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DPST-83-566

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June 6, 1983

MEMORANDUM

TO: M. R. BUCKNER

FROM: P. B. PARKS AND R. G. WILLARD
PBP RGW

THE MARK 15 MARCO LIBRARY AND RECENT UPDATING OF THE MARCO CODE

INTRODUCTION

A demonstration Mark 15 charge is scheduled for irradiation in July, 1983. Site conversion to the Mark 15 is planned for FY-85. This charge, as are all SRP charges, will be designed by determining the number and location of fuel, absorber and control assemblies to yield efficient production and to operate safely.

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* This copy contains only the Introduction and Summary of DPST-83-566.

** This copy includes source listings of SEPSERCH and MARCOLIB on microfiche.

An important parameter of the charge design is the margin-of-control (MOC). The MOC is defined as the degree of reactor subcriticality when all safety rods are withdrawn and all control rods are fully inserted with maximum reactivity conditions (zero power temperatures with Xe135 decay and buildup of Sm149 and Pu239 accounted for). The MARCO code[1-3] predicts the MOC at start and end-of-cycle (or stage). In addition, MARCO predicts the critical rod settings at the initial (zero power) critical condition. MARCO also calculates "statistical weights" used by RRMT to provide updated calculations of the MOC and other parameters based on both calculated and measured reactor power distributions. This report describes the library of cross section information needed by MARCO to compute the MOC, critical settings, and statistical weights for Mark 15 charges. Recent changes in the MARCO code are also documented.

SUMMARY

The Mark 15-MARCO library contains cross section correlations for the Mark 15 fuel, septifoil, sparjet and Mark 60B assemblies. The fuel correlations are applicable to both the control zone and buckled zone Mark 15 assemblies. Two separate septifoil correlations are provided in view of the fact that Gang 3 of the Mark 15 PKL charges will have a less absorptive control rod complement than the complement presently used for the other gangs. New correlations were not created for sparjet and Mark 60B blanket assemblies. Correlations previously created for the Mark 16-31-MARCO library were used for these assemblies in the Mark 15-MARCO library. These correlations are acceptable for Mark 15 charge design use because the accuracy requirements for these low statistical weight assemblies are not as stringent as those for the Mark 15 and septifoil assemblies.

The addition of the Mark 15-MARCO library to the previously existing Mark 16-31 and Mark 22 libraries required several changes in the MARCO code. These changes are documented in the Appendix of this report. The new version of the MARCO code has undergone extensive testing with previously run problems for Mark 16-31 and Mark 22 charges to ensure that the required changes have not altered the results of previous problems.

In addition, the Mark 15 library has been tested by comparing the MOC predicted by MARCO to the MOC predicted by direct GLASS-GRIMHX calculations. At start of cycle, the nominal Mark 15 charge will have a MOC = .0146 when computed with the direct GLASS-GRIMHX codes. MARCO predicts a slightly conservative MOC = .0137. Direct GLASS-GRIMHX calculations of the MOC at end-of-cycle are not practical. At end-of-cycle, the MARCO predicted MOC = .0252 when allowing for partial rod burnup and twenty five days of cooling after shutdown.

The appendix of this report also contains a user's guide to execution of MARCO for Mark 15 charges. In addition, the methodology used to create the Mark 15-MARCO library is documented to serve as a model which may be used in creating new libraries for future charges.

DISCUSSION

This dicussion is designed to accomplish two tasks:

A. Introduce the Mark 15-MARCO library within the context of an overview of the methodology of MARCO;

B. Assess the accuracy of MARCO calculations of the Mark 15 MOC at beginning of cycle.

Details of MARCO methodology, a user's guide to MARCO calculations, and a discussion of the library creation methods are provided in the Appendices.

A. MARCO Libraries

Table 1 lists the correlations and other members of the Mark 15-MARCO library by the names of the JOSHUA records created for the STD data set. The independent variables and ranges of values encompassed by each correlation for the non-septifoil assemblies are also listed. These correlations may be used with confidence as long as the variables do not fall too far outside the ranges listed. For instance, the anticipated value of the moderator purity, expressed as the hydrogen atom percent ratio, for the demonstration charge will be $\sim$.63. This is just outside the range of the HATMRATO variable, yet tests of the accuracy of the MARCO predicted, shutdown reactivity at that purity reveal errors of $\leq$ 0.1% in k_{eff}.

B. MARCO Methodology

MARCO is built around a reactor diffusion theory calculation of the neutron flux distribution in two energy groups for a shutdown reactor. In reference 1, the reactor calculation was provided by a two dimensional, hexagonal geometry code called VAGE which is based on the now obsolete GAUGE code. However, the MARCO code has been modified since reference 1 to use the GRIMHX two dimensional diffusion theory code in place of VAGE.[2]

As reported in reference 1, MARCO will provide calculations of the shutdown reactivity, defined as the reactivity with all control rods fully inserted (but without safety rods). The margin-of-control

(MOC) is defined as the difference in reactivity between the critical condition, $k_{eff} = 1.0$, and the shutdown condition, k_{eff_s}.

$$MOC = 1.0 - k_{eff_s}$$

MARCO also will predict the critical rod settings (i.e. the position of the control rods at the initial, zero power critical condition). Alternatively, if the critical rod positions are known, MARCO can be used to calculate a critical reactivity, k_o. Ideally $k_o = 1.0$, but as in all reactivity calculations, k_o will, in general, have a small error, or bias. If k_o is known from analysis of previous reactor startups, MARCO redefines the MOC as

$$MOC = k_o - k_{eff_s}.$$

For the demonstration charge in K reactor, no basis of prior startups exists to determine k_o. Thus, for this first calculation, k_o must be presumed to be exactly unity.

B.1. Fuel or Target Cross Section Preparation by MARCO

The central task of MARCO is to prepare the fuel or target cell cross sections for the shutdown and initial critical conditions. Those conditions are quite variable even for simple, unstaged charges such as the Mark 15. The shutdown cross section will depend on the moderator temperature. If the startup follows an unplanned but temporary shutdown, the cross sections will also depend on the previous exposure of the charge and the elapsed time since shutdown. The dependence on previous exposure accounts for changes in the isotopic content of the fuel due to fuel burnup. The dependence on elapsed time since shut down accounts for further changes in the Xe135, Sm149 and Pu239 contents due to the decay of the Xe135 and the buildup of Sm149 and Pu239 through the decay of Pm149 and Np239, respectively.

At the beginning-of-cycle, the fuel is quite uniform, both axially and radially, across the reactor. There is no particular need for the MARCO code to compute the MOC at BOC. Cross section generation is quite easy to perform in independent calculations with a transport code such as GLASS[4]. These cross sections may be used in a GRIMHX stand-alone-calculation of the MOC. We use MARCO at BOC primarily for its convenience and its critical rod setting and statistical weight predictions. However, once the fuel has been exposed, the independent GLASS-GRIMHX calculation becomes highly impractical. The exposure of the fuel varies across the entire reactor, creating the need for numerous GLASS calculations, one for each small subregion of the reactor over which the exposure may be presumed reasonably uniform. MARCO was designed to cope with just such a situation.

To obtain the region dependent cross sections for previously exposed fuel or targets, MARCO is run in conjunction with a prior JASON[5,6] calculation of the hot-dirty reactor condition. JASON prepares axially averaged, hot-dirty cross sections for each cell position from previously prepared cross section correlations for all assemblies except the septifoils. These hot-dirty cross sections depend on the local exposure and other independent variables. Reference 7 describes the independent variables of the Mark 15-JASON library of cross sections.

