NATIONAL TRANSPORT CODE COLLABORATION (NTCC)

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Proliferation of Plasma Core Modeling Codes

- There are at least seven large integrated modeling codes in the US fusion community
  - Plus many smaller codes for private use
- Most of the codes were started in the 1970's
  - Written in FORTRAN with monolithic common blocks
- Largest codes are more than 80,000 lines
  - With thousands of variables in common blocks
- Dozens of code developers
  - Some wrote undocumented spaghetti code
- Becoming increasingly difficult to maintain these old codes or to share modules
  - Physics strengths and capabilities dispersed among the codes
  - Each code has missing pieces
  - Physics packages are intertwined within codes so that they are very difficult to port

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Community Versus Institutional Development of Code

- Avoid duplication — in many instances, major codes have limited differences in terms of physics addressed
- Need to develop code (or codes) that use widely available tools to insure extensive and continued use of code
- Researchers are more likely to use code that is a thoroughly validated community owned code
- Integrated modeling code requires broad input
- Improvements and efficiencies associated with community support and maintenance
- Other research fields have been successful in moving to community codes
  - Young investigators comfortable with modern software tools
    - Particularly encapsulation and web accessibility
  - Diversity of institutions yields diversity of ideas

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Integrated Modeling: What do we mean by it?

- Whole-device description on the transport time scale
- Advanced computation in conjunction with theory and experiment can provide a power new tool for scientific understand and innovation in research
  - Aquire scientific understanding needed for predictive models superior to empirical scaling
  - Multiple uses: prediction, analysis, assessment of models, optimization, diagnostic simulation and development
- Disparate space and time scales
  - Huge range of spatial scales (15 orders of magnitude) and time scales (8 orders of magnitude)
- Multiple models - tradeoff of accuracy versus speed
  - Modern computing framework: support flexible connection of modules; user-friendly interface is practical requirement

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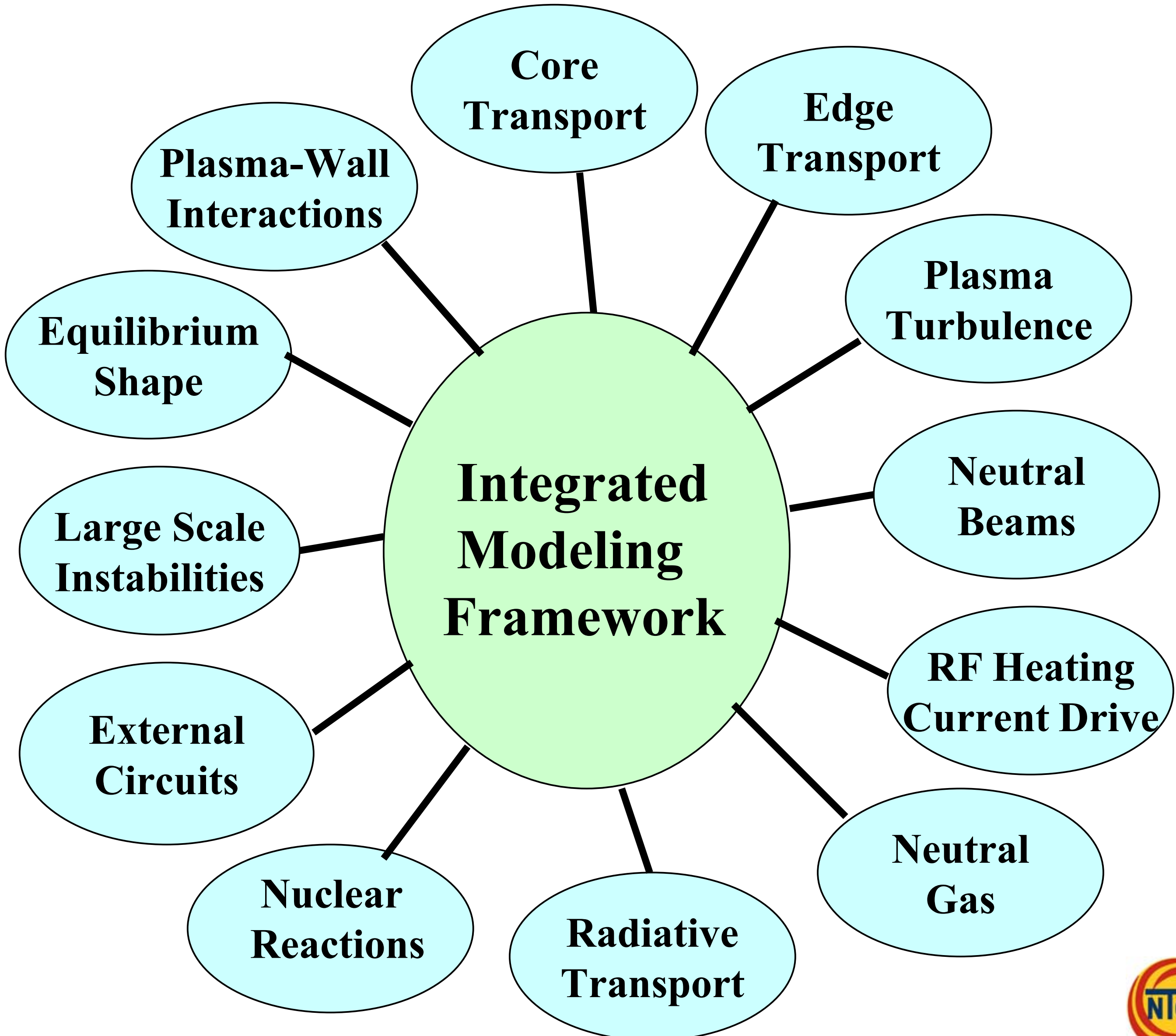
INTEGRATED MODELING CODES



