum (3 days) – Experimental Ideas Proposed
    a. PRGs and TSG research goals distributed to fusion community at large approximately two months prior to Research Forum
        i. Entire community welcome to participate and propose ideas
        ii. Stress that ideas linked to goals, JRT, ITPA priorities have better chance of obtaining run time, but all ideas welcome
    b. Ideas presented during Research Forum in individual TSG breakout sessions (remote participation available)
        i. Ideas can be general or can contain detailed run plan
        ii. Must discuss motivation and how anticipated results can address goals, etc.
        iii. All plenary and breakout TSG presentations on Research Forum website at time of presentation
    c. After all ideas presented, session participants discuss, identify areas of overlap and redundancy, etc.
        i. Suggest modification to original plan

        ii. If overlap, lead responsibility given to those who may not have other XPs, younger researchers, students, but with participation by all
    d. Led by TSG leaders, group will attempt to prioritize proposal ideas
        i. Generally Priority 1, 2 or 3
        ii. Prioritization based on PRGs, TSG goals, ITPA, JRT priorities
        iii. TSG leaders assign **initial** # run of days, when to run to Priority 1 and 2 proposals
            1. Priority 1 takes precedence
            2. When to run (i.e., early, mid, late run) depends on required capabilities, availability of personnel, results from other experiments (if necessary)
            3. Ensures that prioritized run time does not exceed allocation
    e. TSG plans presented to entire Team at end of Research Forum
        i. Areas of overlap identified and resolved as in 2.c.ii
3. Development of individual Experimental Proposals (XPs)
    a. Leaders (as decided in 2.c.ii, 2.e.i) of XPs develop detailed shot plan
    b. Write detailed XP proposal based on template, consisting of:
        i. Overview
        ii. Motivation
        iii. Detailed shot plan
        iv. Device operating requirements (I_p, B_T, etc., shape, configuration, beam and/or RF power, fueling, conditioning, etc)
        v. Required/desired list of diagnostics
            1. "Required" – XP cannot run without this diagnostic (i.e., a turbulence-based XP requires the turbulence diagnostic)
            2. "Desired" – wanted, but not essential. Would still run XP without this diagnostic, even though data from it would be useful.
        vi. Analysis/results dissemination (e.g., ultimate publication and presentation) plans, required tools (software)
    c. XP reviewed by TSG
        i. Physics operator present to identify and resolve operations issues
    d. XP revised by proposers
    e. XP reviewed by Team (general invitation sent out for review meeting?, specific several person review committee identified)
    f. Review led by Run Coordinator (RC)*
        i. Proposer makes presentation?
        ii. Chits generated
        iii. Proposer addresses and resolves chits after meeting
        iv. RC accepts resolution of chits (or schedules re-review if necessary)
    g. Run time for XP scheduled by RC based on capability/personnel availability
        i. XPs run by off-site collaborators (who are traveling to PPPL to run XP) are generally "hard-wired" into the schedule (XP run date

typically fixed and does not change except when machine or diagnostic issues arise)
        ii. Run time allocated in 1 day quanta, sometimes ½ day
        iii. Toward end of run, ¼ day allocations to finish up XP
        iv. XP may be provisionally scheduled for run time prior to final review, but leaving enough time for review and chit resolution (generally at least one week)
            1. In rare instances (unexpected results that offer new insights), an XP may be written with only a few day turn around until XP execution
        v. Run planning meeting every Friday
            1. Finalize following week's run schedule
            2. Discussion of schedule for ensuing one to two weeks

4. Execution of XP
    a. One to two days prior to running XP
        i. Leader contacts diagnosticians to ensure necessary diagnostics available
        ii. Works with physics operators to develop discharge waveforms
    b. Proposer acts as Session Leader during run
        i. Can identify a helper if necessary
        ii. Interfaces with diagnosticians, physics operators to follow shot plan
        iii. Minor modifications to shot plan allowed
            1. Repeats (due to poor discharge conditions, loss of data, results, etc)
            2. Change step sizes in scan
            3. Etc
        iv. Enters comments on shot into electronic? LOGBOOK
    c. Summarizes run at end-of-day meeting
    d. Summarizes run (in more detail) at following Monday's NSTX-U Physics Meeting
    e. good day ~40 shots
5. XP results assessment/analysis
    a. Data accessible to all members of NSTX extended Team
        i. Must have signed NSTX Data Usage and Publication Policy
    b. Leader coordinates assessment and analysis of results
        i. Requests specialized analysis tasks
        ii. Coordinates input from various diagnosticians
    c. Identifies gaps in the data that may require additional run time
        i. RC schedules for additional run time if request can be justified based on XP goals and run time availability
    d. Comprehensive analysis presented at end-of-run Results Review
    e. Analysis should result in publication and/or presentation at scientific conference, or should be an element thereof
        i. Session Leader has right of first refusal on publication reporting overall results and achievement of goals of XP

        ii. Team members can publish follow-up or more specialized results
        iii. Group review of publication and presentation as detailed in [NSTX Data Usage and Publication Policy]()
    f. formal data usage and publication policy
    g. Follow-on experiments possible if good results seen

