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Improvements to the VMEC Free Boundary Equilibrium Reconstruction Code[1]

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The Variational Moments Equilibrium Code (VMEC) is a free boundary equilibrium reconstruction code that is used routinely in conjunction with motional Stark effect (MSE), external magnetics, and kinetic measurements on TFTR to self consistently determine the time evolution of the safety factor profile of the plasma. VMEC has undergone several improvements recently, including updates to the internal spline representation of the pressure and iota profiles, and a new algorithm for positioning the the plasma boundary up against the nearest TFTR limiter. In addition, a versatile user interface eases the preparation for TFTR data input files needed for time sequence processing, and offers the flexibility of scheduling the code to run on any of several different local computer systems. Results will be presented that illustrate the reconstruction process as applied to a series of discharges that exhibit strong reversed magnetic shear.

[1]Work supported by the U.S. D.o.E. Contract DE-AC02-76CH03073

Introduction

The 3D Variational Moments Equilibrium code **VMEC** has been modified to perform 2D equilibrium reconstruction of q and p profiles using MSE, measured thermal pressure and numerically computed fast ion beam pressure, and external magnetics data.

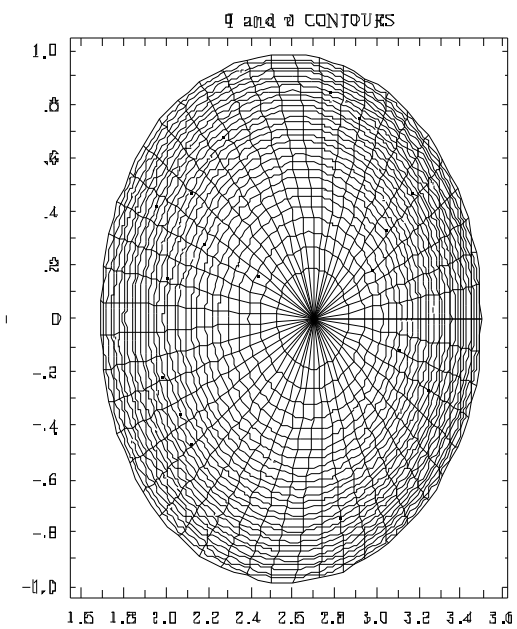
What is Reconstructed ?

· The equilibrium solution in *inverse* coordinates -

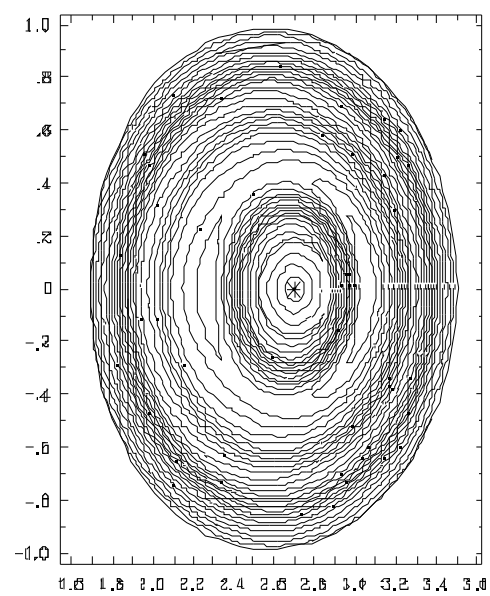
$$R(\psi,\theta) = \sum_{m=0}^{M} R_m(\psi) \cos(m\theta)$$

$$Z(\psi,\theta) = \sum_{m=0}^{M} Z_m(\psi) \sin(m\theta)$$

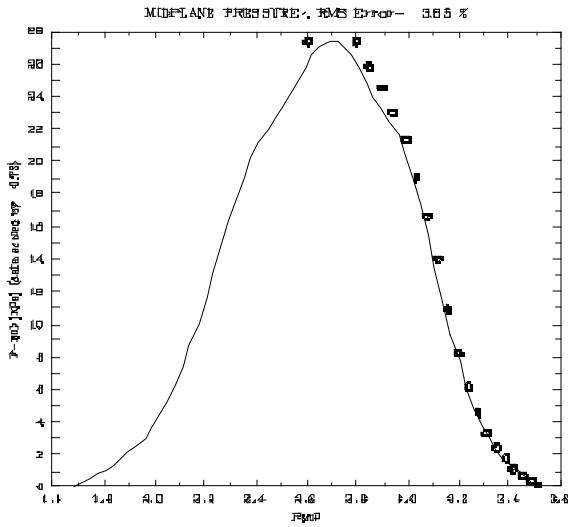
ψ(R,Z)



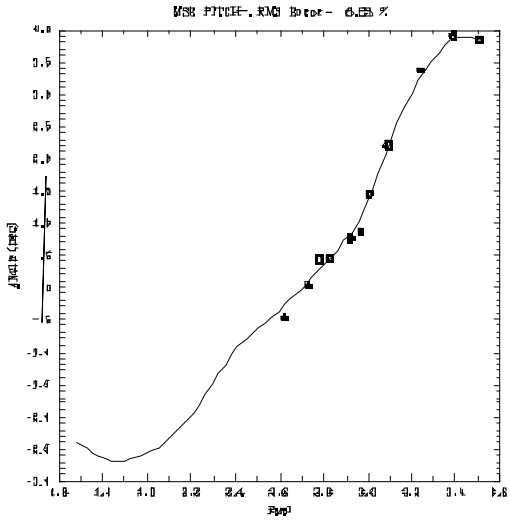
jphi(R,Z)



- The pressure profile p(ψ) based on the midplane pressure p(R) from TRANSP or SNAP



- The midplane B_P/B_T pitch angle based on the MSE diagnostic



· Magnetics : Plasma Current I_P

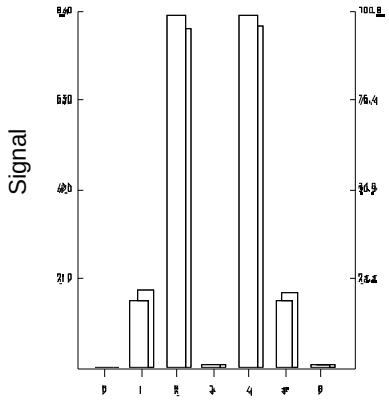
Diamagnetic Flux Φ_{dia}

(6) Saddle Coil Fluxes (shown below)

(50) B_θ,B_ρ B loop pairs (shown below)

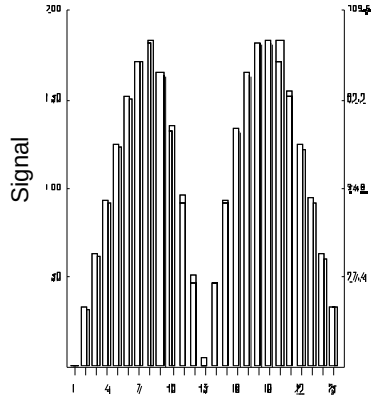
(15) Mirnov loop B's

Saddle Coils

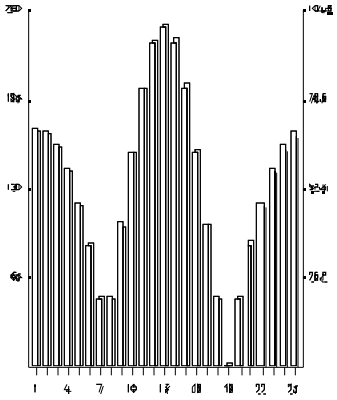


Data in front
Reconstruction in rear

B_R Loops



B_Z Loops



What is the Algorithm ?