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Purpose of NTCC

- Develop open-source, flexible, easily used, community-based, integrated predictive modeling code for toroidal magnetic fusion devices
- Provide a tool to aid in the understanding of fusion experiments and to plan for future experiments
  - The open-source nature of the project enables contributions from entire fusion community, leads to more rapid development, and reduces duplication
- NTCC code designed to be highly flexible, so that physics and numerical modules can be inserted as they are developed
- NTCC makes use of physics modules extracted from existing codes

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NTCC Objectives

Change way fusion modeling codes are constructed and used based on modern software engineering

- **Module Library - contains portable, re-usable modules with clearly defined interfaces**
- **Web-invocable integrated predictive modeling code**
  - NTCC integrated modeling code designed to bring strongly interacting physics together self-consistently
    - including transport, large scale instabilities, boundary conditions, sources and sinks, and the effects of plasma shape
  - Used to test models against experimental data and predict confinement in new experiments
- **Design a transport modeling code to be used by experimentalists, theoreticians and modelers**

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NTCC Goals

Determine development path for transport code that is

- **Flexibly and modularly written for**
  - inclusion of new physics
  - inclusion of new solvers
  - use in the continuum from analysis to prediction
  - integration of data from multiple sources
- **Useful at multiple levels**
  - Modifiable by multiple developers
  - Easily run by multiple users
    - Scriptable by experienced users
    - Conveniently used by casual users
    - Web invocable to eliminate need to build and port (the WWW has revolutionized computer access)
- **While reusing large base of validated software**
  - Reuse facilitated by Module Library

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NTCC Components

- Module Library
  - Isolated parts of transport codes
- Transport Code
  - For predictive simulations and scenerio modeling
- Data Accessor
  - For uniform access to experimental and simulation data
- Client-Server Framework
  - For Web-invocable code
- Education

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NTCC Module Library

- Web-based, community-owned library of modules
- Each module is self-contained software that is:
  - designed to carry out a specific task (transport model, heating model, numerical technique, …)
  - isolated, with a clearly defined interface (such as an argument list to a procedure or subroutine)
  - with driver program and test cases
  - well documented
  - subjected to review process
- Module library available at http://w3.pppl.gov/NTCC
- Each module is refereed by the module committee
  - to ensure that standards established by the community are satisfied.
- There are now 39 modules submitted and 16 approved

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http://w3.pppl.gov/NTCC

National Transport Code Collaboration

Modules Library   Review Procedures   Download

Guide for Submitters   View Submissions

What Is NTCC?