The MARCO libraries contain only changes in the cross sections of fuel and target assemblies when making the transition from hot-dirty conditions at power to shutdown conditions prior to startup. Thus, the basic methodology of the JASON-MARCO combination of codes for predicting shutdown reactivity and other parameters is that the shutdown cross sections of fuel or targets are obtained by first calculating hot-dirty cross sections with JASON and then changing those cross sections in MARCO to form the shutdown set.

The current version of MARCO prepares shutdown cross sections for fuel assemblies with

$$\Sigma'_{MARCO} = \Sigma_{JASON} + C_1(1-f_{Xe}) + C_2(1-H) + C_3\,F(t) \qquad (1)$$

where f_{Xe} is the fraction of equilibrium xenon at startup, $H = \frac{T-20^\circ}{70^\circ}$ with T the moderator temperature at startup, and $F(t) = 1 - e^{-\lambda t}$ where t = elapsed time since shutdown and $\lambda = \frac{\lambda_{Np} + \lambda_{Pm}}{2}$. The constants C_1, C_2, and C_3 constitute part of the MARCO library and are contained in the JOSHUA records

INPUT.MARCO.LIBRARY, MARK15.(Fuel name).0.

MARCO has a provision by which the cross section Σ'_{MARCO} may be "fine tuned" by adjusting Σ_{c_2} of the fuel such that the Δk_{eff} computed by GLASS in going from hot-dirty to shutdown conditions is maintained. The reference Δk_{eff} value is computed with

$$\Delta k_{eff} = \Delta k_{Xe}\,(1-f_{Xe}) + \Delta k_T(1-H) + \Delta k_{Sm,Pu}F(t) \qquad (2)$$

where the constants Δk_{Xe}, Δk_T and $\Delta k_{Sm,Pu}$ account for the changes in reactivity due to total Xe decay, temperature change, and complete buildup of Sm149 and Pu239 through Pm149 and Np239 decay. These constants constitute the remainder of the fuel library and are stored in the JOSHUA records

INPUT.MARCO.DELTAK.(Library Name).(Stage Name).

However, as discussed in Section C, no such record has been created for the Mark 15-MARCO library since "fine tuning" leads to overly conservative estimates of the MOC in Mark 15 charges.

B.2 Septifoil Cross Section Preparation by MARCO

MARCO libraries contain two types of cross section sets for septifoils. In the FEWGRP set, cross sections have been created for each gang which represent no rod insertion (FZ0), five rod insertion with the two partial rods at 800 VU (FZ5) and seven rod insertions with all rods at 1000 VU (FZ7). The FEWGRP set contains cross sections for both 90° and 20° moderator temperatures. The other type of cross section set is contained in records whose JOSHUA name string begins with

INPUT.MARCO.GRIMHX,RODDATA.

Four of these records exist for each gang in the reactor, one for each combination of partial rods that could conceivably be inserted into the septifoils. These records contain the variation of septifoil cross sections as a function of the full rod insertion in terms of veeder units (Vu). The uses of the FEWGRP and INPUT.MARCO sets of cross sections within MARCO are discussed in Appendix A.

Gang 3 in the demonstration Mark 15 charge will have a different complement of control rods from those used in Gangs 1 and 2.[8,9] Two of the rods in Gang 3 will have a much smaller loading of ^6Li than previously used to provide a closer degree of control for power shaping purposes. The segregation of the FEWGRP and INPUT.MARCO septifoil records by gang makes the use of multiple rod complements possible.

B.3 Special Assembly Cross Section Preparation by MARCO

For special assemblies such as the sparjet and the Mark 60B blanket of the Mark 15 charge, equation 1 is altered to

$$\Sigma_{MARCO} = \Sigma_{JASON} + C_1(1-f_{Xe}) + C_2(1-H). \qquad (3)$$

The last term of equation 1 is dropped since no Sm149 or Pu239 is generally present. If it is, as in Mark 53B assemblies, the Sm149

and Pu239 buildup effects on the cross sections are presumed to cancel. In the case of the lithium bearing sparjet and Mark 60B assemblies, C_1 is zero since no Xe135 exists within these assemblies. "Fine tuning" is not employed for special assemblies.

Adequate MARCO cross section records for the sparjet and Mark 60B assemblies already existed in the Mk16-31 library. These were copied into the Mark 15 library.

C. Accuracy of the MARCO MOC at Beginning-of-Cycle

C.1. Direct GLASS-GRIMHX Benchmarks.

No direct experimental or operational experience exists for the current Mark 15 charge to use in testing the accuracy of the MARCO MOC prediction. Instead, we must rely on direct GLASS-GRIMHX calculations of the MOC for testing MARCO. Such calculations are practical only at the beginning-of-cycle.

The argument that supports reliance upon the GLASS-GRIMHX predictions of the MOC proceeds as follows. The critical buckling of a lattice of prototype (11.5") Mark 15 slugs was measured in the LTR.[10] GLASS calculations for the prototype Mark 15 slugs were normalized to the LTR measurement by altering the resonance capture width of the 6.65 ev resonance in U238 and by using the U235OLD cross sections.[7] These cross section changes are also applicable to Mark 15 charge calculations for the current slug length of 8.72 inches. Control rod worths were also measured in the SE.[11] These and similar measurements for ED and Mark 22 lattices support the corrections to the GLASS calculated, septifoil rod worths that were derived by W. G. Winn.[12] The sparjet and Mark 60B assemblies are either few in number or have insignificant statistical weight. Thus, normalization to experiment for these two assemblies is unnecessary.

The use of properly normalized, GLASS-derived cross sections for each assembly is, in principle, only part of the problem of assuring an accurate estimate of the MOC. Some small error of the diffusion theory used in GRIMHX could exist. However, for a uniform reactor of the Mark 15 type with such large dimensions, that error should be vanishingly small. Thus, for the Mark 15 charge, the accuracy of the GRIMHX prediction of the MOC depends almost entirely on the accuracy of the assembly cross sections. Since the statistically important cross sections have been normalized against experiment, the GLASS-GRIMHX prediction should be highly accurate.

In principle, the most accurate GRIMHX calculation would be 3 dimensional (hex,z) and would use supercell homogenized cross sections. The supercell is a patch of seven assemblies with one septifoil surrounded by six Mark 15 assemblies. Some small loss in

accuracy could occur if cell (assembly) homogenized cross sections were used. Even more loss in accuracy could occur if the axial variation in the septifoils and the Mark 15 assemblies were averaged so that a 2 dimensional (hex) GRIMHX calculation could be performed.

However, if care is taken to preserve the patch reactivities (bucklings) computed by GLASS with proper normalization to experiment, then even the use of cell cross sections and the use of 2D GRIMHX calculations should affect the computed shutdown reactivity only marginally. Proof of this assertion is offered in Table 2 which shows the computed shutdown reactivities from the three different calculations outlined above. These calculations are for both the case with the special rod complement in Gang 3 (normal elsewhere) and the case with only the normal rod complement in all gangs. Note that the margin-of-control is reduced from .01600 to .01455 Δk_{eff} in these sample problems by using the special rod complement in Gang 3. This small loss is tolerable.

C.2 JASON-MARCO Predictions of the MOC at Start-of-Cycle

Test problems with JASON AND MARCO at start-of-cycle showed the results given in Table 3. When these results are compared to the direct GLASS-GRIMHX results on the previous table, we conclude that:

1) The JASON-MARCO MOC will be somewhat smaller (by $\leq$ .001 in Δk_{eff}) than the direct GLASS-GRIMHX results and hence conservative;

2) Fine tuning causes an even larger degree of conservatism.