Use the standard VMEC inverse equilibrium solver using p' and ι' ...

[S.P. Hirshman and J.C. Whitson, Phys. Fluids 26, 3553 (1983)]

Embedded inside is a solution to the LSQ problem associated with the measured data to be "fit" ...

[S.P. Hirshman et. al., Phys. Plasmas 1, 2277 (1994)]

What is the p and iota representation ?

- Cubic splines with tension
- MSE data 1st splined in R space to provide $\iota(0)$
- p and iota represented by knot values equidistantly distributed in "sqrt(s)" space

  $s = \Phi/\Phi_0$ where Φ is the toroidal flux
- iota knots include a known value at the plasma edge, based on total I_p, to insure full coverage of plasma interior
- Cast the LSQ problem in terms linear in the pressure and iota spline knot values

RECENT IMPROVEMENTS

Spline knot positioning

before-	knots located at MSE data points
now-	knots located equidistant in sqrt(s) space
benefits-	characterization of the spline space is less dependent on the distribution of the data

How does the # of Spline knots affect the resulting q profiles ?

For the TFTR cases studied here ...

- the chi square flattens out after n =6
- the variation in the reconstructed q profile subsides for n >= 6

Automatic Positioning with Respect to the Limiter

When?

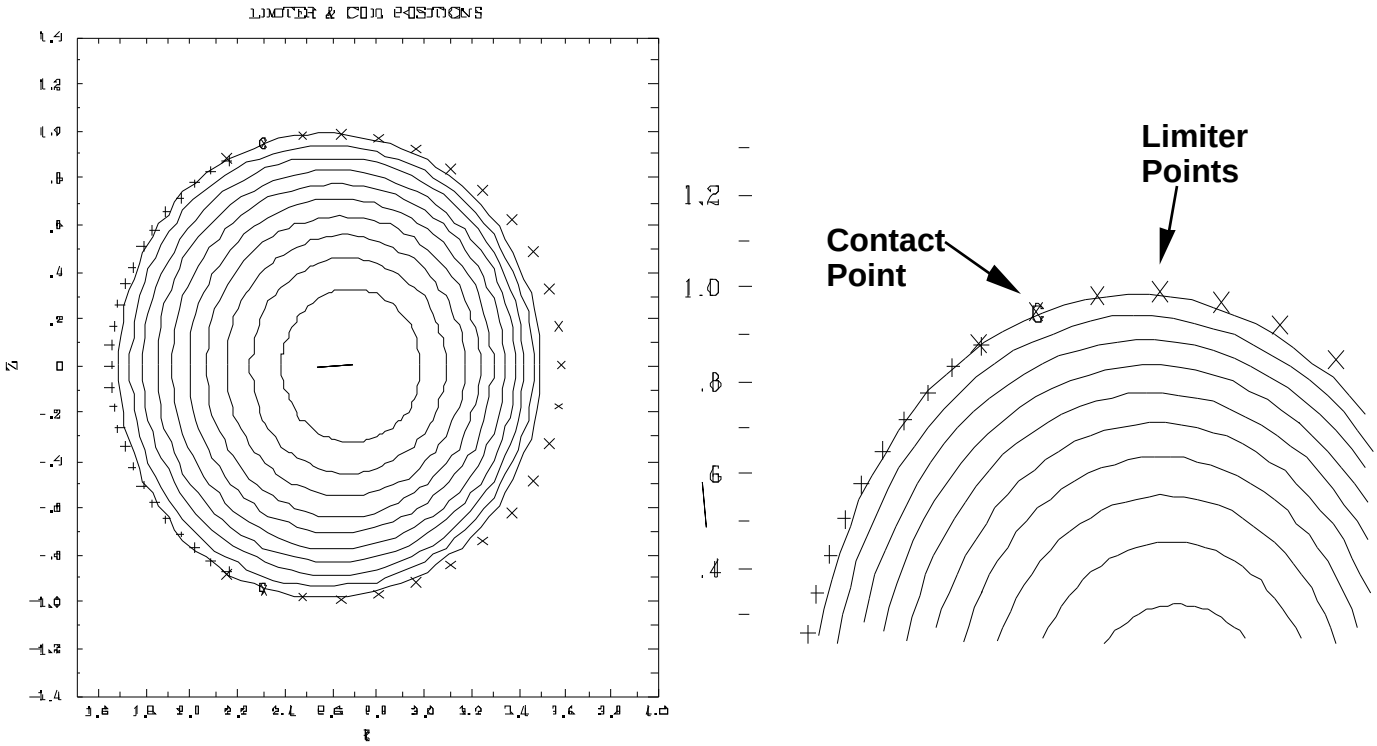
for limiter plasmas

How?

- Scale the enclosed toroidal flux in a feedback loop

- Feedback signal depends on number of boundary points inside or outside of the limiter and the “near” distance

- Use Cauchy Integral Formula to evaluate “inside” and “outside”