The goal of the National Transport Code Collaboration (NTCC) project is to bring about a change in the way fusion modeling codes are constructed and used in the fusion community. The objective is to develop modern transport codes to address major physics issues facing the fusion program. To this end, a project is proposed to promote sharing and community ownership of transport code modules (see List of Modules Table in ps for GhostView or in pdf for Acrobat or in html for MAC format) , and to develop a new framework based on modern computing techniques for rapidly assembling customizable transport codes. Development of national transport codes will be based on collaboration among theorists, modelers and experimentalists located in many of the institutions engaged in fusion research.

Who are the NTCC Members?

- General Atomics
- Ga Tech
- Massachusetts Institute of Technology
- Oak Ridge National Laboratory
- Lawrence Livermore National Laboratory
- Lehigh University
- Princeton Plasma Physics Laboratory
- Tech-X Corporation
- University of Texas

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NTCC Module Standards

Module standards designed to facilitate reuse of code

Standards include the following:

- **Source code should:**
  - be isolated through a well defined interface
  - compile and run correctly on different computers
  - include driver program with test cases
  - minimize external dependencies
  - provide error checking
- **Documentation should describe:**
  - how to compile and use the module
  - input and output, interface to module
  - name of contact person for support
- **Modules are reviewed according to these standards**
  - Interaction between referee and author tends to improve modules

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NTCC Module Review Process

- **Modules submitted to the NTCC Modules Library are refereed by the module library committee**
  - Jon Kinsey (chair), Doug McCune, Glenn Bateman, Wayne Houlberg, Lynda Lodestro, and John Mandrekas
- **The module review process involves the following steps:**
  - Authors submitting modules are asked to make sure their modules conform to the published NTCC standards
  - After a module is submitted, a referee is assigned
  - There is usually interaction between the referee and the author resulting in improvements in the module
  - The referee prepares a detailed review, keyed to the standards
  - A module is approved if 4 affirmative votes are received from the 6 members of the module committee

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What Have We Learned About Developing Modules?

- Much harder to develop modules than we thought
  - Documentation that may seem obvious to the author may seem confusing or incomplete to the reader
  - Cross-platform compatibility is difficult to achieve
  - If there is a way to misuse a module, someone will find it
- Nearly everyone in the fusion community likes the idea of a module library
  - The NTCC module library makes it easier to share models
- Module library URL is a useful way to reference modules
  - Each module is complete, documented, and up-to-date
  - Unfortunately, journals do not accept URLs as references
- The process of reviewing modules has greatly improved the usability of the modules

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NTCC DEMO Code Features

- **NTCC project developed a Web-invocable demo code**
- **Code can be used to access data or run simulations**
  - Access data from experiments or other simulations from the International (ITER) Profile Database or MDS+ tree
  - Run transport simulations to predict the time evolution of temperature and other plasma profiles
- **NTCC Web-invocable demo code is easy to use**
  - Can be run from any computer on the internet
  - Provides uniform access to data
  - User can select transport model and other options
  - NTCC demo code can be run as a time-dependent code or run to steady state with fixed plasma conditions
- **NTCC Code calibrated against ITER 1m^2/sec test cases**