Fine tuning is not recommended for Mark 15 charges. In fact, fine tuning will not be available for routine MOC calculations since the record INPUT. MARCO. DELTAK. MARK 15.0 has not been placed in the STD data set. The user should not place any such record anywhere in the reference hierarchy of data sets when he executes a Mark 15 MARCO problem.

C.3 JASON-MARCO Predictions of the MOC at End-of-Cycle

Test calculations with the JASON-MARCO codes have also been performed to predict MOC for several sets of conditions following shutdown at the end of a 3% Pu240 cycle. As stated before, no direct GLASS-GRIMHX calculations for EOC conditions have been performed because of their immense complexity. These test problems were run simply to fully exercise the codes and libraries and to demonstrate the effect of several MARCO input choices. The conditions for the calculations and the computed shutdown reactivities are given in Table 4. Tests 3 and 4 have inconsistent

Xe fractions, Np239 and Pm149 decay times or moderator temperatures and are, thus, aphysical. These tests were run only to show the magnitudes of the dependence of the MOC on input value choices.

D. Acknowledgements

The authors are very grateful to W. E. Graves for many helpful suggestions made during the course of this work. Particularly valuable was his suggestion for normalization of the septifoil data with the data of Reference 12.

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TABLE 1

MEMBERS OF THE MARK 15 - MARCO LIBRARY
AND RANGES OF VARIABLES

Non-Septifoil Assemblies

INPUT. MARCO. LIBRARY. MARK15. (Assembly Name).0

Assembly Name	Variables	Ranges
M15-3F M1577F M15-6F M15-3B M1577B M15-6B	HATMRATO (%) R6/5 Fission Exposure (MWD/ft)	0.140 - 0.558 0.0 - 0.1 0.0 -37.8
SPJT	^{6}Li/ft (gm/ft) U235 burnup (grams)	0.0 - 6.0 0.0 - 650.
B60B	^{6}Li/ft (gm/ft) U235 burnup (grams)	0.5 - 4.0 0.0 - 650.

Septifoils

FEWGRP. MARK15. GANG1. SEPT-FZ0. MACRO. D2OT20C
. D2OT90C
SEPT-FZ5. MACRO. D2OT20C
. D2OT90C
SEPT-FZ7. MARCO. D2OT20C
D2OT90C

FEWGRP. MARK15. GANG2. SEPT-FZ0. MACRO. D2OT20C
. D2OT90C
SEPT-FZ5. MACRO. D2OT20C
. D2OT90C
SEPT-FZ7. MACRO. D2OT20C
. D2OT90C

FEWGRP. MARK15. GANG3. SEPT-FZ0. MACRO. D2OT20C
. D2OT90C
SEPT-FZ5. MACRO. D2OT20C
. D2OT90C
SEPT-FZ7. MACRO. D2OT20C
. D2OT90C

TABLE 1 (CONT.)

```
INPUT. MARCO. GRIMHX. RODDATA. MARK15. K-BP-G1
                                     . K-SP-G1
                                     . K-WP-G1
                                     . K-NP-G1
                                     . K-BP-G2
                                     . K-SP-G2
                                     . K-WP-G2
                                     . K-NP-G2
                                     . K-BP-G3
                                     . K-SP-G3
                                     . K-WP-G3
                                     . K-NP-G3
```

TABLE 2

NORMALIZED GLASS-GRIMHX SHUTDOWN REACTIVITIES AT START-OF-CYCLE

20°-clean, no safety rods,
6/5=0.0, mod. purity=99.375% D_2O

	k_{eff}
With normal complement in Gangs 1 and 2 and special complement in Gang 3.	
1. 3D - GRIMHX supercell cross sections	.98545
2. 3D - GRIMHX cell cross sections for septifoil and MK15 assemblies	.98528
3. 2D - GRIMHX axially averaged septifoil axially uniform MK15	.98533
With normal complement in Gangs 1, 2 and 3	
1. 3D - GRIMHX supercell cross sections	.98400
2. 3D - GRIMHX cell cross sections for septifoil and MK15 assemblies	.98386

TABLE 3

JASON-MARCO
SHUTDOWN REACTIVITIES AT START-OF-CYCLE

20°-clean, no safety rods
6/5=0.0, mod. purity=99.375%D_2O

	k_{eff}
With normal complement in Gangs 1 & 2 and special complement in Gang 3.	
1. no fine tuning	.98635
With normal complement in Gangs 1, 2 and 3	
1. no fine tuning	.98483
2. with fine tuning	.98592

TABLE 4

JASON-MARCO
SHUTDOWN REACTIVITIES AT END-OF-CYCLE

20°-dirty, no safety rods,
6/5=0.0, mod. purity=99.375%D_2O

With normal complement in Gangs 1 & 2 and special complement in Gang 3.

Case	k_{eff}
1. no fine tuning 25 days decay of Np239 & Pm149 0.0 Xe135 fraction no partial rod burnup	.97337
2. no fine tuning 25 days decay of Np239 & Pm149 0.0 Xe135 fraction with partial rod burnup	.97485
3. no fine tuning 0 days decay of Np239 & Pm149 0.0 Xe135 fraction with partial rod burnup	.97540
4. no fine tuning 0 days decay of Np239 & Pm149 1.0 Xe fraction with partial rod burnup	.94627

APPENDIX A

MARCO CROSS-SECTION METHODOLOGY

A.1 Pre-1981 Versions of MARCO

The manner in which older versions of MARCO prepared shutdown cross sections from previously exposed fuel and targets is described below.

$$1)\ \Sigma'_{MARCO\ (old)} = \Sigma_{JASON} + C_1\ (1-f_{xe}) + C_2\ (1-H) \qquad (1)$$

where $\Sigma'_{MARCO\ (old)}$ was a shutdown cross section accounting for Xe135 and the temperature changes, but not Np239 and Pm149 decay. The variable f_{xe} is the fraction of equilibrium Xe135 remaining at the time of startup (typically 0.0 after a prolonged shutdown). The variable H is the fractional change in moderator temperature T, defined as

$$H = \frac{T-20}{70},$$

from a nominal startup temperature of 20°. The hot, at-power temperature is presumed to be 90°. The constants C_1 and C_2 were defined within the MARCO library for the fuel or target assembly. These constants depended, in principle, on the same set of independent variables that were used to create the JASON cross section library.

The decay of Np239 and Pm149 was accounted for in the older versions of MARCO by "fine tuning" the fuel thermal capture cross section. The premise of this fine tuning was that the changes to the infinite lattice reactivity due to Np239 and Pm149 decay were small and would be accurately accounted for by making a small alteration in Σ_{c_2} of the fuel alone. MARCO used an equation of the form

$$\Delta k = \Delta k_{xe}\ (1-f_{xe}) + \Delta k_T\ (1-H) + \Delta k_{Sm,Pu} F(t) \qquad (2)$$

to compute what the overall change in the infinite lattice reactivity ought to be following changes in Xe135 concentration, moderator temperature and Sm149 and Pu239 concentrations. The term F(t) was defined as

$$F(t) = 1 - e^{-\lambda t}$$

$$\text{where } \lambda = \frac{\lambda_{Pm} + \lambda_{Np}}{2}$$

The terms Δk_{Xe}, Δk_T and $\Delta k_{Sm,Pu}$ were stored in the MARCO library in the form of precomputed correlations dependent on exposure and the same independent variables as were chosen for the C_1 and C_2 constants of the cross section correlations. MARCO executed a GILDA reactivity calculation with an appropriate set of septifoil cross sections and the computed hot-dirty or shutdown fuel and target cross sections. If the GILDA-computed change in reactivity in going from hot-dirty to shutdown conditions was not equal to the Δk computed by Equation 2 from the correlated data, MARCO changed the Σ_{c_2} of the fuel until equality was obtained.