VMEC TFTR Data Processing Tools

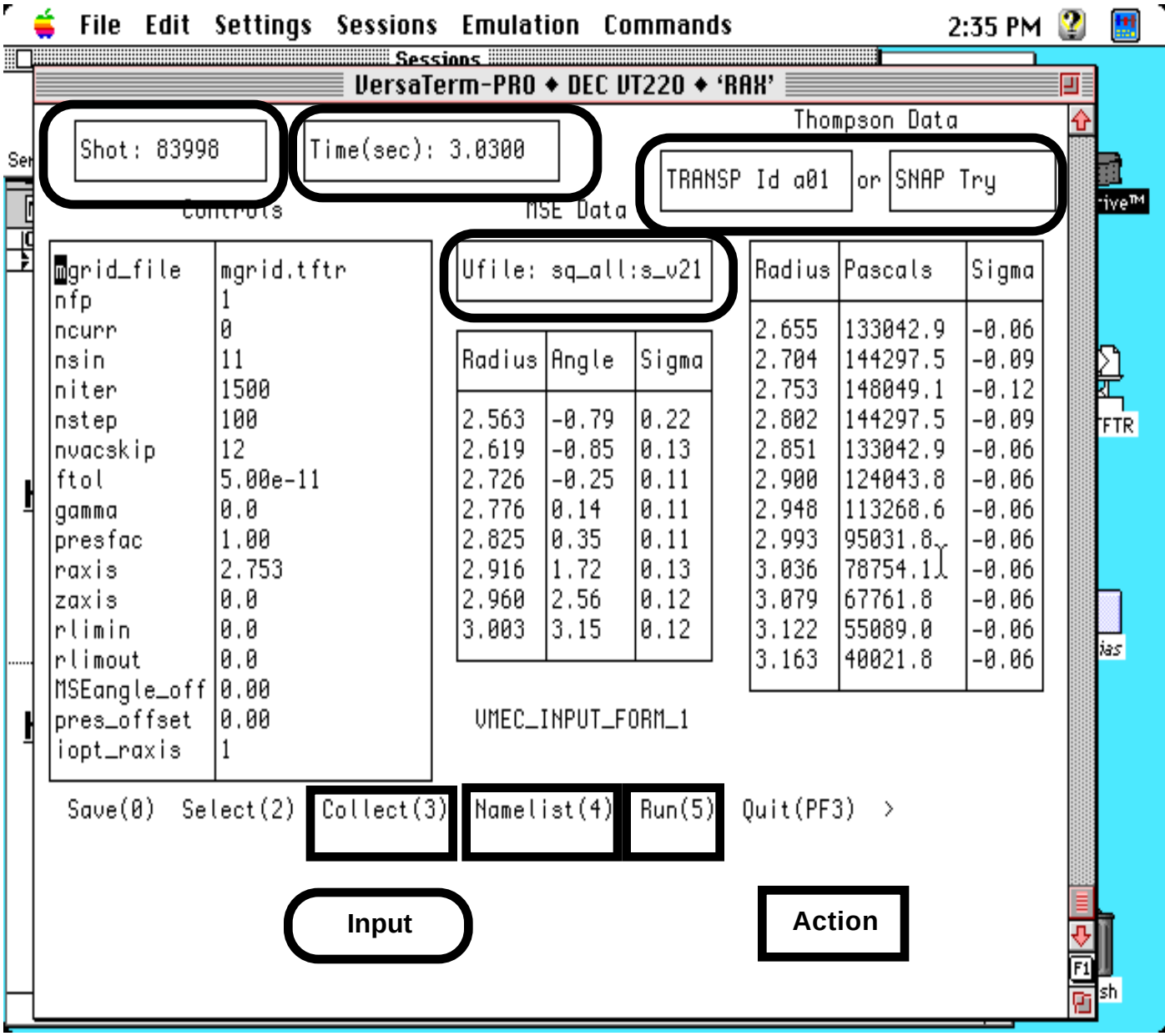
Why?

- Over 90 data signals to process per time slice
- Multiple time slice processing
- Both input data pre-processing and VMEC execution can be run in batch mode

How?

- Use GUI form for single time slice preparation ...

VMI


File Edit Settings Sessions Emulation Commands
2:35 PM
Sessions
VersaTerm-PRO ♦ DEC VT220 ♦ 'RAH'
Shot: 83998
Time(sec): 3.0300
Thompson Data
TRANSP Id a01
or
SNAP Try
Controls
MSE Data
mgrid_file mgrid.tftr
nfp 1
ncurr 0
nsin 11
niter 1500
nstep 100
nvacskip 12
ftol 5.00e-11
gamma 0.0
presfac 1.00
raxis 2.753
zaxis 0.0
rlimin 0.0
rlimout 0.0
MSEangle_off 0.00
pres_offset 0.00
iopt_raxis 1
Ufile: sq_all:s_v21
Radius Angle Sigma
2.563 -0.79 0.22
2.619 -0.85 0.13
2.726 -0.25 0.11
2.776 0.14 0.11
2.825 0.35 0.11
2.916 1.72 0.13
2.960 2.56 0.12
3.003 3.15 0.12
Radius Pascals Sigma
2.655 133042.9 -0.06
2.704 144297.5 -0.09
2.753 148049.1 -0.12
2.802 144297.5 -0.09
2.851 133042.9 -0.06
2.900 124043.8 -0.06
2.948 113268.6 -0.06
2.993 95031.8 -0.06
3.036 78754.1 -0.06
3.079 67761.8 -0.06
3.122 55089.0 -0.06
3.163 40021.8 -0.06
VMEC_INPUT_FORM_1
Save(0) Select(2) Collect(3) Namelist(4) Run(5) Quit(PF3) >
Input
Action

How (continued)?

- Use batch script to run VMI on groups of time slices and optionally queue for execution and post-processing

  $ vmi/batch[/queue=r_norm] [/run] shots.lis

  shots.lis =

```
88299   a01   sq_all:s_v03.ang
  0.7505   0.7755   0.8005   0.8255
88299   a01   sq_all:s_v03.ang
  0.8505   0.8755   0.9005   0.9255
88299   a01   sq_all:s_v03.ang
  0.9505   0.9755   1.0005   1.0255
88299   a01   sq_all:s_v03.ang
  1.0505   1.0755   1.1005   1.1255
88299   a01   sq_all:s_v03.ang
  1.1505   1.1755   1.2005   1.2255
88299   a01   sq_all:s_v03.ang
  1.2505   1.2755   1.3005   1.3255
88299   a01   sq_all:s_v03.ang
  1.3505   1.3755   1.4005   1.4255
88299   a01   sq_all:s_v03.ang
  1.4505   1.4755   1.5005   1.5255
88299   a01   sq_all:s_v03.ang
  1.5505   1.5755   1.6005   1.6255
88299   a01   sq_all:s_v03.ang
  1.6505   1.6755   1.7005   1.7255
88299   a01   sq_all:s_v03.ang
  1.7505   1.7755   1.8005   1.8255
88299   a01   sq_all:s_v03.ang
  1.8505   1.8755   1.9005   1.9255
88299   a01   sq_all:s_v03.ang
  1.9505   1.9755   2.0005   2.0255
88299   a01   sq_all:s_v03.ang
  2.0505   2.0755   2.1005   2.1255
88299   a01   sq_all:s_v03.ang
  2.1505   2.1755   2.2005   2.2255
88299   a01   sq_all:s_v03.ang
  2.2505   2.2755   2.3005   2.3255
88299   a01   sq_all:s_v03.ang
  2.3505   2.3755   2.4005   2.4255
88299   a01   sq_all:s_v03.ang
  2.4505   2.4755
88299   a01   sq_all:s_v03.ang
  2.9505   2.9755   3.0005   3.0255
88299   a01   sq_all:s_v03.ang
  3.0505   3.0755   3.1005   3.1255
88299   a01   sq_all:s_v03.ang
  3.1505   3.1755   3.2005   3.2255
88299   a01   sq_all:s_v03.ang
  3.2505   3.2755
```

How (continued)?