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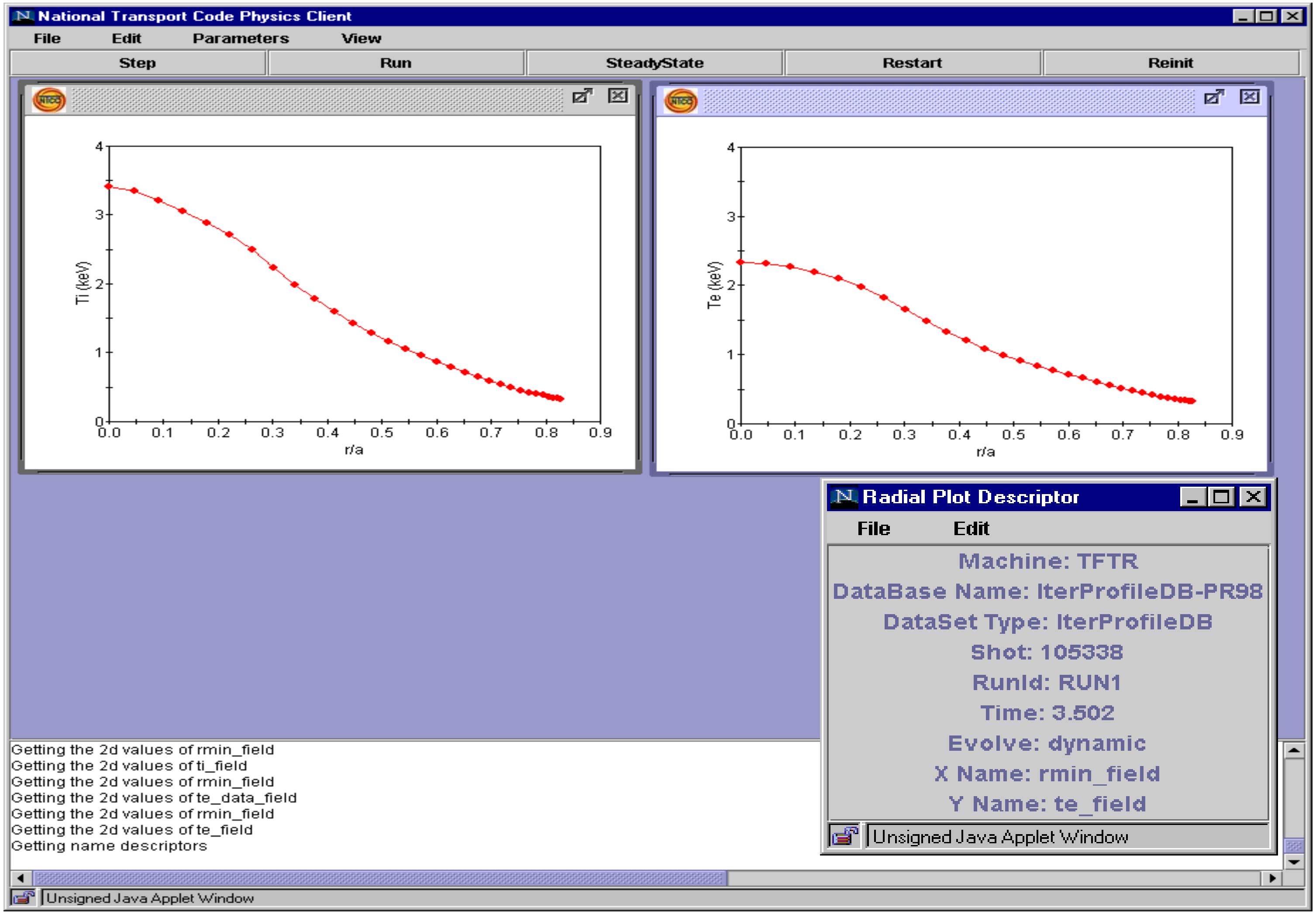
Run the Physics Code From the Web



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Capabilities of the NTCC Transport Code

- Theory-based transport models
  - GLF23, Multi-Mode, IFS/PPPL, and NCLASS
- Access to the entire International (ITER) Profile Database and MDSplus data trees
  - To read sources, sinks, and equilibrium versus time and radius
- Flow shear stabilization
  - Produces internal transport barriers
- Multiple transport equations in time and radius
  - Time evolution of T_i, T_e, momentum, and turbulence profiles
- Results presented at the 2000 IAEA meeting
  - M. Murakami, et al, IAEA-CN-77/EX5/1
  - Simulations of DIII-D impurity injection discharges
    - impurity injection resulted in enhanced confinement

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NTCC Data Accessor

- NTCC Code accesses data through Data Accessor
- Web-invocable NTCC data accessor provides uniform standardized access to databases regardless of source
  - International (ITER) Profile Database
  - MDSplus trees
- Data Accessor applies rules for missing data
  - For example, computes impurity density from Z_{eff}, n_e and Z_{imp}
- Brings data together in a uniform way
  - with standardized set of names and units
  - interpolated in time and radius to a prescribed radial grid
- Web-based documentation
  - with definitions and units for all variables
- Allows single transfer of complex, composite data
  - connected to the NTCC transport code

