BREEDER NEUTRONICS: U.S. OVERVIEW

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US/JAPAN FUSION NEUTRONICS WORKSHOP
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CRITICAL REQUIREMENTS FOR MEANINGFUL NEUTRONICS EXPERIMENTS

- THE PROGRAM MUST CONTRIBUTE SIGNIFICANTLY TO RESOLVING THE TRITIUM BREEDING FEASIBILITY ISSUES

- ACCURACY GOALS:

  - EXPERIMENT (OVERALL): ~ 5% OR BETTER

  - ANALYSIS (MODELING): ~ 5% OR BETTER

- NO VALUE IN DOING EXPERIMENTS WHERE THE UNCERTAINTIES ARE LARGE AS THEY PROVIDE ZERO INFORMATION

- WE MUST FOCUS ON HIGH PAYOFF EXPERIMENTS

- PRE-EXPERIMENT ANALYSIS AND PLANNING ARE CRITICAL

U.S. CONTRIBUTION TO U.S./JAPAN COOPERATION

A. DIRECT OFE SUPPORT

- ~ 6 MAN-YEARS AT ANL, UCLA, AND ORNL

B. INDIRECT OFE SUPPORT

- ~ 15 MAN-YEARS
- ANL, ORNL, GA, UCLA, LANL, RSIC, AND BNL
- DATA EVALUATION AND COMPILATION
- SHIELDING INTEGRAL EXPERIMENTS
- METHODS DEVELOPMENT
- DATA LIBRARIES AND CODE MAINTENANCE AND DISTRIBUTION

C. INDIRECT NON-OFE SUPPORT (BES, FISSION, ETC.)

- VERY LARGE PRESENTLY
- DRAWS ON PREVIOUS LARGE INVESTMENT
- INCLUDES:
  - DIFFERENTIAL DATA MEASUREMENTS
  - DATA EVALUATION
  - METHODS AND CODE DEVELOPMENT
  - ANALYTICAL BENCHMARKS
  - INTEGRAL EXPERIMENTS

PRESENT ISSUES

PHASE I

- EXPERIMENT #1:
  - DO WE HAVE ENOUGH INFORMATION TO ANALYZE/CALCULATE THE EXPERIMENT?
  - ACCURACIES?
  - WHAT CAN WE LEARN FROM EXPERIMENT #1 IN ORDER TO PLAN BETTER FUTURE EXPERIMENTS?
- EXPERIMENTS #2 AND #3:
  - SCHEDULE
  - CHARACTERISTICS: MATERIALS, GEOMETRY, CONFIGURATION

PRESENT ISSUES

PHASE II

- SCHEDULE
- CHARACTERISTICS: MATERIALS, GEOMETRY, CONFIGURATION
- NEUTRON SOURCE: HIGH OR LOW INTENSITY?
- OPTIONS BEING ANALYZED:

1. EXTENSION OF PHASE I:
   A. LI_2O SLAB WITH MORE HETEROGENITY
   B. KEY ISSUES: ROOM RETURN, ACCURACIES

2. 4π (SPHERE OR CUBE) GEOMETRY:
   A. RELEVANT MATERIALS ARE EXPENSIVE
   B. OTHER LESS EXPENSIVE MATERIALS?

3. RECTANGULAR GEOMETRY WITH ONE SIDE RELEVANT BREEDER MATERIAL
   A. BETTER ACCURACIES?
   B. SPECTRUM AT FIRST WALL: BETTER OR WORSE?

U.S./OFE: DIRECT SUPPORT TO U.S./JAERI COOPERATION ON BREEDER NEUTRONICS

- PLANNING:
  - PARTICIPATE IN PLANNING THE EXPERIMENTS
  - PHASE I WAS PLANNED PRIMARILY BY JAERI
  - U.S. SHOULD BE ACTIVE IN PLANNING PHASE II

- EXPERIMENTAL PERSONNEL:
  - U.S. EXPERIMENTALIST TO PARTICIPATE IN CONDUCTING THE EXPERIMENT AT FNS (TWO PERIODS PER YEAR, EACH PERIOD IS ONE MONTH AND FOUR WEEKS)

- ANALYTICAL:
  - ANALYTICAL BENCHMARKS
  - PRE-EXPERIMENT ANALYSIS (FOR GENERAL PLANNING AS WELL AS FINE TUNING OF THE EXPERIMENTS)
  - POST-EXPERIMENT ANALYSIS: NEUTRON TRANSPORT, NUCLEAR RESPONSE CALCULATIONS, SENSITIVITY ANALYSIS, ETC. (A GOOD PART OF OUR EFFORT)
  - PROVIDING JAERI WITH "STANDARD" LIBRARIES AND CODES

- EXPERIMENTAL TECHNIQUES AND INSTRUMENTATION DEVELOPMENT:
  - DEVELOP AND PROVIDE INSTRUMENTATION FOR KEY MEASUREMENTS; DETAILS HAVE BEEN AGREED UPON

- MATERIALS:
  - BERYLLIUM FOR LATTER PART OF PHASE I
  - BREEDER MATERIAL FOR PHASE II (COST SHARE?)