- Use “Hot Restart” mode to sequence through a time slice series using previous solution
- this mode is a precursor to embedding VMEC in TRANSP for full free boundary operation

SEQ	ITERS	CHISQ/N	TORCUR	PRESMAX	PHIEDGE	R00	CPU-TIME	EXTENSION
1	603	1.01	1.08	17.34	-13.37	2.69	21.29	88152a02t075
2	444	1.10	1.09	22.53	-13.38	2.70	12.53	88152a02t077
3	721	0.84	1.10	28.12	-13.40	2.73	19.95	88152a02t080
4	352	0.43	1.11	24.54	-13.40	2.72	9.91	88152a02t082
5	414	0.27	1.12	22.60	-13.42	2.70	11.66	88152a02t085
6	188	0.35	1.13	26.28	-13.41	2.70	5.46	88152a02t087
7	255	0.53	1.14	30.28	-13.47	2.71	7.32	88152a02t090
8	570	0.26	1.14	23.55	-13.48	2.67	16.00	88152a02t092
9	378	0.33	1.16	28.79	-13.45	2.69	10.65	88152a02t095
10	361	0.39	1.17	28.47	-13.50	2.69	10.22	88152a02t097
11	450	0.26	1.17	27.25	-13.51	2.68	12.82	88152a02t100
12	379	0.55	1.19	37.70	-13.49	2.72	10.71	88152a02t102
13	437	0.31	1.20	34.58	-13.49	2.70	12.33	88152a02t105
14	307	0.53	1.21	44.11	-13.51	2.72	8.71	88152a02t107
15	424	0.32	1.21	37.84	-13.49	2.70	12.02	88152a02t110
16	1235	0.33	1.23	36.40	-13.47	2.70	34.71	88152a02t112
17	337	0.29	1.23	37.45	-13.50	2.70	9.57	88152a02t115
18	435	0.34	1.25	43.32	-13.50	2.71	12.18	88152a02t117
19	400	1.01	1.26	52.52	-13.59	2.74	11.24	88152a02t120
20	659	0.39	1.27	42.33	-13.54	2.71	18.25	88152a02t122
21	489	0.78	1.28	53.39	-13.60	2.74	13.72	88152a02t125
22	467	0.63	1.29	55.39	-13.59	2.74	13.13	88152a02t127
23	423	0.61	1.30	53.06	-13.58	2.74	11.92	88152a02t130
24	366	0.80	1.31	53.61	-13.60	2.75	10.24	88152a02t132
25	378	0.50	1.32	57.46	-13.55	2.74	10.61	88152a02t135
26	407	0.60	1.33	57.63	-13.58	2.74	11.50	88152a02t137
27	445	0.29	1.34	54.62	-13.52	2.73	12.47	88152a02t140
28	338	0.37	1.35	52.75	-13.55	2.72	9.46	88152a02t142
29	379	0.56	1.36	59.38	-13.59	2.73	10.62	88152a02t145
30	345	0.62	1.37	61.77	-13.60	2.74	9.67	88152a02t147
31	605	0.56	1.38	51.75	-13.64	2.73	16.76	88152a02t150
32	403	0.59	1.40	64.15	-13.61	2.74	11.27	88152a02t152
33	345	0.82	1.40	63.79	-13.63	2.74	9.66	88152a02t155
34	493	0.36	1.42	54.70	-13.58	2.71	13.81	88152a02t157
35	337	0.65	1.43	65.74	-13.61	2.74	9.52	88152a02t160
36	606	0.97	1.44	70.38	-13.63	2.76	16.91	88152a02t162
37	663	0.65	1.45	66.55	-13.61	2.74	18.56	88152a02t165
38	298	0.60	1.46	67.53	-13.62	2.75	8.39	88152a02t167
39	327	0.48	1.47	67.30	-13.60	2.74	9.29	88152a02t170
40	467	0.62	1.48	76.19	-13.61	2.75	13.10	88152a02t172
41	341	0.40	1.49	67.57	-13.60	2.74	9.56	88152a02t175
42	273	0.50	1.50	70.52	-13.61	2.74	7.70	88152a02t177