Since Δk computed by GILDA is known to duplicate closely the Δk computed by GLASS from which the Δk's of the library were computed, the fine tuning had little or no effect on the thermal capture cross sections when accounting for Xe135 and temperature changes. (There is an important exception to this statement when considering buckled zone fuel and targets as discussed in section A.4.) However, no direct cross section changes were performed by MARCO via equation 1 to account for Sm149 or Pu239 buildup from Pm149 and Np239 decay. Thus, when fine tuning was employed by MARCO, some change in Σ_{c_2} was almost always imposed to account for the Pm149 and Np239 decay.

A.2 Post-1981 Versions of MARCO

In reference 3, revisions are described which, in effect, alter Equation 1 to:

$$\Sigma'_{MARCO} = \Sigma_{JASON} + C_1 (1-f_{xe}) + C_2 (1-H) + C_3 F(t). \quad (3)$$

With the addition of the constant C_3 to the MARCO fuel and target libraries, explicit account of the Sm 149 and Np 239 decay is taken. Equation 2 is preserved, but with the new expression for Σ'_{MARCO},

fine tuning employed by MARCO has little or no effect. That is,

$$\Sigma_{MARCO}\ (\text{fine tuned}) \tilde{=} \Sigma'_{MARCO}\ (\text{by equation 3}).$$

In another revision mentioned in reference 3, special MARCO libraries are required to be created for the cases of start-of-cycle or start-of-stage. At start-of-cycle, no prior exposure exists in the fuel or targets. At start-of-stage, no prior exposure exists in fresh target assemblies (such as the Mark 31). This revision was made "to account for possible discontinuities in the (JASON) correlated assembly data resulting from non-equilibrium or zero concentrations of Sm149 and Xe135 at the start of a subcycle". Of equal or more importance to the Mark 15 charge is the temporary holdup of Pu239 in the form of Np239. Figure A1 demonstrates the near discontinuity of the production cross section of the Mark 15 fuel assembly at near zero exposure due to Pu239 hold up in the form of Np239. It is impractical to require the correlation forming routines used to create the JASON correlations to account for such sharp slope changes.

The changes in the methodology used to create the MARCO fuel and target libraries necessitated by these revisions have not been documented previously. The prescriptions of reference 1 are no longer adequate. Appendix C documents the current procedures used for the Mark 15 assemblies to provide guidance to the creators of future libraries should the need arise.

A.3 Treatment of Buckled Zone Cross Sections in MARCO

MARCO does not distinguish between control zone and buckled zone fuel or target assemblies when fine tuning is employed. The GILDA calculations performed within MARCO contain a FZ5 septifoil (all rods except the two cadmium rods inserted) and the six surrounding fuel or target assemblies, regardless of their position in the reactor. The fine tuning is, thus, inappropriate for buckled zone assemblies. Fortunately, the error introduced by the fine tuning of the buckled zone assemblies is not large due to the small statistical weight of that region. However, if fine tuning is not used, as in Mark 15 calculations, even this small error is avoided.

A.4 Septifoil Cross Section Preparation by MARCO

Cross section preparation by MARCO for the septifoils follows an entirely different procedure from that described for the fuel and

target assembliles. Both hot (90°) and cold (20°) undepleted cross sections (not changes) for three different cross section sets are stored in the MARCO septifoil library. These sets are for:

no rod insertion	(FZ0)
partials at 800 Vu; full rod insertion at 1000 Vu for all except cadmium rods	(FZ5)
partials at 1000 Vu; full rod insertion at 1000 Vu including cadmium rods	(FZ7)

The cross sections at the actual moderator temperature T are calculated by MARCO with

$$\Sigma_{MARCO}(T) = \Sigma_{90°} - (\Sigma_{90°} - \Sigma_{20°})\,(1-H) \qquad (4)$$

where again $H = \frac{T-20}{70}$.

The FZ5 set is used for the fine tuning corrections of the fuel Σ_{c_2} as discussed in sections A.2 and A.3. The FZ7 septifoil cross sections are used for the shutdown reactivity calculation. The FZ0 set is used in the statistical weight calculations.

The calculation of the rod position (Vu inserted) at critical requires still another type of septifoil data to be contained in the MARCO library. A representation of the cross sections suitable for the 2 dimensional (hex geometry) reactor calculation is created to relate the axially averaged septifoil cross sections to the veeder units of rod insertion. These cross sections are created only at 20°C. (See Appendix C for the library creation methods.)

In older versions of MARCO, a 90°C set of cross sections vs veeder units was created within MARCO by employing the equation[1]

$$\Sigma_{c_2}^{90°} = -1.023 \times 10^{-3} + 0.98416\,\Sigma_{c_2}^{20°} + 0.95362\left(\Sigma_{c_2}^{20°}\right)^2 .$$

In the present version of MARCO, the change in cross section between 90° and 20° for the above FZ7 set is applied uniformly to the 20° cross sections vs veeder units of the library to form the 90° cross sections vs veeder units. Equation 4 is then applied to obtain the septifoil cross sections vs veeder units at any other moderator temperature.

In the previous MARCO coding only the 20° cross sections vs veeder units were contained in JOSHUA records stored in the STD data set. All of the FZ0, FZ5 and FZ7 cross section sets were "hardwired" in the MARCO coding. This mode of coding was practical before the advent of the Mark 15 charge since only one septifoil library exisited which was used for both Mark 16-31 and Mark 22 calculations. The neutron spectrum at the septifoil positions is sufficiently different in Mark 15 charges that the septifoil cross sections exhibit considerable difference from the cross sections used in the Mark 16-31 and Mark 22 calculations. Thus, a new septifoil library specific to Mark 15 charges was necessary.

In addition, Gang 3 in the demonstration Mark 15 charge will have a different complement of control rods from the normal complement used in Gangs 1 and 2.[8] Table A1 shows the complements and order of withdrawal for K reactor.[9] Thus, two septifoil libraries are needed, one to be applied in Gangs 1 and 2 and the other to be applied in Gang 3. These added complications make continued hardwiring of the FZ0, FZ5 and FZ7 cross sections impractical. All septifoil cross section sets are now contained in JOSHUA records stored in the STD data set. JOSHUA records which duplicate the previously hardwired FZ0, FZ5 and FZ7 sets for Mark 16-31 and Mark 22 calculations have also been created in STD.

Note that the geometrical placement of rods in the septifoils of K reactor for the normal complement (Table A1) is now the same as that used in P and C reactors. All of the Mark 15 data is based on this arrangement of rods following publication by RRMT of plans to change the K reactor complement so that the arrangement in all reactors will be uniform.[9] The Mark 16-31 and Mark 22 septifoil data for K is different from that for P and C. In the future, this data should be made uniform by copying the P and C set over the old K set.

MARCO makes one additional correction to the septifoil cross sections to account for burnup.[2] The correction is performed only on the cross sections which represent weak partial rod insertion under the premise that burnup in full length rods and strong partial rods is likely to be inconsequential.