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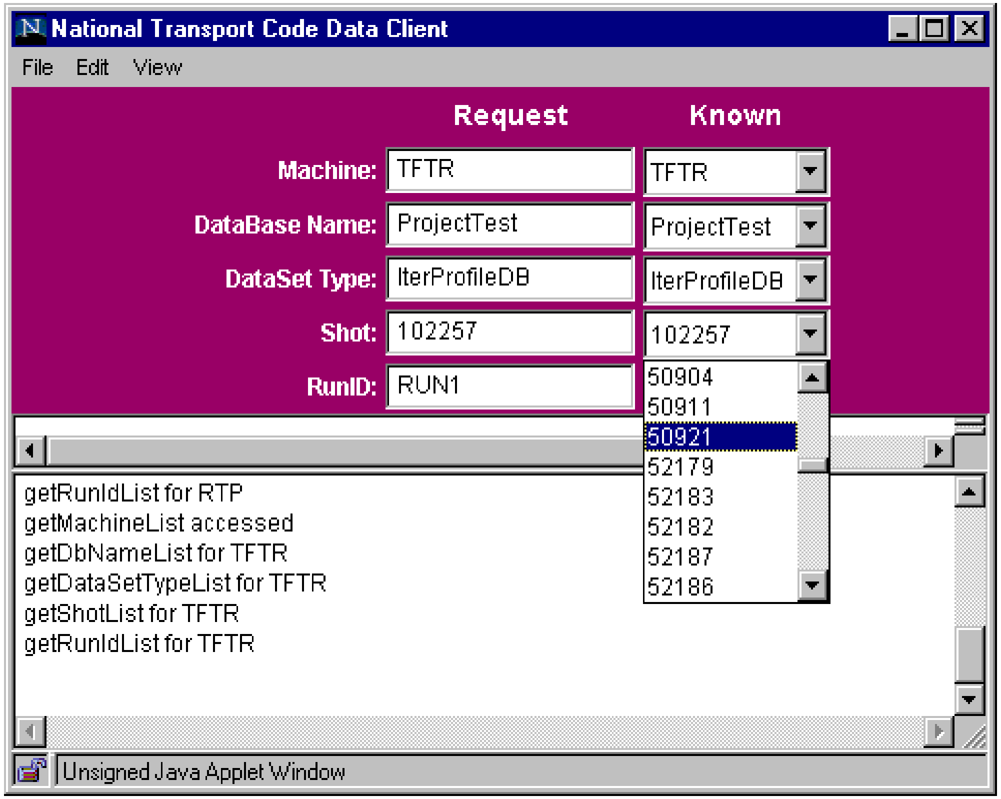
NTCC Data Accessor Menus

- Pull-down menus allow the user to select:
  - tokamak,
  - database name and type
  - discharge number
  - simulation RunID
- Client-server framework for data accessor
  - Server written in C++
  - GUI written in JAVA
  - Data transfers using CORBA



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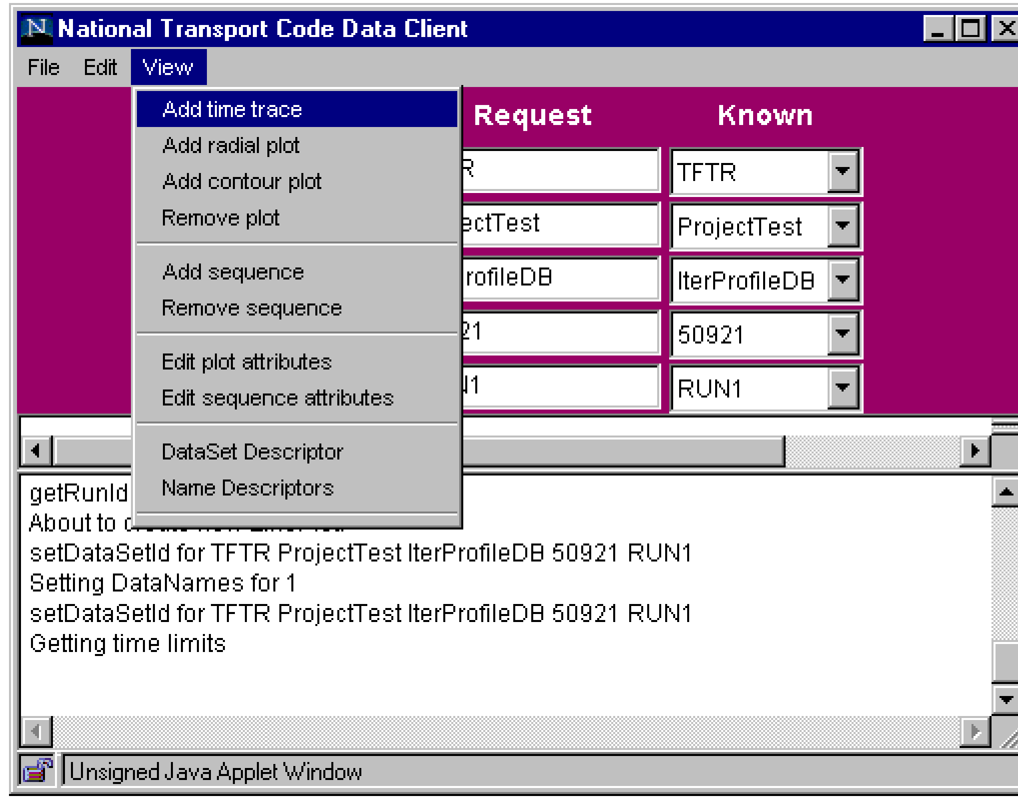
NTCC Data Accessor Menus