OTHER GENERAL ITEMS OF COLLABORATION

- PERSONNEL EXCHANGE AS APPROPRIATE, E.G., JAERI ANALYSTS VISITS TO US

- JOINT WORKSHOPS: ONCE PER YEAR

- INFORMATION EXCHANGE:
  - EXPERIMENTAL RESULTS WILL BE PROVIDED BY JAERI TO THE US. CARE WILL BE EXERCISED IN DISSEMINATING THE INFORMATION TO THOSE OUTSIDE THE COLLABORATION. PUBLICATIONS WILL REQUIRE PRIOR JOINT APPROVAL BY THE TWO TECHNICAL COORDINATORS (NAKAMURA AND ABDOU).

- ENHANCE COLLABORATION ON OTHER AREAS OF NEUTRONICS:
  - NUCLEAR DATA MEASUREMENTS, EVALUATION
  - DATA LIBRARIES
  - METHOD AND CODE DEVELOPMENT

US-JAPAN COLLABORATION

TERMS OF AGREEMENT

OBJECTIVES

PLAN AND CONDUCT JOINT NEUTRONICS EXPERIMENTS AT FNS AND ANALYZE THE RESULTS FOR THE PURPOSES OF:

- IDENTIFYING DEFICIENCIES IN DATA AND METHODS.
- PROVIDING KEY INPUT TO PREDICTING THE OVERALL UNCERTAINTY IN PRESENT ESTIMATES OF BREEDING RATIO FOR CANDIDATE BLANKET CONCEPTS. FEASIBILITY ISSUE: CRUCIAL TO REJECTION/SELECTION OF CANDIDATE BLANKET CONCEPTS AND DEMONSTRATING THAT A FEASIBLE ENGINEERING CONCEPT EXISTS.
- VALIDATING METHODS AND DATA.

TIME	M-2	M-1	M	M+1	M+2	//	M+5	M+6
			EXPERIMENT "I" (M to M+1)				EXPERIMENT "I+1" (M+5 to M+6)	

ORGANIZATION	PRE-ANALYSIS TO EXPERIMENT "I+1"	POST-ANALYSIS TO EXPERIMENT "I"
UCLA	• GEOMETRICAL SENSITIVITY ANALYSIS, E.G.: - ROOM RETURN EFFECT - VARIATION IN ENERGY AND ANGLE OF THE SOURCE - FIRST WALL INCLUSION - COOLANT CHANNELS INCLUSION, ETC. • COMPARE PRE-ANALYSIS RESULTS TO THOSE OBTAINED BY ANL	• CROSS-SECTION SENSITIVITY AND UNCERTAINTY ANALYSIS TO EXPERIMENT "I"--COMPARE UNCERTAINTY RESULTS TO DISCREPANCIES BETWEEN MEASUREMENTS AND ANALYTICAL ESTIMATES (IF ANY) • EVALUATE PERFORMANCE USING TRIDENT-CTR AND GENERATE ϕ, ϕ^* • UTILIZE ALSO ϕ, ϕ^* PROVIDED BY ORNL • COMPARE TRIDENT-CTR AND DOT 4.3 RESULTS
ORNL		• PERFORM 2D CALCULATION WITH DOT 4.3 AND DOT 3.5 (BASED ON ENDF/B-V AND IV, RESPECTIVELY) • PROVIDE RESULTS OBTAINED WITH DOT 3.5 TO UCLA TO SEND TO JAERI • PROVIDE UCLA WITH ϕ, ϕ^* (BASED ON ENDF/B-V) • STUDY THE EFFECT OF USING VARIOUS NUMERICAL APPROXIMATIONS (E.G., BIASED AND SYMMETRIC QUADRATURE, FIRST COLLISION SOURCE, ETC.)