43	328	0.41	1.51	72.81	-13.59	2.74	9.43	88152a02t180
44	303	0.70	1.52	74.79	-13.62	2.75	8.52	88152a02t182
45	399	0.61	1.52	79.86	-13.61	2.75	11.22	88152a02t185
46	645	0.53	1.54	71.42	-13.62	2.74	17.94	88152a02t187
47	305	0.55	1.55	71.05	-13.62	2.74	8.64	88152a02t190
48	384	0.82	1.57	80.02	-13.63	2.75	10.77	88152a02t195
49	342	0.59	1.58	79.61	-13.62	2.75	9.65	88152a02t197
50	518	0.55	1.59	69.05	-13.63	2.73	14.44	88152a02t200
51	351	0.41	1.59	73.39	-13.60	2.72	9.92	88152a02t202
52	611	0.76	1.59	88.56	-13.64	2.75	17.03	88152a02t205
53	343	0.60	1.59	82.67	-13.63	2.75	9.71	88152a02t207
54	383	0.66	1.59	84.63	-13.63	2.75	10.78	88152a02t210
55	599	0.59	1.59	78.97	-13.64	2.74	16.63	88152a02t212
56	450	0.35	1.59	67.22	-13.60	2.72	12.51	88152a02t215
57	250	0.68	1.59	79.41	-13.65	2.74	7.10	88152a02t217
58	303	0.41	1.59	77.80	-13.60	2.73	8.54	88152a02t220
59	342	0.46	1.59	77.77	-13.63	2.73	9.66	88152a02t222
60	301	0.69	1.59	85.04	-13.65	2.75	8.47	88152a02t225
61	314	0.45	1.59	80.94	-13.62	2.74	9.00	88152a02t227
62	303	0.69	1.59	90.79	-13.66	2.75	8.60	88152a02t230
63	283	0.62	1.59	86.19	-13.65	2.74	7.97	88152a02t232
64	330	0.60	1.59	88.37	-13.64	2.74	9.31	88152a02t235
65	300	0.60	1.59	84.67	-13.64	2.74	8.49	88152a02t237
66	370	0.58	1.59	81.14	-13.64	2.74	10.40	88152a02t240
67	432	0.71	1.59	91.49	-13.65	2.75	12.15	88152a02t242
68	546	0.54	1.58	78.69	-13.66	2.73	15.22	88152a02t245
69	362	0.60	1.58	81.50	-13.64	2.73	10.20	88152a02t247
70	298	0.32	1.59	85.28	-13.63	2.73	8.50	88152a02t250
71	347	0.42	1.59	92.98	-13.63	2.74	9.69	88152a02t252
72	305	0.38	1.60	91.91	-13.63	2.73	8.72	88152a02t255
73	348	0.31	1.59	102.81	-13.58	2.73	9.82	88152a02t257
74	317	0.38	1.59	111.64	-13.56	2.74	9.04	88152a02t260
75	356	0.37	1.59	125.30	-13.56	2.75	9.99	88152a02t262
76	390	0.39	1.59	130.99	-13.56	2.76	11.02	88152a02t265
77	334	0.33	1.59	139.98	-13.55	2.76	9.39	88152a02t267
78	354	0.39	1.59	140.07	-13.52	2.76	10.02	88152a02t270
79	364	0.36	1.59	146.53	-13.53	2.77	10.20	88152a02t272
80	201	0.39	1.59	153.72	-13.56	2.77	5.72	88152a02t275
81	270	0.38	1.58	147.10	-13.54	2.77	7.86	88152a02t277
82	386	0.36	1.58	155.77	-13.51	2.77	10.81	88152a02t280
83	636	0.60	1.58	156.23	-13.56	2.79	17.68	88152a02t282
84	532	0.81	1.58	167.99	-13.56	2.81	14.72	88152a02t285
85	408	0.43	1.58	171.32	-13.60	2.80	11.32	88152a02t287
86	481	0.54	1.59	161.66	-13.55	2.78	13.28	88152a02t290
87	534	0.42	1.57	137.51	-13.60	2.77	14.94	88152a02t292
88	497	0.66	1.57	145.08	-13.63	2.79	13.90	88152a02t295
89	438	0.55	1.58	113.54	-13.68	2.76	12.20	88152a02t297
90	347	0.40	1.57	108.72	-13.67	2.76	9.81	88152a02t300
91	483	0.39	1.58	92.64	-13.71	2.74	13.51	88152a02t302
92	313	0.58	1.58	103.50	-13.67	2.75	8.79	88152a02t305
93	269	0.48	1.58	89.20	-13.70	2.74	7.58	88152a02t307
94	315	0.51	1.58	86.97	-13.66	2.74	8.98	88152a02t310
95	555	0.55	1.58	83.13	-13.69	2.73	15.53	88152a02t312
96	358	0.55	1.58	79.35	-13.68	2.73	10.11	88152a02t315
97	317	0.63	1.58	83.97	-13.68	2.74	9.01	88152a02t317
98	274	0.42	1.59	71.51	-13.66	2.72	7.89	88152a02t320
99	214	0.52	1.58	76.30	-13.68	2.73	6.07	88152a02t322
100	193	0.66	1.58	77.37	-13.68	2.73	5.62	88152a02t325

Where does it run?

- Launch jobs from VMS machines where the TFTR data is collected into a single, portable data namelist file

- Execute VMEC jobs anywhere on PPL computer cluster :

  Unix machines
  or
  VMS/Alpha machines

- Postprocess graphics with NCAR graphics on Unix machine

- Postprocess profiles into 2d Ufiles

- Postprocess profiles and scalars into VMEC database with INGRES on VMS machine

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Table “VMEC” holds scalars, 1 row per time slice

```
RAX$ sql tftr
INGRES TERMINAL MONITOR Copyright (c) 1981, 1992 Computer Associates Intl, Inc.
)0INGRES VAX Version 6.4/05 (vax.vms/02) login  2-NOV-1995 15:46:41

go
* help table vmec\g
Executing . . .

Name:                 vmec
Owner:                publicdb
Created:              16-sep-1995 20:31:00
Location:             ii_database
Type:                 user table
Version:              ING6.0
Row width:            780
Number of rows:       7628
Storage structure:    btree with unique keys
Compression:          none
Duplicate Rows:       not allowed
Number of pages:      4196
Overflow data pages:  0
Journaling:           disabled
Base table for view:  no
Optimizer statistics: none

Column Information:
                                                                  Key
Column Name                      Type       Length Nulls Defaults Seq
shot                             integer         4  yes      no
shotid                           vchar           8  yes      no     1
time                             float           4  yes      no     2
type                             integer         4  yes      no
who                              vchar           8  yes      no     3
timestamp                        date               yes      no
raxismse                         float           4  yes      no
raxiscalc                        float           4  yes      no
dmfexp                           float           4  yes      no
dmfcalc                          float           4  yes      no
pscale                           float           4  yes      no
chisqmse                         float           4  yes      no
chisqpres                        float           4  yes      no
chisqsdl                         float           4  yes      no
chisqbr                          float           4  yes      no
chisqbz                          float           4  yes      no
rmsmse                           float           4  yes      no
rmspres                          float           4  yes      no
rmssdl                           float           4  yes      no
rmsbr                            float           4  yes      no
rmsbz                            float           4  yes      no
ns                               integer         4  yes      no
nu                               integer         4  yes      no
mu                               integer         4  yes      no
niter                            integer         4  yes      no
imse                             integer         4  yes      no
itse                             integer         4  yes      no
```