- **Pull-down menus allow the user to select plots**
  - Time trace or radial plot
  - Can overlay plots
- **Menu also allows access to descriptions of data**
  - Part of Web-based documentation



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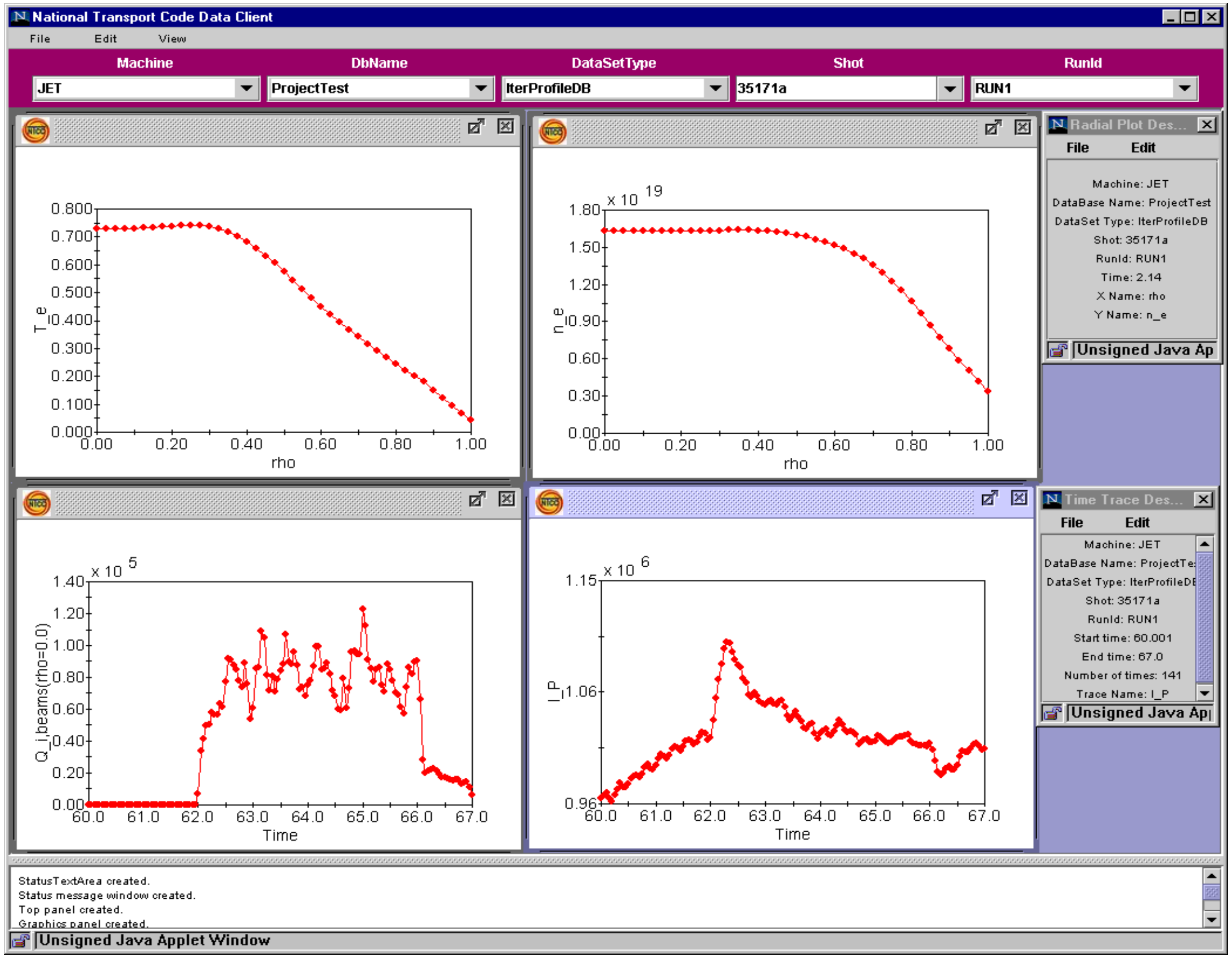
NTCC Has Developed Java Clients For Web-based Examination of Data