TIME: M-2 | M-1 | M | M+1 | M+2 | M+5 | M+6

EXPERIMENT "I" (M to M+1)

EXPERIMENT "I+1" (M+5 to M+6)

ORGANIZATION	PRE-ANALYSIS TO EXPERIMENT "I+1"	POST-ANALYSIS TO EXPERIMENT "I"
LANL	← DATA & CODES →	

LANL

- GENERATE THE MULTIGROUP CROSS-SECTION LIBRARY BASED ON ENDF/B-V AND IV--REFERENCE DATA LIBRARIES
- GENERATE PARTIAL CROSS-SECTION LIBRARY
- GENERATE COVARIANCE MATRICES LIBRARY
- PROVIDE ASSISTANCE IN CODES IMPLEMENTATION AND APPLICATIONS (E.G., MCNP, TRIDENT-CTR, SENSIT-2D, ETC.)

ANL

Pre-analysis to Experiment "I+1":

- PRE-ANALYSIS TO EXPERIMENT "I+1" TO STUDY THE EFFECT OF:
  - ROOM RETURN EFFECT
  - VARIATION IN THE SOURCE CHARACTERISTICS
  - INCLUSION OF ADDITIONAL MATERIAL OR ZONES TO EXPERIMENT "I+1", E.G., FIRST WALL, MULTIPLIER, COOLANT CHANNEL, ETC.
- PERFORM PRE-EXPERIMENT ANALYSIS TO THE EXPERIMENTS OF PHASE II (CONTINUED TASK DURING PHASE I)

Post-analysis to Experiment "I":

- CALCULATE NEUTRONICS PERFORMANCE USING MCNP AND MORSE CODES (USING ENDF/B-V AND IV, RESPECTIVELY)
- PROVIDE RESULTS OBTAINED WITH MORSE CODE TO JAERI TO COMPARE WITH MORSE-CG AND MORSE-DDX

$TBR \equiv$ TRITIUM BREEDING RATIO

$T_R \equiv$ REQUIRED TBR

$$T_R = 1 + G_O + \Delta_G$$

$G \equiv$ DOUBLING TIME MARGIN

$\Delta_G \equiv$ UNCERTAINTY IN REQUIRED G

DOUBLING TIME MARGIN

- REQUIRED TO COVER FOR:
  - LOSSES DUE TO RADIOACTIVE DECAY OF T BETWEEN PRODUCTION AND USE
  - SUPPLYING INVENTORY FOR STARTUP OF OTHER FUSION REACTORS
  - HOLD UP INVENTORY TO ACCOUNT FOR TIME DELAY BETWEEN T PRODUCTION AND USE AS WELL AS RESERVE STORAGE
- G_O IS A FUNCTION OF:
  - $I \equiv$ TRITIUM INVENTORY (BLANKET, FUELING, STORAGE, ETC.)
  - $T_D \equiv$ DOUBLING TIME

$\Delta_G \equiv$ UNCERTAINTY IN G_O

- EXAMPLES OF UNCERTAINTIES ARE:
  - T INVENTORY IN BLANKET
  - NECESSARY STORAGE RESERVE
  - T FRACTIONAL BURNUP IN THE PLASMA