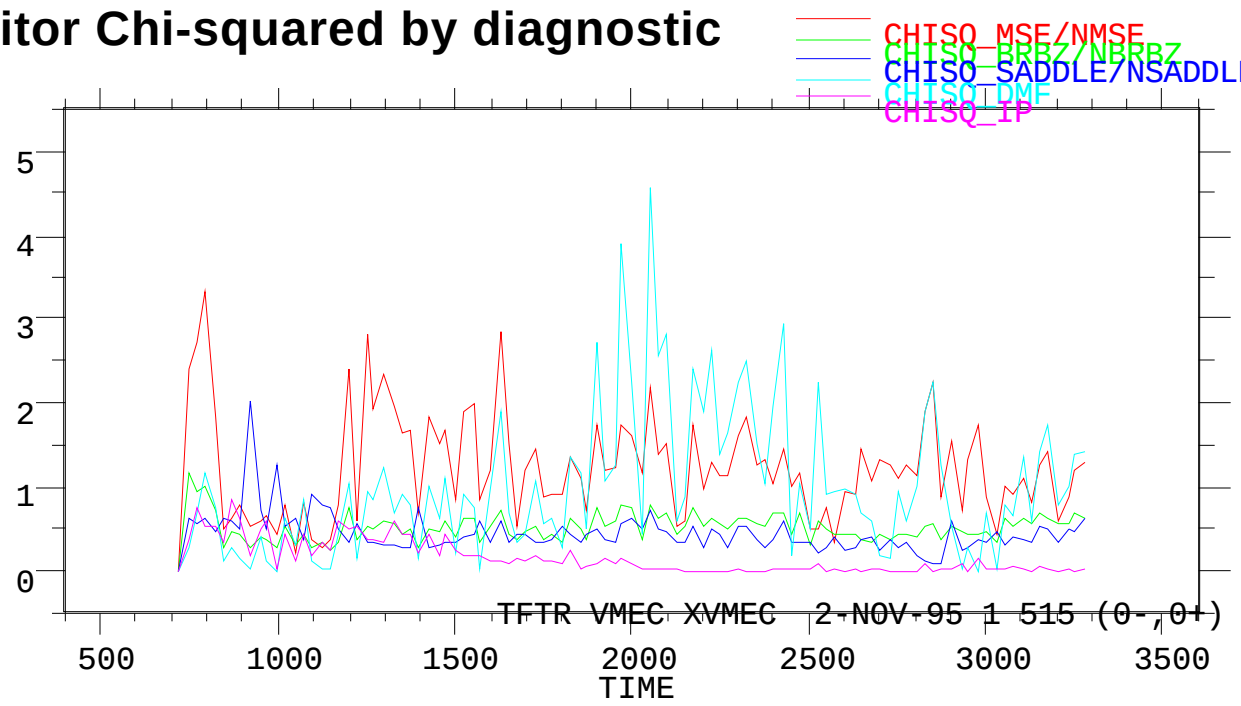
Column Name	Type	Length	Nulls	Defaults	Seq
nflxs	integer	4	yes	no	
nobser	integer	4	yes	no	
nbfld	integer	4	yes	no	
nbcoils	integer	4	yes	no	
ipsig	float	4	yes	no	
delphisig	float	4	yes	no	
ptension	float	4	yes	no	
itension	float	4	yes	no	
mseangoff	float	4	yes	no	
iter	integer	4	yes	no	
fsqr	float	4	yes	no	
fsqz	float	4	yes	no	
fsql	float	4	yes	no	
arfb	float	4	yes	no	
pshift	float	4	yes	no	
jphi0	float	4	yes	no	
ipexp	float	4	yes	no	
ipcalc	float	4	yes	no	
phitexp	float	4	yes	no	
phitcalc	float	4	yes	no	
p0exp	float	4	yes	no	
p0calc	float	4	yes	no	
r0exp	float	4	yes	no	
r0calc	float	4	yes	no	
apresexp	float	4	yes	no	
aprescalc	float	4	yes	no	
a0exp	float	4	yes	no	
a0calc	float	4	yes	no	
b0exp	float	4	yes	no	
b0calc	float	4	yes	no	
rinexp	float	4	yes	no	
rincalc	float	4	yes	no	
routexp	float	4	yes	no	
routcalc	float	4	yes	no	
vol	float	4	yes	no	
area	float	4	yes	no	
sarea	float	4	yes	no	
circ	float	4	yes	no	
a0varaxis	float	4	yes	no	
a0edge	float	4	yes	no	
a0var0	float	4	yes	no	
e0	float	4	yes	no	
d0	float	4	yes	no	
psiedge	float	4	yes	no	
eedge	float	4	yes	no	
dedge	float	4	yes	no	
shift	float	4	yes	no	
pint	float	4	yes	no	
bpsq	float	4	yes	no	
btsq	float	4	yes	no	
bsq	float	4	yes	no	
ekin	float	4	yes	no	
betatot	float	4	yes	no	
betapol	float	4	yes	no	
betator	float	4	yes	no	
fedge	float	4	yes	no	
betastar	float	4	yes	no	
betapk	float	4	yes	no	
rt	float	4	yes	no	
rg	float	4	yes	no	
rl	float	4	yes	no	
muishaf	float	4	yes	no	
s1rt	float	4	yes	no	

Column Name	Type	Length	Nulls	Defaults	Seq
s1rg	float	4	yes	no	
s1rl	float	4	yes	no	
s2rt	float	4	yes	no	
s2rg	float	4	yes	no	
s2rl	float	4	yes	no	
s3rt	float	4	yes	no	
s3rg	float	4	yes	no	
s3rl	float	4	yes	no	
lirt	float	4	yes	no	
lirg	float	4	yes	no	
lirl	float	4	yes	no	
muirt	float	4	yes	no	
muirg	float	4	yes	no	
muirl	float	4	yes	no	
betairt	float	4	yes	no	
betairg	float	4	yes	no	
betairl	float	4	yes	no	
betamuis1rt	float	4	yes	no	
betamuis1rg	float	4	yes	no	
betamuis1rl	float	4	yes	no	
lambdart	float	4	yes	no	
lambdarg	float	4	yes	no	
lambdarl	float	4	yes	no	
lambdas1s2rt	float	4	yes	no	
lambdas1s2rg	float	4	yes	no	
lambdas1s2rl	float	4	yes	no	
shaf1rt	float	4	yes	no	
shaf1rg	float	4	yes	no	
shaf1rl	float	4	yes	no	
rfbrt	float	4	yes	no	
rfbrg	float	4	yes	no	
rfbrl	float	4	yes	no	
q0	float	4	yes	no	
qedge	float	4	yes	no	
nbrbz	integer	4	yes	no	
chisq_brbz	float	4	yes	no	
nsaddle	integer	4	yes	no	
chisq_saddle	float	4	yes	no	
npressure	integer	4	yes	no	
chisq_pressure	float	4	yes	no	
nmse	integer	4	yes	no	
chisq_mse	float	4	yes	no	
nip	integer	4	yes	no	
chisq_ip	float	4	yes	no	
ndmf	integer	4	yes	no	
chisq_dmf	float	4	yes	no	
niota	integer	4	yes	no	
chisq_iota	float	4	yes	no	
qmin	float	4	yes	no	
rqmin	float	4	yes	no	
shearmin	float	4	yes	no	
rshearmin	float	4	yes	no	
raxistransp	float	4	yes	no	
presoff	float	4	yes	no	
sqmin	float	4	yes	no	
qmins	float	4	yes	no	
phiscale	float	4	yes	no	
mseshift	float	4	yes	no	
nmir	integer	4	yes	no	
chisqmir	float	4	yes	no	
rmsmir	float	4	yes	no	
chisq_mir	float	4	yes	no	