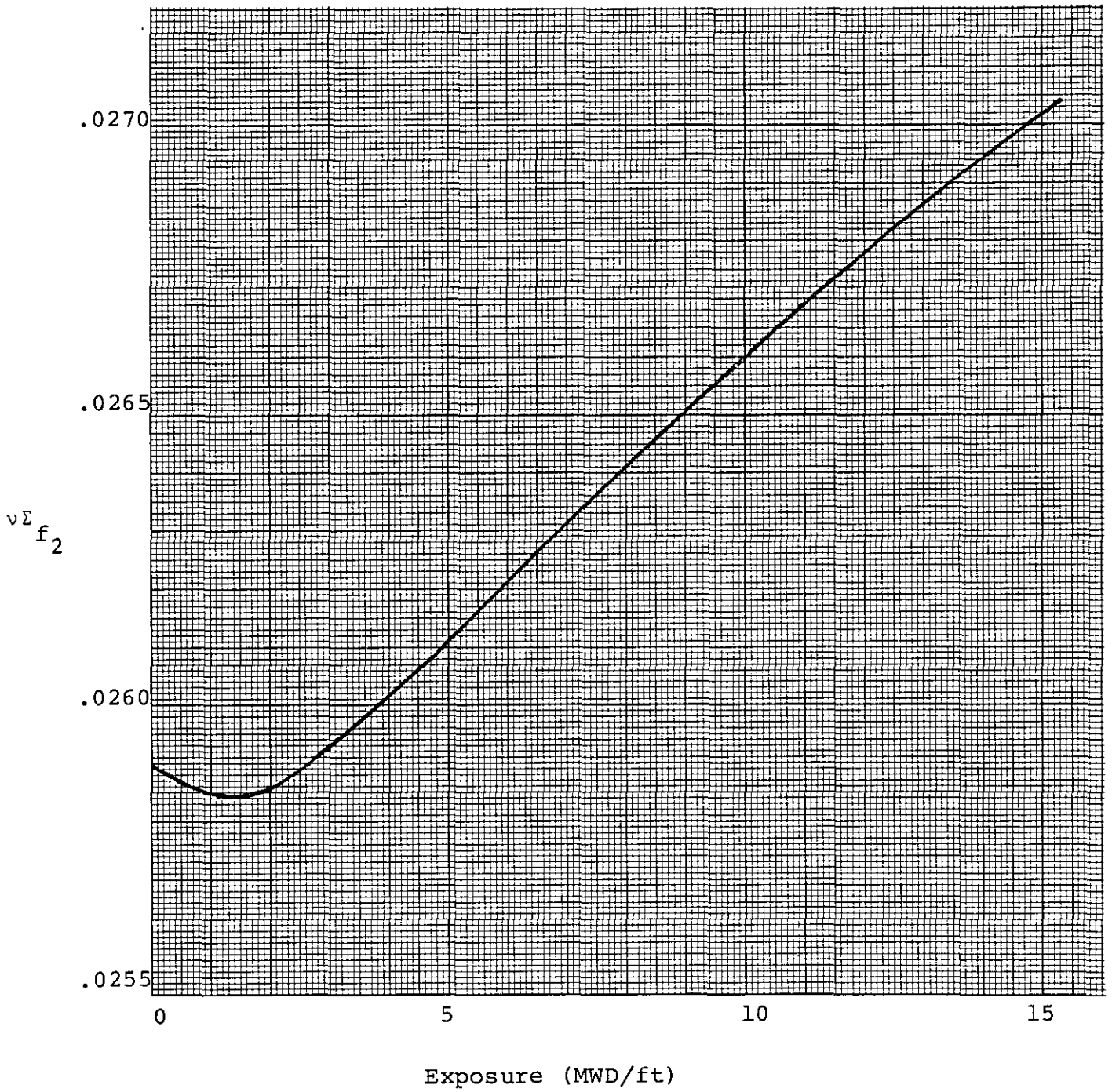
Table Al

GEOMETRICAL PLACEMENT OF CONTROL ROD TYPES AND ORDER OF WITHDRAWAL FOR K REACTOR

F A
E G B
D C

Rod Type		Length	Order of Full Rod Withdrawal
Normal Complement (Gangs 1 and 2 in Mark 15 Charge)			
A	Strong Li (2.0 gm/ft^{6}Li)	full	3
B	Weak Li (0.5 gm/ft^{6}Li)	full	4
C	Weak Li (0.5 gm/ft^{6}Li)	partial	
D	Cd	full	2
E	Weak Li (0.5 gm/ft^{6}Li)	full	5
F	Strong Li (2.0 gm/ft^{6}Li)	partial	
G	Cd	full	1
Special Complement (Gang 3 in MK15 Charge)			
A	Strong Li (2.0 gm/ft^{6}Li)	full	3
B	Weak Li (0.5 gm/ft^{6}Li)	full	4
C	Weak Li (0.5 gm/ft^{6}Li)	partial	
D	Cd	full	2
E	Very Weak Li (0.2 gm/ft^{6}Li)	full	5
F	Very Weak Li (0.2 gm/ft^{6}Li)	partial	
G	Cd	full	1

Figure A1 Illustration of the Holdup of Pu239 Production in Np239 and its Effect on the Thermal Production Cross Section in Mark 15 Assemblies.



APPENDIX B

User's Guide to the MARCO-Mark 15 Charge Library

The MARCO-Mark 15 charge library consists of all of the JOSHUA records listed in Table 1. No other "special assembly" libraries have been created to date. These records are stored in the write-protected STD data set. The user should not store altered copies of any of these records in his user data set. To do so invites errors in calculations of the MOC, critical rod settings and statistical weights.

Entries in the MARCO Records

The updates in the MARCO code described in this document require no changes to the only MARCO input record under the user's control,

INPUT. MARCO. JOB. JOB$.

Thus, JOB records already in existence for Mark 16-31 and Mark 22 charges need not be changed.

The independent variables of the MARCO-Mark 15 library are the same as those of the JASON-Mark 15 library (excluding the U235 enrichment). The user should run the JASON-Mark 15 problem first, using the User's Guide sections of references 1 and 7. Independent variable specification occurs in the JASON problem. One additional record,

INPUT. JASON. FWPAT. ?,

will be needed if a MARCO problem is to follow the JASON problem.

A sample problem input is shown in Table B1 for a MARCO-Mark 15 problem to predict the shutdown parameters at the end of cycle. The CRIP2 and GRIMHX printlevels are optional. The stage number for a Mark 15 cycle should be 1. The proper charge type for a Mark 15 calculation should be "MARK15". The user's JASON stage name should be entered on page 2 in place of MK15K. SANSEND should be specified for step for an end-of-cycle calculation but SANSTART should be specified for a beginning-of-cycle calculation. Partial rod depletion is accounted for by entering the JASON stage name and either SPEC or PSPEC.

The GM/FMWD used in the Mark 15 JASON checkout problems was 1.163; however, this constant is not used in MARCO even though called for on the template. The fraction of equilibrium zenon should be zero for start of cycle and for long times after shutdown; values of from 0.0 to $\geq$ 1.0 should be used depending on the time after shutdown. The moderator temperature should be the expected temperature at startup. The critical eigenvalue must be 1.0 for the

demonstration charge. After the demonstration charge, the critical eigenvalue may be altered to reduce the errors of MARCO found by comparison to the initial critical rod setting. The reactor type entry should be K for the demonstration charge (though the partial rod positions will be identical in P, K and C). The time for Pm149 and Np239 decays should be the actual time after shutdown in the event of a restart after an unplanned shutdown. Twenty five days accomplishes essentially complete decay of the Pm149 and Np239. The full rod position at critical entry is filled with a non-zero value only if the critical eigenvalue is being sought. The statistical weights are normally wanted. The GILDA edits and higher-than-1 MARCO print levels are generally used only for MARCO checkout purposes. Finally, the number of septifoil materials should be identical to the number of unique septifoil names identified on the INPUT. JASON. RXPAT. ? record. The partial rod complement choice is at the discretion of the user and will depend on experience gathered from previous charges.