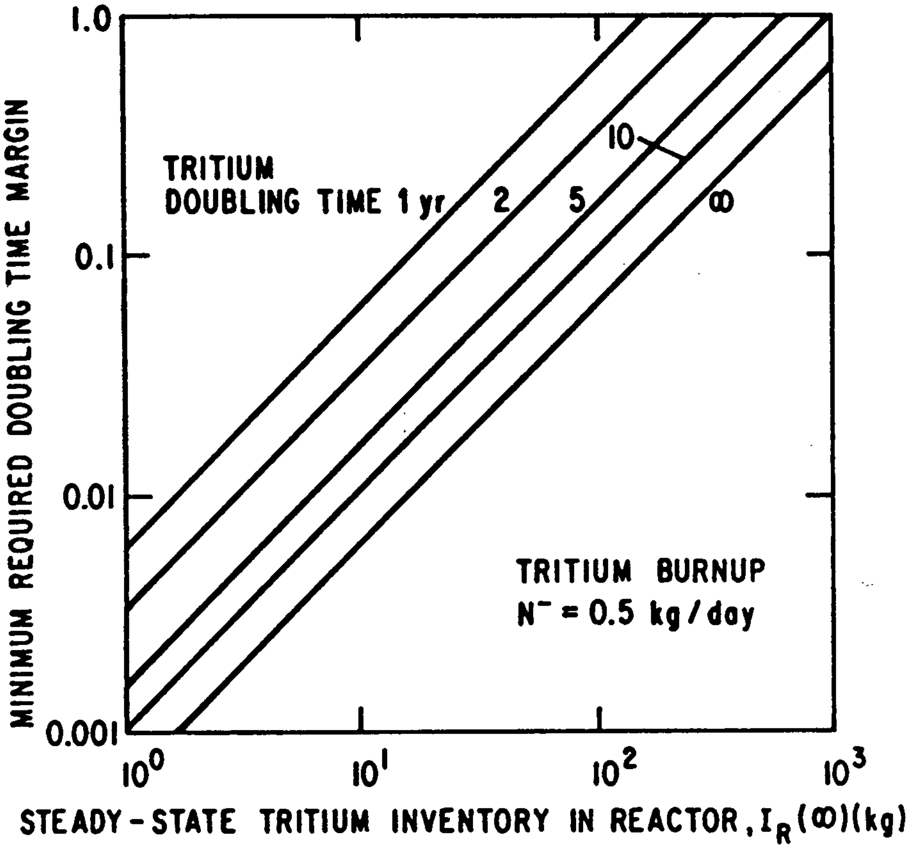

Figure III.2-2. Minimum required doubling time margin as a function reactor tritium inventory at several values of the doubling time.

$T_A \equiv$ ACHIEVABLE TBR

- PROBLEM: WE CANNOT PREDICT PRECISELY T_A BECAUSE:
  - WE DO NOT KNOW THE EXACT SPECIFICATIONS OF WHAT TO BUILD
  - FOR GIVEN REACTOR SPECIFICATIONS, WE CANNOT PREDICT PRECISELY THE PERFORMANCE

- WE CAN ONLY CALCULATE A TBR FOR A REFERENCE SYSTEM WITH ASSUMPTIONS ABOUT ITS SPECIFICATIONS

$$T_A = T_C - \sqrt{\Delta_S^2 + \Delta_P^2}$$

$T_C \equiv$ TBR CALCULATED (THE BEST WE KNOW HOW TODAY, 3D, ETC.) FOR A SPECIFIED BLANKET IN A SPECIFIED REACTOR

$\Delta_S \equiv$ UNCERTAINTY ASSOCIATED WITH <u>SYSTEM DEFINITION</u> [CHANGES IN CALCULATED TBR RESULTING FROM CHANGES IN THE REFERENCE REACTOR SYSTEM (E.G., REFERENCE REACTOR SYSTEM HAS LIMITER AND REACTOR TO BE BUILT COULD HAVE A DIVERTOR)]

$\Delta_P \equiv$ UNCERTAINTIES IN <u>PREDICTING</u> TBR FOR A GIVEN SYSTEM

$$\Delta_P = \sqrt{\Delta_M^2 + \Delta_D^2 + \Delta_C^2}$$

$\Delta_M \equiv$ UNCERTAINTIES ASSOCIATED WITH GEOMETRIC <u>MODELING</u>

$\Delta_D \equiv$ UNCERTAINTIES ASSOCIATED WITH NUCLEAR <u>DATA</u>

$\Delta_C \equiv$ UNCERTAINTIES ASSOCIATED WITH <u>CALCULATIONAL</u> METHODS

TYPES OF UNCERTAINTIES IN PREDICTING ACHIEVABLE TBR

UNCERTAINTIES ASSOCIATED WITH SYSTEM DEFINITION (Δ_S)

- FIRST WALL/BLANKET DEFINITION
  - CONFIGURATION DETAILS, STRUCTURE, COOLANT, MANIFOLDS, FORM AND POROSITY OF SOLID BREEDERS, THERMOPHYSICAL PROPERTY VARIATIONS, ETC.

- REACTOR DEFINITION
  - TECHNOLOGY CHOICES (TYPE OF RF VS. NEUTRAL BEAMS, LIMITER VS. DIVERTOR, ETC.)
  - REQUIREMENTS AND SPEFICICATIONS FOR SPECIFIC TECHNOLOGY CHOICES (E.G., SIZE AND CONFIGURATION OF PENETRATIONS FOR LIMITER, MATERIAL CHOICES FOR LIMITER)
  - PRESENCE OF YET UNDEFINED COMPONENTS (E.G., PENETRATIONS FOR DIAGNOSTICS AND FUELING, I&C
  - POSSIBLE NEED FOR COMPONENTS TO SATISFY YET UNDEFINED REQUIREMENTS (E.G., PASSIVE COPPER COILS IN THE BLANKET FOR PLASMA STABILIZATION, SECTOR TO SECTOR ELECTRICAL JOINTS, ETC.)