- Roles and responsibilities

- Topical Science Group
    - Groups centered around physics topics
        - Macroscopic stability
        - Transport and turbulence
        - Waves and energetic Particles
        - Edge (including divertor) physics
        - Materials and plasma facing components
        - Non-inductive startup and rampup
        - Advanced scenario development
        - ITER and cross-cutting
    - Develop research goals in respective areas
    - Allocate run time based on prioritization of XPs
    - Initial review of XPs
    - Followup on analysis of XPs
    - Membership by any member of NSTX Team (on or off-site)
    - Membership informal and fluid
- NSTX-U Team Member
    - PPPL employees and collaborators funded to participate in NSTX-U experiments, analysis or theory research
    - Unfunded collaborators may have access to NSTX-U data and perform analysis or theory through NSTX Team Member contact
    - All need to sign and follow guidelines of NSTX Data Usage and Publication Policy
- Topical Science Group Leader
    - Team member leading the Topical Science Groups
    - TSG Leader assisted by two Deputies; at least one of the three is a theorist (generally one of the Deputies)
    - TSG leader and Deputies chosen by Program managers (with discussion among Team members and nominee; nominee must be willing to serve)
- Run Coordinator – Team member whose responsibilities include:
    - Rotating position (yearly) among Team members having broad overview of program
    - Chosen by Program managers
    - Ensuring programmatic objectives are achieved
    - Coordinating XP reviews and having final approval authority
    - Interfacing among TSG leaders, physics operators, machine engineers for device readiness and capability, researcher availability

  - Scheduling XPs from all TSGs on specific days (generally with a ~3 week day-by-day run plan issued weekly
  - Holding Friday PM Run Planning meeting (during operations) to finalize following week schedule and discuss schedule one to two weeks following
  - Adjusting run plan based on immediate issues
  - Providing summaries of XPs for NSTX-U Weekly Update
  - Generally given honor of presenting major results from entire run period at APS and/or IAEA (in Overview talk)
- Session Leader
  - Usually the lead author of the XP
  - Coordinates researcher, diagnostic availability for scheduled XP
  - Interfaces with physics operator to develop waveforms for XP discharges (prior to XP execution)
  - Interfaces among physics operator, diagnosticians, analysts during XP execution to assess each discharge and prepare for next
    - Has authority and responsibility to make minor modifications to run plan during XP execution
    - Responsible for entering shot-by-shot comments pertaining to physics results into the run LOGBOOK
  - Responsible for summarizing initial results, achievement of goals of XP at Monday Physics meeting following XP, as well as for preparing a summary of the XP results for the NSTX-U Weekly Update
  - Coordinates analysis of XP results among diagnosticians and analysts, presenting results ultimately to TSG and then to full group
  - Lead author on publication and/or presentation of XP results
- Physics Operator
  - Physicist in charge of machine operation (changing and applying discharge waveforms, ensuring proper pre-XP and between-shot wall conditioning, interfacing with machine engineers to ensure all systems are ready for operation, etc).
  - Interfaces with Session Leader before run to develop baseline waveforms for plasma control system
  - Interfaces with Session Leader between shots to plan for next shot
  - Enters comments pertaining to machine operating conditions on a shot-by-shot basis into LOGBOOK

Appendix: Sample Data Usage & Publication Policy Agreement

The DIII-D National Program is a multi-institutional collaboration. In addition, the DIII-D Program extends collaborations and outreach to national and international facilities and organizations to carry out the scientific research called for in the DIII-D Program objectives.

Collaborators are offered full access to DIII-D data as it is collected and analyzed. However, with these privileges come the responsibility for collaborators to ensure that the data used are correct and are correctly interpreted and to ensure that appropriate credit for providing measurements and analysis are given.

The following agreement is intended to help avoid misunderstandings over these responsibilities and to avoid potential loss of data access:

1. No collaborator will be given direct access to unpublished DIII-D data until this agreement has been signed.
2. Presentations at conferences and workshops of papers that make substantial use of unpublished DIII-D results will be coordinated and approved by the DIII-D Director or his designee. For major conferences, a rehearsal presentation to DIII-D peers is normally expected.
3. The DIII-D program has a technical review process for all papers. Papers by General Atomics (GA) researchers must be issued as a GA-A report. Collaborators' papers relating to programmatic results must also publish their papers as GA-A reports. Such papers will be published with DIII-D National Fusion Facility in the journal masthead. Researchers who develop specialized diagnostics or subsystems or carry out specialized analysis with their individual diagnostics or modeling codes, normally submit such papers under their institution's DOE guidelines with their institution in the journal masthead. These papers are also to proceed through DIII-D Program peer review, called "courtesy review" before submission to journals. The DIII-D Director is responsible to assure that publications are not unreasonably withheld or delayed.
4. GA's role in operating the DIII-D National Program for DOE includes the contractual responsibility for technical quality and to disseminate knowledge to the public and the national collaborators. This responsibility is met by posting GA-A reports, after they have cleared DOE review, on the DIII-D publications web site. For papers copyrighted at a collaborator's institution, normally the paper is posted on the collaborator's web site and linked to the GA DIII-D server in a timely manner, or, if the collaborator agrees, the paper will be posted on the DIII-D publications web site.
5. If a computer account is required on a General Atomics Fusion Group system, then the collaborator must contact the User Service Center and sign the "Computer Usage Policies and Procedures and User Responsibilities" document before an account can be issued.

In addition, some general data analysis routines (e.g., GAPROFILES) make use of Atomic Data and Atomic Structure (ADAS) data. ADAS users must abide by rules established in the GA-ADAS Project Agreement executed on February 1, 1999. The primary rules for data users are:

1. Publications using results from ADAS should identify the ADAS database by name and include a reference stating that: "The originating developer of ADAS is the JET Joint Undertaking."
2. ADAS programs, subroutines or data sets may not be transferred to anyone outside the DIII-D Program without the express written permission of the owner of that program, subroutine or data set.

* All fields are required.

DIII-D contact *

Institution *

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(If Institution is not in the list, enter Institution in text box.)

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