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NTCC Client-Server Framework

- The NTCC client-server framework combines the NTCC Transport Code, Data Accessor, and GUI
  - to produce a Web-invocable code with easy-to-use graphical user interface (GUI)
- Framework can use up to 3 computers simultaneously when required
  - (Computer 1) GUI access on local PC, Mac, or workstation
  - (Computer 2) runs powerful simulation code
  - (Computer 3) may contain remote database
- Code written in free, standardized computer languages
  - JAVA language used for client, runs on any computer
  - CORBA used for transmitting data over the internet
    - CORBA is used widely by banks and other companies for secure, standardized data transfers between programs

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NTCC Software

- Designed to produce computer codes that are:
  - Easy to maintain
    - written in modern object-oriented computer languages
  - Customizable
    - scripted code with plug-in modules
  - User friendly, Web-invocable
    - graphical user interface
- Development team is geographically dispersed
  - Developers Web page provides help and aids standardization
  - CVS used to store all versions of the source code
  - Frequent e-mails and conference calls used to keep the developers informed
  - Workshops are held several times a year

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Proposed NTCC Project

- **Current NTCC "demo code" is a transport-model tester**
- **Proposed new project: Develop a full-function integrated modeling code over a three-year period**
- **Preliminary new proposal**
  - Presented to and considered by FFCC in March 2001
  - Reviewed by NTCC PAC in April 2001
    - PAC made suggestions for consideration by NTCC management (A. Kritz, J. Cary, R. Cohen, and D. McCune)
- **New proposal developed by NTCC management**
  - Aided by NTCC Facility Reps – P. Bonoli, M. Murakami and S. Kaye
  - Reviewed by PAC September 2001 – S. Jardin, Chair, T. Casper, V. Chan, P. Collela, M. Greenwald and S. Kaye

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Proposed NTCC Project

- **PAC Report Sept. 19, 2001 – Report intro below**

"The NTCC PAC has reviewed the document 'Proposal for the NTCC: 2001-2004'. We commend the NTCC management for responding in a constructive way to the majority of our April 12th recommendations. We agree with the basic premise of the proposal that there be a staged development of the NTCC Code with clear focus on the needs of the three major U.S. experimental facilities. We also take note that they have responded to our recommendation that there be a project plan and a clear delineation of management responsibilities. We further agree that the increased funding level specified in the proposal is necessary to carry out the plan."

  - Additional PAC recommendations in report were considered and responded to by NTCC Management, October 2001

- **New proposal considered by FFCC in November 2001**

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Scope of the Proposed NTCC Project

- First stage: code to advance temperatures and v_j with a fixed boundary MHD equilibrium solver
  - compute sources and sinks from RF and NBI modules
- In later stages: add multi-species particle transport
  - additional sources/sinks (including fusion reactions), additional transport models, MHD stability computations, free-boundary MHD equilibrium
  - upgrade demo code's graphical user interface, scriptability, and remote access to the code and data
- Gantt Chart details approximately 100 tasks
  - for each task -- start and end dates, dependencies on other tasks, the individuals or groups assigned to carry out the task, and the level of support

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Code and Schedule Are Designed to Address Physics Issues

- What are the effects of heating modulation and gas puffing on transport?
- Which (if any) of the transport models describe heat pinches associated with off-axis heating?
- Do available theory based transport models adequately describe confinement of ICRF minority heated plasmas?
- Can transport models that describe evolution in NBI plasmas also describe ICRF and EC heated plasmas?
- What scenarios in the combined ICRF/LH power space will lead to maximum plasma beta with stability?
- What causes density ITBs in ICRF heated discharges?
- Are the measured profiles consistent with those predicted by transport models when $T_i >> T_e$ or $T_e >> T_i$?