"Fine tuning" should not be used in MARCO-Mark 15 calculations. No INPUT. MARCO. DELTAK. MARK15.0 record exists in the STD data set. If such a record exists anywhere in the hierarchy of referenced data sets in the execution of the MARCO problem, fine tuning will be attempted by the code, leading to probable error.

The updated source version of MARCO presently exists in PDS= SRL. JAS4329T under the member name MARCO. When the necessary approvals have been obtained, this updated version of MARCO will be placed in SRL. REAC. PROD. and SRL. REAC. SOURCE.

Table B1

3354. INPUT. MARCO. JOB. MRCO3354
CRIP2 (Input processor) print level 0 (0-Min, 3-Max)
GRIMHX print level 3 (0-Min, 3-Max)

Stage number 1

Charge type Mark15 (Either 'MK16-31'
'MARK22')

Page 1

3354. INPUT. MARCO. JOB. MRCO3354
Base information for MARCO is taken from the output of a previously executed JASON calculation. VAGE INPUT records are converted at SANSTART/SANSEND to GRIMHX INPUT.

The base information for MARCO comes from JASON with the following qualifiers, STAGE=MK15K , STEP=SANSEND

If partial rod burnup is to be included, read burnup from OUTPUT. JASON. AVGCONT. MK15K PSPEC

Page 2

3354. INPUT. MARCO. JOB. MRCO3354

GM/FMWD used in JASON.....	1.1630
Fraction of equilibrium XENON.....	0.0000
Moderator temperature (deg C).....	20.00
Critical Eigenvalue.....	1.00000
RX type for partial rod position (P/K/C)	K
Time for PM-149 & NP-239 decay (days)....	25.0
Full rod position @ Critical.....	0.
Statistical weights (Y/N).....	Y
GILDA edits (Y/N).....	Y
MARCO print level (1=Normal, 7=All)....	7

Page 3

3354. INPUT. MARCO. JOB. MRCO3354
Number of septifoil materials 9
Partial rod complement (1=both, 2=single strong, 3=single weak, 4=none)

1 1 1 1 1 1 1 1 1

Last Page 4

APPENDIX C

METHODS USED TO CREATE THE MARK 15 MARCO LIBRARIES

C.1 Mark 15 Assemblies

The methods used to create the MARCO library for Mark 15 assemblies with non-zero exposure follow the prescriptions of Reference 1 reasonably closely. Reference 1 does not mention the methods used at zero exposure since the need for such a special library had not been recognized at that time. This appendix will, of necessity, repeat some of the same information given in Reference 1 and will add material which is vital to current library creation but not documented elsewhere.

C.1.a Mark 15 Control Zone Assemblies

The control zone assemblies have JASON correlations of the hot-dirty, cross sections as functions of the independent variables shown in Table C1. In principle, one should create Mark 15 correlations in the MARCO libraries utilizing the same variables. Also, the JASON libraries used 3 level Box-Behnken designs to fully support quadratic dependencies on all of the independent variables. One might expect to use the same correlation design in the Mark 15 MARCO libraries.

However, slavish copying of the JASON procedures in creating the Mark 15-MARCO libraries is unnecessary. One of the variables used in the JASON library is no longer needed. At the time the Mark 15-JASON library was created, there was some concern that the final Mark 15 enrichment might have to be something other than 1.1 wt% ^{235}U. That enrichment has since been frozen at 1.1 wt%. Thus, the only variables needed in MARCO are the $^{236}U/^{235}U$ ratio, the moderator purity (expressed as HATMRATO) and the exposure. Also, there is no need to compute fully quadratic correlations for the changes in cross section when going from hot-dirty to shutdown conditions. Those changes are small and can be expressed adequately in terms of linear correlations of all independent varibles (with the possible exception of exposure). Thus, the independent variable space required for the Mark 15-MARCO correlations is covered with the relatively small number of values shown in Table C2. Linear dependencies on the $^{236}U/^{235}U$ ratio and HATMRATO and a quadratic dependence on exposure are supported in this design.

C.1.a.1 Non-Zero Exposure Library

The cross sections which embody the reactivity variation in making the transition from hot-dirty to shutdown conditions are generated with GLASS. The Mark 15 ASSEMBLY records used by GLASS

for hot-dirty conditions may be taken for the set derived during creation of the JASON correlations. The creators of JASON libraries should preserve the so called "ASSY(?)" assembly records to facilitate creation of the MARCO libraries.

Four successive GLASS k_{eff} search calculations at 60 μB transverse buckling were run for each set of independent variable values to obtain all of the data from which the non-zero exposure library was constructed.

1. hot-dirty - This case used the chosen Mark 15 ASSY(?) record from the GLASS output preserved during creation of the JASON library and a nominal septifoil ASSEMBLY record.

2. hot-no Xe - This case used the same Mark 15.ASSY(?) record except that the Xe135 content was set to zero. A FZ5 cluster geometry, septifoil ASSEMBLY record was also created to be used in this GLASS run.

3. cold-no Xe - All of the coolant, moderator, and metal temperatures were changed in the Mark 15.ASSY(?) and septifoil FZ5 ASSEMBLY records to 20°C. Material densities of the coolant and moderator were changed to the appropriate values.

4. cold-no Xe - 25 day buildup of Sm and Pu - The buildup of Sm149 and Pu239 is accomplished through the decay of Pm149 and the decay of U239 and Np239, respectively. A 25 day wait is more than sufficient to accomplish essentially complete decay of these isotopes. Thus, the atom concentrations of the decaying isotopes in the preceding ASSY(?) record need only be added to the Sm149 and Pu239 atom concentrations to form the new ASSY(?) record.

The output of the GLASS problems (48 for the non-zero exposure, Mark 15 library) was catalogued with the CHIP2 code. The output of each GLASS job was stored on tape LA0209 in Files 1-51 with DSN = SPD.NPQAFILE.MARC. (Files 7-9 contain data not included in the CHIP2 catalogue.) File 68 contains all of the CHIP2 catalogued data for both the non-zero and the zero exposure problems.

Two GILDA k_{eff} search problems at 60 μB were also run for each set of independent variable values. This code uses the GLASS produced FEWGRP.?.?.?.MACRO.? records for both the Mark 15 and the septifoil as input data. The FZ5 septifoil FEWGRP record of the hot-no Xe problem was combined with the Mark 15 FEWGRP records of the hot-dirty and hot-no Xe problems, respectively, for the two GILDA problems.

The GLASS FEWGRP and k_{eff} output data, catalogued by CHIP2, and the GILDA k_{eff} data were formed into INPUT.MARCO.LIBRARY.MARK15.(assembly name).0 and INPUT.MARCO.DELTAK.MARK15.0 records by the MARCOLIB code. The "constants" C_1, C_2, and C_3 (actually functions of the independent variables) are contained in the LIBRARY record and the Δk_{Xe}, Δk_T and $\Delta k_{Sm,Pu}$ values are contained in the DELTAK record. The source listing of the MARCOLIB is preserved on microfiche in selected copies of the report since it is not a protected JOSHUA code. The Mark 15 input data is also preserved as a sample problem.

C.1.a.2 Zero Exposure Library

Because of the zero-exposure errors encountered with the cross section correlations employed in JASON, a different procedure for generating cold-clean cross sections to be used in MARCO was devised for the Mark 15 charge. Equation 3 in Appendix A is used by MARCO to compute the cold-clean cross sections at zero exposure. The constants C_1, C_2, and C_3 have different values from these created for the non-zero exposure case. Moreover, the entries in the DELTAK records (Δk_{Xe}, Δk_T, and $\Delta k_{Sm,Pu}$) have not only different values, but in one case different definitions.