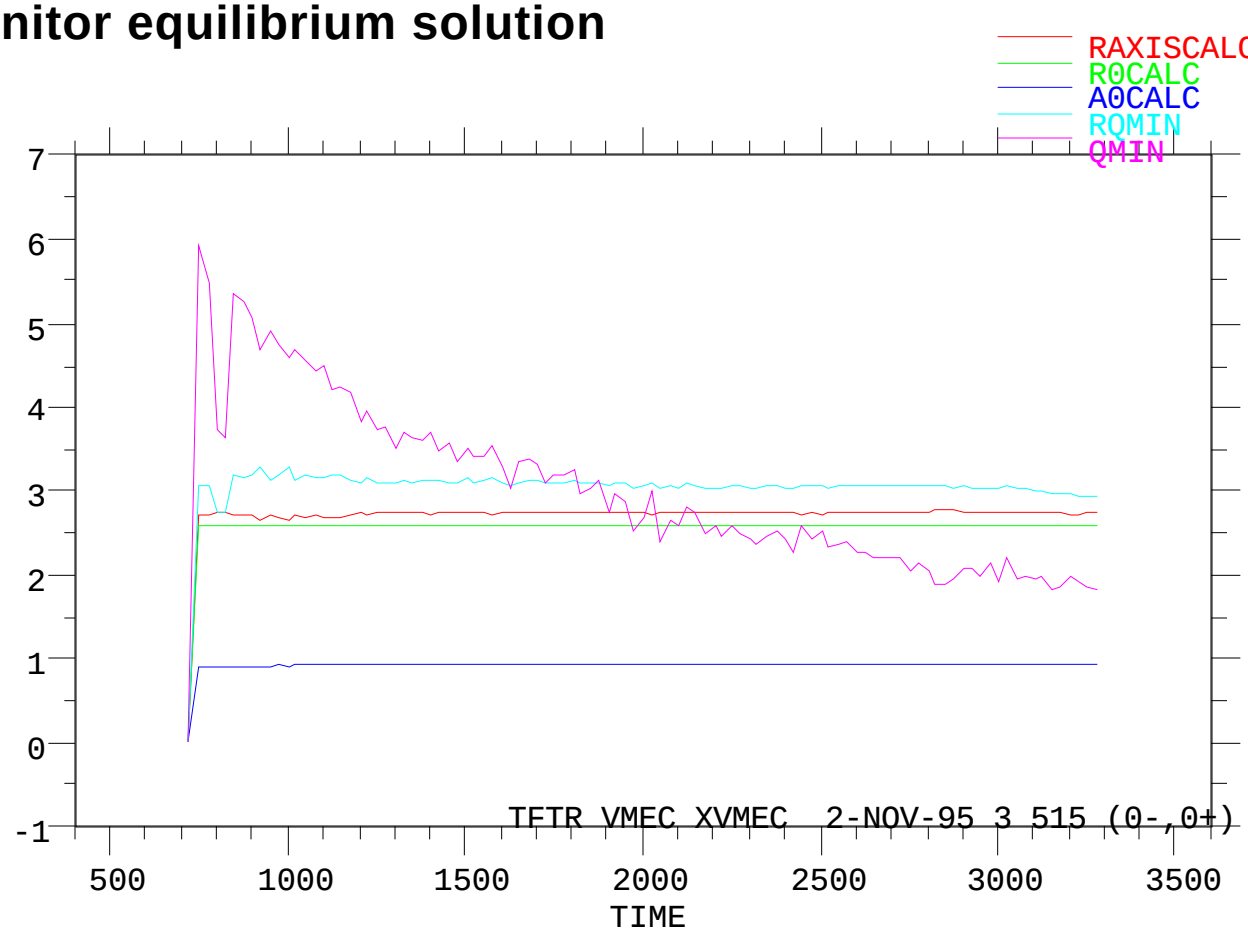
Table “VMECP” holds profiles, 61 rows per time slice

```
continue
* help table vmecp\g
Executing . . .

Name:                 vmecp
Owner:                publicdb
Created:              16-oct-1995 11:25:00
Location:             ii_database
Type:                 user table
Version:              ING6.0
Row width:            104
Number of rows:       89792
Storage structure:    btree with unique keys
Compression:          none
Duplicate Rows:       not allowed
Number of pages:      11010
Overflow data pages:  0
Journaling:           disabled
Base table for view:  no
Optimizer statistics: none

Column Information:
                                                                  Key
Column Name                      Type       Length Nulls Defaults Seq
shot                             integer         4  yes      no
shotid                           vchar           8  yes      no     1
time                             float           4   no      no     2
who                              vchar           8  yes      no     3
timestamp                        date               yes      no
s                                float           4  yes      no
x                                float           4  yes      no
rmid                             float           4  yes      no     4
amid                             float           4  yes      no
psi                              float           4  yes      no
vol                              float           4  yes      no
q                                float           4  yes      no
shear                            float           4  yes      no
p                                float           4  yes      no
alf                              float           4  yes      no
jtor                             float           4  yes      no
pitchangle                       float           4  yes      no

Secondary indexes:    none



continue
* \q
INGRES Version 6.4/05 (vax.vms/02) logout
 2-NOV-1995 15:47:38
RAX$
```