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Milestones and Scheduling - Year 1

- Oct: Initiate Framework redesign
- Mar: Model two-temperature plasma with new framework
- May: Ability to read equilibrium information from EQDSK or MDS plus TRANSP trees
- May: Model lower-hybrid heating and current drive
- May: Store results in local experimental MDS plus trees
- Jun: Ability to model ICRF and ECH
- Jul: Framework capable of handling arbitrary number of dynamic fields tested
- Jul: Ability to model high-harmonic, fast-wave heating
- Jul: Ability to model neutral-beam heated plasmas
- Sep: Ability to model fixed-boundary flux evolution including RF and NB current drive

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Tasks and Level of Effort

- For continuing value to the community
  - add capabilities as dictated by physics objectives
    - requires development of new physics modules
  - ongoing tasks of user support, testing, maintenance
    - code, modules, and documentation, including web sites management, and contingency
- Proposed project -- 6 FTE for 3 years
  - 4.0 FTE devoted to addition of capability
  - 1.3 FTE for the ongoing tasks
  - 0.7 FTE reserved as contingency

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Motivation for Modules Currently Under Development

- **NBI and RF heating modules are needed for integrated modeling codes**
  - **These modules provide self-consistent computations of heating, current drive, and particle sources**
    - **which are needed for scenario modeling of new experiments and fusion reactor designs**
  - **NBI and RF heating modules also compute fast particle energy distribution functions**
    - **Fast particles can affect transport and plasma stability**
    - **Fast particles are spatially redistributed by sawtooth crashes and other large scale plasma instabilities**

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Redesign of NTCC Physics Server Code

- Goal is to facilitate upgrade to a full function integrated modeling code
  - Simplify wrapping of NTCC library modules
  - Maximize and simplify user control
- Physics server redesigned for greater flexibility
  - Interchangeable solvers and solution algorithms
- Parts of redesign now implemented
  - Models by reference instead of inheritance
  - Wrapping of models simplified
- Data server now available as a separate module
  - Serves data in TRANSP trees in MDS+ as well as other databases

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Motivation for Continuing NTCC

- **Proposed project to produce a community integrated predictive modeling code is likely to be of significant value to the fusion community**
  - There is an important benefit of having all the physics together in an integrated predictive modeling code to carry out the scenario modeling of new experiments and to predict the performance of fusion reactor designs
- **Proposed project is well thought through, employs innovative concepts, takes advantage of community capabilities and makes good use of collaborative arrangements**
  - Potential problems are recognized and the NTCC management has an approach to deal with such problems
- **Requested 6 FTE budget is required to carry out the proposed project**

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Need for an Integrated Predictive Modeling Code

- **Despite many codes, many community needs are not satisfied**
  - Physics strengths and capabilities dispersed among the codes
  - Substantial additional investment is required to implement many of the tasks not readily carried out with existing codes
- **Integrated modeling codes can bring strongly interacting physics together in context**
  - Explore synergies between different physical processes
- **Simulations allow comparison of experimental measurements with theoretical predictions**
  - In contrast, specialized computations explore physical processes in isolation
- **Community Approach**
  - Diversity of scientists and institutions yields diversity of ideas

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Benefits of NTCC to Fusion Community

- **Modules in NTCC Module Library comprise a significant contribution from the NTCC project**
  - Contributions to the Module Library allow a wider variety of modules to be shared
  - Fusion community members benefit through the use of these modules in their own codes
  - Modules can be used in stand-alone mode to examine physics issues
- **Integrated predictive capability is needed throughout the world**
  - To understand physics in present-day experiments
  - To help design new experiments
- **A large team is required to develop, maintain and validate a large integrated modeling code**

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