At start-of-cycle, the Mark 15 assemblies will, by definition, contain no Xe135, Sm149, Pm149, U239, Np239 or Pu239. However, the cross section correlations of the JASON library, when extrapolated to zero-exposure are consistent with an assembly having an equilibrium concentration of Xe135 and unknown (but presumably small) concentrations of the above other isotopes. It is all but impossible to create a hot-dirty, Mark 15 assembly record fully consistent with the cross sections computed by JASON at zero exposure. Thus, there is no practical way to duplicate the same procedures followed in compiling the non-zero exposure library when creating the zero-exposure library.

The procedures adopted for the Mark 15 zero-exposure library are explained with reference to Table C3 which compares the zero and non-zero procedures. The MARCOLIB input data ostensibly requires 4 k_{eff} values and 4 Mark 15 sets of cross sections from the GLASS problems. In addition two k_{eff} values at 60 B transverse buckling are needed from GILDA problems. As stated before, the output of MARCOLIB is C_1, representing the particular cross section change from eliminating Xe, and C_2, representing the particular cross section change in going from hot to cold conditions. The corresponding Δk values are

$$\Delta k_{Xe} = k_{H\text{-}noXe}\ (GILDA) - k_{HD}(GILDA)$$

and $\Delta k_T = k_{C\text{-}noXe}(GLASS) - k_{H\text{-}noXe}(GLASS)$.

The C_3 and $\Delta k_{Sm,Pu}$ have different definitions in the non-zero and zero exposure libraries. In the non-zero library, C_3 represents the particular cross section change in accounting for 25 days of Sm149 and Pu239 buildup following shutdown. The corresponding

$$\Delta k_{Sm,Pu} = k_{C\text{-}noXe\text{-}25dSm,Pu}(GLASS) - k_{C\text{-}noXe}(GLASS).$$

However, in the zero-exposure library, C_3 is to have zero value and the corresponding $\Delta k_{Sm,Pu}$ is to have zero value. In effect, the zero-exposure library is to have no correction for Np239 and Pm149 decay since these isotopes do not exist in a start-of-cycle assembly.

A "faked" set of catalogued GLASS data must be constructed in preparation for the zero-exposure MARCOLIB run. The hot-dirty GLASS problem is a copy of the hot-no Xe GLASS problem. The cold-no Xe, 25 days of Sm & Pu GLASS problem is a copy of the cold-no Xe GLASS problem. After CHIP2 has been run, the FEWGRP.STD2GRP.LATNAM(?).LATVERS(?).CONTENTS record is altered to contain k_{eff}(GILDA) values for every state rather than the k_{eff}(GLASS) values. Moreover, the cross section obtained from the zero-exposure JASON correlation is substituted for the GLASS hot-dirty cross section for each hot-dirty state. This cross section may be obtained by running the PARXS1 code or the CRAB2 code on the CRASS correlated data of the JASON library. If both of these codes are unavailable, the zero-exposure extrapolated cross sections may be obtained by running JASON long enough to obtain the START set of cross sections for each set of independent variables values.

The MARCOLIB code must be run with the non-zero exposure, CHIP2 catalogued data and the non-zero GILDA k_{eff} data prior to a second MARCOLIB problem which creates the zero-exposure library. In this second problem, the "faked" CHIP2 catalogued data set and the output of the first MARCOLIB problem must be referenced in the data set hierarchy. The zero-exposure, GILDA k_{eff} values are entered manually into the input data for this second problem.

The final output of MARCOLIB from the non-zero and zero-exposure problems will contain the records

INPUT.MARCO.LIBRARY.(Library name).(assembly name).(stage name)

and INPUT.MARCO.DELTAK.(Library name).(stage name).

The LIBRARY records will have four sets of entries, one for the non-zero exposure coefficients, C_1 - C_3, for assembly cross sections without target type dependence (e.g. Mk31A or Mk31B), the next set for non-zero exposure coefficients with target type dependence, the third set for zero-exposure coefficients without target dependence, and the fourth for zero-exposure coefficients with target dependence. In the case of the Mark 15 assembly library records, the second set is a copy of the first set, and the fourth set is a copy of the third set. The DELTAK record will have only two sets of entries, the first for non-zero exposures and the second for zero-exposures. (Note that the Mark 15 DELTAK record has not been copied into STD since "fine tuning" is not recommended.)

C.1.b. Mark 15 Buckled Zone Assemblies

Unlike the JASON library of cross sections, the MARCO library for the Mark 15 charge does not have separate libraries for the control zone and buckled zone assemblies even though different cell names exist in listings of Table 1 in the main text. The entries in the LIBRARY buckled zone Mark 15 records were copied from the flat zone Mark 15 records. (For that matter, there is no distinction in the MARCO libraries for the length of the cycle. Records with separate names referencing the length of the cycle are provided solely to be consistent with the JASON library construction). Little or no error accrues from this practice since the changes in cross section vs Xe, temperature and Sm and Pu buildup are esentially independent of the core location.

C.2 Septifoil Assemblies

The central task in preparation of a MARCO septifoil library is to provide septifoil cross sections which accurately preserve the true reactivity of a control zone cluster of one septifoil and six Mark 15 assemblies. The difficulty of this task comes from the fact that the septifoil is not axially uniform. Yet MARCO is a two dimensional (hex geometry) code without an axial model. Thus, the septifoil library must be prepared in such a way that all of the axial effects from control rod insertion to any depth are encapsulated in a set of septifoil cross sections vs veeder units (Vu) of rod insertion. The procedures which accomplish this task start with a GLASS calculation at 20°C of the material buckling (at k_{eff} = 1.0) and the associated FEWGRP cross sections for every possible combination of integral control rods. These integral rod cross sections are converted into cross sections vs. veeder units of rod insertion by successive manipulations of the cross sections in the codes SEPSERCH, GILDA and SCRAM1 as described in the following discussion. GILDA with hex geometry is used rather than HILDA with r,θ geometry as

described in Reference 1. This change is consistent with the current use of GRIMHX in MARCO.

The GLASS computed material buckling vs integral rod insertion is known to be slightly in error. W. G. Winn has proposed a simple correction scheme in which B_m^2 is corrected according to the number of control rods inserted into the septifoil (assuming the normal order of insertion).[12] The ΔB_m^2 corrections vary from -8.0 μB with one weak rod inserted to +27.0 μB with all seven rods inserted.

SEPSERCH problems were run to obtain septifoil cross sections for all the integral rod combinations at the corrected values of B_m^2. SEPSERCH is a modification of an undocumented code written by N. H. Kuehn. This code changes Σ_{c_2} of a base septifoil set of cross sections such that GILDA will predict a k_{eff} or a B_m^2 in agreement with an input value of k_{eff} or B_m^2. The fast group capture cross section, Σ_{c_1}, is modified according to the search value of Σ_{c_2} by the equation.

$$\Sigma_{c_1} = \Sigma_{c_1}\,(\text{base}) \left[1 + \frac{\Sigma_{c_2} - \Sigma_{c_2}(\text{base})}{\Sigma_{c_2}(\text{base})} \right]. \qquad \text{(C1)}$$

The source listing of the SEPSERCH code is given on microfiche since this code exists only in a private edit data set.

The base set of cross sections represents the GLASS FEWGRP data obtained with a septifoil cluster containing one weak (0.548 gm ft ^{6}Li) and one strong (2.021 gm/ft ^{6}Li) rod. The normal (Gang 1 and Gang 2) and Gang 3 rod complements were arbitrarily selected to have the same diffusion coefficients and downscatter cross section. (Upscatter cross sections are set to zero in MARCO and MARCO libraries.) In the SEPSERCH problems only Σ_{c_1} and Σ_{c_2} are varied: the other cross sections are invariant.