$\Delta_P \equiv$ UNCERTAINTIES ASSOCIATED WITH PREDICTING TBR FOR A GIVEN SYSTEM

- APPROXIMATIONS IN GEOMETRICAL MODELING (Δ_M)
  - APPROXIMATING ENGINEERING 3D SURFACES AND VOLUMES BY TRADITIONAL MATHEMATICALLY CONVENIENT SHAPES (INTERSECTION OF CONES, CYLINDERS, SPHERES, CUBES, ETC.)
  - APPROXIMATING DISCRETE BY CONTINUOUS GEOMETRIC ZONES
  - APPROXIMATING THE DETAILS OF HETEROGENITY
- NUCLEAR DATA (Δ_D)
  - UNCERTAINTIES IN BASIC NUCLEAR DATA
  - APPROXIMATIONS IN DATA PROCESSING
  - APPROXIMATIONS IN FINAL DATA LIBRARIES (NUMBER OF ENERGY GROUPS, WEIGHTING FUNCTIONS, ETC.)
- CALCULATIONAL METHODS (Δ_C)
  - INHERENT IN METHODS AND CODES
  - INTRODUCED BY ANALYST (E.G., ORDER OF S_N, P_N, ETC.)

PROPOSED FIGURE OF MERIT FOR TBR

$$I = \frac{T_C - (1 + G_0)}{\sqrt{\Delta_G^2 + \Delta_S^2 + \Delta_P^2}} \qquad 0 < I < 1.0$$

T_C ≡ NET TBR CALCULATED FOR THE BLANKET UNDER CONSIDERATION IN 3D GEOMETRY FOR REFERENCE REACTOR CONDITIONS (E.G., MARS WITH A SET OF ASSUMPTIONS ABOUT DESIGN CHOICES; OR STARFIRE WITH SPECIFIED LIMITER, LOWER HYBRID, ETC.)

G_0 ≡ REQUIRED DOUBLING TIME GAIN UNDER REFERENCE CONDITIONS AND ASSUMPTIONS

Δ_G ≡ UNCERTAINTY IN PREDICTING REQUIRED DOUBLING TIME MARGIN

Δ_S ≡ UNCERTAINTY ASSOCIATED WITH SYSTEM DEFINITION

Δ_P ≡ UNCERTAINTY IN PREDICTING TBR FOR A GIVEN SYSTEM

PROCEDURE AND RESPONSIBILITIES

- EACH CONCEPT DESIGN GROUP WILL DEVELOP THE BLANKET DESIGN TO THE DEGREE OF DETAIL REQUIRED FOR CALCULATING T_C
- JUNG (WITH ASSISTANCE FROM OTHERS) WILL CALCULATE T_C FOR TOKAMAKS
- T_C FOR MIRRORS WILL BE CALCULATED BY: ? AND GORDON
- UNCERTAINTY TERMS WILL BE EVALUATED FOR EACH CONCEPT FOR BOTH MIRRORS AND TOKAMAKS:

Δ_G	JUNG
Δ_S	GOHAR/JUNG/SHIN/ABDOU
Δ_M	SHIN/ABDOU/JUNG
Δ_D	YOUSSEF
Δ_C	GOHAR/JUNG/YOUSSEF/ABDOU

TRITIUM BREEDING PROGRAM

- REDUCE UNCERTAINTIES IN PREDICTING TRITIUM BREEDING RATIO (T)
- IMPROVE PREDICTABILITY OF UNCERTAINTY IN T

TRITIUM BREEDING PROGRAM ELEMENTS

REDUCE UNCERTAINTIES IN PREDICTING T

- DESIGN DEFINITION:
  - NARROW MATERIALS AND DESIGN CONCEPTS
  - GREATER ENGINEERING DETAIL
- CALCULATIONS:
  - MODEST IMPROVEMENT IN METHODS
  - MORE DETAILED GEOMETRICAL MODELING
- NUCLEAR DATA:
  - MEASUREMENTS
  - EVALUATION
  - DATA REPRESENTATION AND PROCESSING

TRITIUM BREEDING PROGRAM ELEMENTS (CONTD.)

IMPROVE PREDICTABILITY OF UNCERTAINTY IN T

- INTEGRAL EXPERIMENTS:
  - BASIC EXPERIMENTS
  - SIMPLE ENGINEERING EXPERIMENTS
  - MOCK-UP
- SENSITIVITY ANALYSIS:
  - IMPROVE METHODS
  - PERFORM SENSITIVITY STUDIES

(GEOMETRY, MATERIAL COMPOSITION, CROSS SECTIONS, SECONDARY NEUTRON SPECTRA)