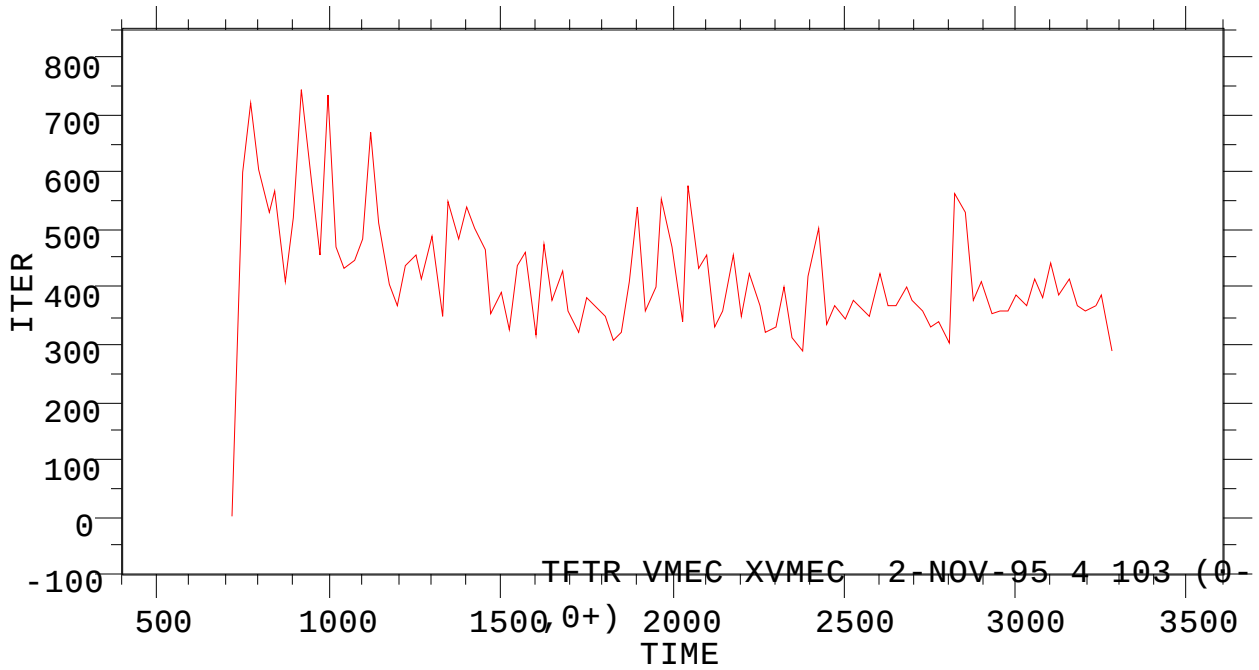
Monitor Chi-squared by diagnostic



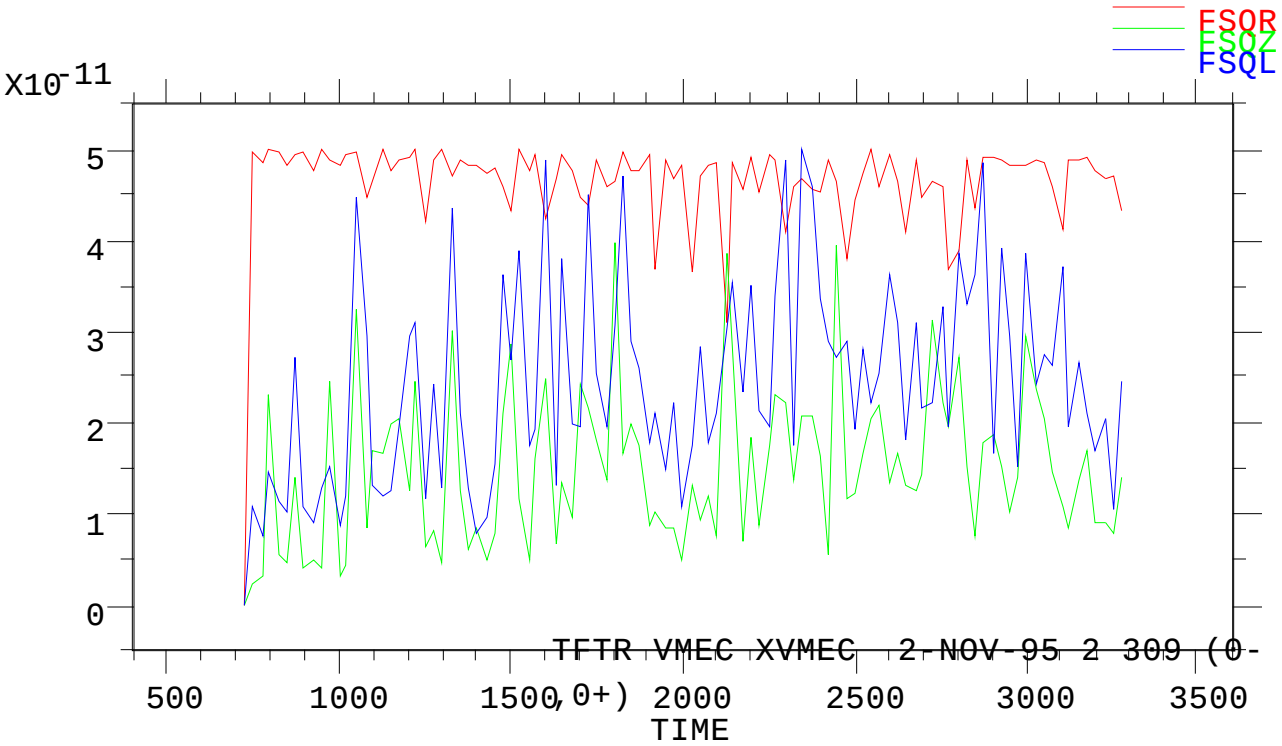
Monitor equilibrium solution



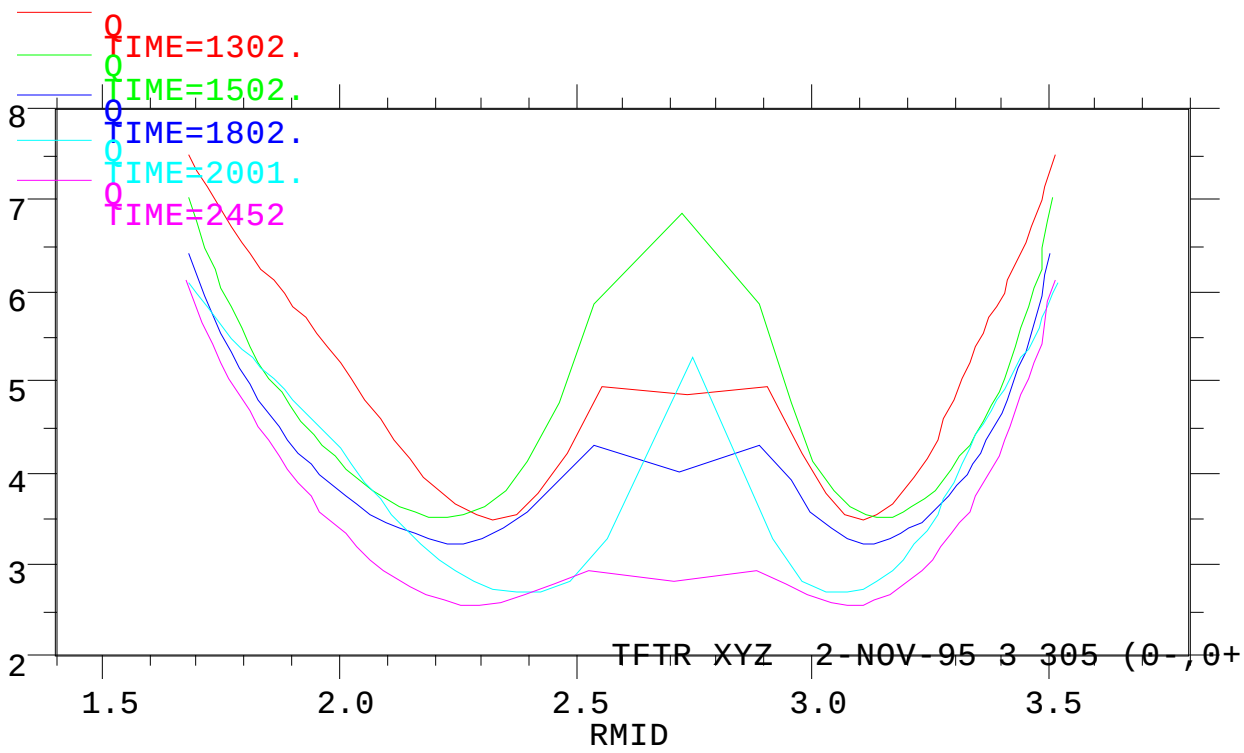
Monitor iterations to convergence



Monitor force balance



Compare q profiles at different times



REPRINTS

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