The modified base, septifoil cross sections from the SEPSERCH problems for the integral rods were combined with the base Mark 15 cross sections (from the base GLASS problem) in a separate GILDA problem to obtain supercell cross sections at the corrected B_m^2. These supercell cross sections, representing the various integral rod combinations, were used in one dimensional calculations of the axial flux shape and infinite

lattice reactivity in the control zone with SCRAM1. The transverse (radial) buckling was set to zero. The basic axial description modeled in SCRAM1 is given in Table C4.

A separate SCRAM1 problem was run for each combination of partial rods (at 800 Vu insertion) and 100 Vu incremental insertion of full length rods. The k_{eff} (infinite lattice) output of SCRAM1 was then used in another SEPSERCH problem to find the modified base septifoil cross section which yields the same infinite lattice reactivity with B_z^2 = 54.8 μB as SCRAM1 yielded with B_r^2 = 0.0. The value of B_z^2 = 54.8 μB is the best estimate of the axial buckling computed by SCRAM1 in an axially uniform lattice of unexposed 13.08 ft Mark 15 assemblies, partially reflected on top and bottom by the endfitting regions. The axial buckling recommended for the Mark 16-31 lattice in Reference 1 was 56.0 μB.

By this involved procedure, the integral rod FEWGRP cross sections computed by GLASS have been converted into a set of cross sections which represent in a two dimensional (hex geometry) calculation with GRIMHX all the axial effects from the insertion of partial rods and incremental insertion of full length rods. Table 1 in the main text lists the INPUT.MARCO.GRIMHX.RODDATA.?.? records which were created for the septifoil library. These records contain the variation of Σ_{c_2} vs veeder units of full length rod insertion (0-5000 Vu) for each gang in K reactor. Gangs 1 and 2 have the same data. Gang 3 is different reflecting the special rod complement. The P and C reactor sets should be the same as the K reactor set reflecting the recent change in K reactor septifoil loading.[9] P and C sets will be copied into STD at a later time.

The variation of Σ_{c_1} is computed within MARCO by the same equation as was incorporated into SEPSERCH, Equation C1. The base cross section values for D_1, D_2, and $\Sigma_{s_{1->2}}$ are contained in a second type of JOSHUA record in the septifoil library called FEWGRP.MARK15.GANG(?).SEPT-FZ(?).MARCO.D2OT20C or D2OT90C. The manner in which these records were created is discussed next.

Three types of FEWGRP.MARK15.GANG(?).SEPT-FZ(?) records were created for each gang at both 20° and 90°C moderator temperatures. The FZ0 and the FZ5 cross sections at 20°C were computed as part of the preparation for the INPUT.MARCO.GRIMHX.RODDATA records. The FZ0 and FZ5 cross sections at 90°C were computed in exactly the same manner, the sole difference being the temperature of the coolant and moderator. The FZ7 (20° and 90°C) problems also used the same procedure except that the SCRAM1 model was modified to place the bottom of the partial rods at 1000 Vu rather than at 800 Vu. (See Table A4)

The ways in which these FEWGRP records are used in MARCO was discussed in Appendix A. They replace the previously "hardwired" septifoil data. FEWGRP.MK16-31 and MARK22 records have also been prepared which duplicate the previously hardwired cross sections.

Source listing of MARCOIB with sample problem

Only in selected copies

Source listing of SEPSERCH with sample problem

Only in selected copies

TABLE C1

INDEPENDENT VARIABLES OF THE JASON-MARK 15 ASSEMBLY, CROSS SECTION CORRELATIONS

WT%U35-1	Weight percent of ^{235}U in the fuel minus 1.
HATMRATO	Hydrogen atom ratio = 100 -D_2O % purity.
R65	$^{236}U/^{235}U$ weight ratio
PEXPOSE	Fission exposure (MWD/ft)

TABLE C2

INDEPENDENT VARIABLES AND VALUES SUPPORTING
THE MARCO-MARK 15 ASSSEMBLY LIBRARIES WITH NON-ZERO EXPOSURE

GLASS CASE #	R65	HATMRATO	PEXPOSE
1	0.05	0.140	2.756
2			19.993
3			37.842
4	0.05	0.558	2.755
5			19.993
6			37.841
7	0.00	0.348	2.756
8			19.993
9			37.842
10	0.10	0.348	2.756
11			19.993
12			37.842

TABLE C3

COMPARISON OF MARK 15 MARCO LIBRARY PROCEDURES
FOR ZERO AND NON-ZERO EXPOSURES

Non-Zero Exposure

Hot-Dirty	Hot-No Xe	Cold-No Xe	Cold-No Xe, 25d Sm & Pu
GLASS MK15-ASSY(?) Sept-Nominal Output k_{eff} Σ_{15}(HD) GILDA Σ_{15}(HD) Σ_s(FZ5-hot) Output k_{eff}	GLASS Mk15-ASSY(?) No Xe Sept-FZ5-Hot Output k_{eff} Σ_{15}(Hot-noXe) Σ_s(FZ5-hot) GILDA Σ_{15}(hot-noXe) Σ_s(FZ5-hot) Output k_{eff}	GLASS MK15-ASSY(?) Cold-No Xe Sept-FZ5-Cold Output k_{eff} Σ_{15}(cold-noXe)	GLASS Mk15-ASSY(?) Cold-No Xe, 25 days Sm & Pu buildup Sept-FZ5-cold Output k_{eff} Σ_{15} (cold-noXe, 25d Sm&Pu)

TABLE C3 (Continued)

Zero Exposure

Hot-Dirty	Hot-No Xe	Cold-No Xe	Cold-No Xe, 25 d Sm & Pu
PARXS1-Mk15 Output Σ_{15}(HD) GILDA Σ_{15}(HD) Σ_{s}(FZ5-hot) Output k_{eff}	GLASS Mk15-Hot-Clean (no exposure) Sept-FZ5-hot Output Σ_{15}(hot-No Xe) Σ_{s}(FZ5-hot) GILDA Σ_{15}(hot-No Xe) Σ_{s}(FZ5-hot) Output k_{eff}	GLASS Mk15-Cold-clean (no exposure) Sept-FZ5-cold Output Σ_{15}(cold-no Xe) Σ_{s}(FZ5-cold) GILDA Σ_{15}(cold-no Xe) Σ_{s}(FZ5-cold) Output k_{eff}	Identical to Cold-No Xe

TABLE C4

SCRAM1 AXIAL MODEL OF THE MARK 15 CONTROL ZONE

AXIAL REGION	TOP OF REGION (Elevation above Tank Bottom)	Comment
1	22.86	bottom of active portion of full rods at 1000 Vu
2	38.36	bottom of active portion of partial rods at 1000 Vu
3	53.59	bottom of Mark 15 core
4	67.97	bottom of active portion of full rods at 900 Vu
5	113.08	bottom of active portion of full rods at 800 Vu
6	128.58	bottom of active portion of partial rods at 800 Vu
7	158.19	bottom of active portion of full rods at 700 Vu
8	203.30	bottom of active portion of full rods at 600 Vu
9	248.41	bottom of active portion of full rods at 500 Vu
10	254.90	top of active portion of partial rods at 1000 Vu
11	293.52	bottom of active portion of full rods at 400 Vu
12	338.63	bottom of active portion of full rods at 300 Vu
13	345.12	top of active portion of partial rods at 800 Vu
14	383.74	bottom of active portion of full rods at 200 Vu
15	428.85	bottom of active portion of full rods at 100 Vu
16	452.27	top of Mark 15 core
17	462.30	bottom of top poison plate