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**Finite-Element Calculations of Near-Field
Transient Horizontal Temperature and
Thermal Stress Distributions for
the Climax Granite Nuclear
Spent-Fuel-Storage Experiment**

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March 1980

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

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CONTENTS

Abstract	1
Background	1
Description of the Model	3
Computer Programs	5
Boundary Conditions	5
Choice of Elements	5
Results	7
Conclusions	9
Acknowledgments	9
References	10
Appendix A	11
Appendix B	19
Appendix C	28
Appendix D	36
Appendix E	44

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Transient Horizontal Temperature and Thermal-Stress
Distributions for the Climax Granite Nuclear Spent-Fuel-Storage Experiment

ABSTRACT

We present calculations of near-canister temperature and thermal stress fields in a horizontal plane through a typical spent nuclear fuel canister in the Climax granite experiment, assuming homogeneity of the rock mass. The methodology is described for future use and for the benefit of others who would apply these results to other projects and/or other experiments.

Three different canister spacings were investigated. The resulting temperature and stress plots (Appendixes A through D) show that a row of canisters may be satisfactorily approximated by a distributed plane source for points of interest which are at greater distances from the row than the canister spacing. Further, the thermal tensile stress changes are trivial and very much less than the calculated residual horizontal geostatic compressive stresses.

A listing of the mesh-generator input is given in Appendix E for use in additional analyses.

BACKGROUND

The U.S. Department of Energy (DOE) is funding a demonstration project for spent fuel storage in the Climax granite formation in Nevada.¹ The site is within the DOE Nevada Test Site (NTS) in Southwestern Nevada. This body of granitic quartz-monzonite rock is intrusive in origin, with an estimated age of 93 million years, and outcrops at the base of a large mountain in an area of lava flows, ash falls, and ancient calderas.

The hard-rock repository concept is illustrated in Fig. 1 and is applicable to rock formations other than granite. In the Climax experiment, one tunnel will contain fuel canisters and the two side tunnels will contain electric heaters to simulate a larger repository.

The objectives of this work were to investigate the near-field temperature and thermal stress effects for several spacings of canisters and to answer two questions:

FIG. 1. The hard-rock repository concept with parallel tunnels with spent fuel canisters placed in regularly spaced holes drilled into the floor. (Section A-A is shown in Fig. 2.)

- At what distance can a line of canisters be represented by a heat source distributed on a plane passing through all canisters?
- Does a significant tensile field develop around or between adjacent canisters?

Canister hole surface stresses are also calculated. These data may be applied in estimating surface decrepitation of the holes.

DESCRIPTION OF THE MODEL

To perform finite element analyses for the stated objectives, a plane strain mesh was developed and is shown as the shaded region in Fig. 2.

The mesh width (Y) is taken as one-half the canister spacing (S), and the model length (Z) is set at 100 ft, which is much larger than the actual tunnel spacing. The hole diameter was fixed at 2 ft, consequently the ratio of Y/D varied with canister spacing. In a plan. strain mesh, the thickness is implicitly a one-dimensional unit, in this case 1 ft.

The canister spacings chosen were 10 ft (the Climax design spacing), 5 ft (twice as much power loading), and 15 ft (66% as much power loading as in the experiment).

Preliminary estimates of power levels, canister size, and material properties were used since that was all that was available at the time. These are shown in Table 1. These were early estimates and should not be interpreted as definitive values for the Climax demonstration project. The power loading represents 1867 W distributed over the assumed 15-ft canister length.

TABLE 1. List of thermal and mechanical properties used.

Property	Symbol	Value	Unit
Heat capacity	C	7.0197×10^4	J/ft ³ K
Thermal conductivity	κ	0.92964	Watts/ft K
Elastic modulus	E	7.3×10^6	lb/in ²
Poisson's ratio	ν	0.2	
Thermal expansion coefficient	γ	0.222×10^{-5}	K ⁻¹
Power loading	Q	124.444	Watts/ft of canister

FIG. 2. Horizontal plane at midheight through a line of canisters of uniform spacing.

COMPUTER PROGRAMS

The computer programs used for this study were ADINAT² for the thermal analyses and ADINA³ for the thermal stress analyses. In both cases, the latest (late 1977) releases were used.

The selection, testing, and qualification of ADINAT and ADINA were reported by the author⁴ and were discussed at the 1979 ADINA User's Conference. Spacings of 5, 10 and 15 ft were investigated without major difference in results. Due to double symmetry, the computer model consisted of only the shaded region.

BOUNDARY CONDITIONS

The thermal boundary condition at $Z = 100$ is $\Delta T = 0$ and the mechanical boundary condition on this edge is free, which constitutes a conservative assumption for determining worst-case tensile stresses.

Other possible boundary assumptions at $Z = 100$ are the following:

- Elastic support (most realistic).
- "Roller" support (unconservative for estimating of tensile stresses).
- "Roller" support (symmetric) at $Z = 1/2$ tunnel spacing.

On the long edges, the thermal model is free (symmetric, adiabatic) and the mechanical model is roller supported (plane of symmetry). On the short edge at $Z = 0$, the thermal model is free and the mechanical model is roller supported (symmetric). On the curved canister wall, the thermal model is thermal flux-loaded and the mechanical model is free. These boundary conditions are illustrated in Fig. 3.

CHOICE OF ELEMENTS

All calculations described here were performed using the ADINAT Program for temperature distributions and ADINA for thermal stress. These programs provide for two- and three-dimensional elements with linear or quadratic interpolation within the elements and up to 4×4 quadrature for elemental integration. A similar capability does not exist in any other program pair at LLNL.

(a) Thermal analysis boundary conditions

(b) Mechanical analysis boundary conditions

FIG. 3. Thermal and mechanical boundary for the horizontal planar temperature and thermal stress calculations.

Thermal-stress calculations are complicated in isoparametric elements since thermal strains are interpolated to a higher order within the element than the mechanical strains they produce.⁴ This difference is largely alleviated by the use of 8-node, two-dimensional elements and 20- or 21-node, three-dimensional elements. These elements will normally interpolate thermal effects parabolically and mechanical effects linearly. In regions of constant temperature gradients, the results will be exact; however, in regions of changing gradients, the errors will be smaller than in those with constant-strain elements.

Simple elements (4-node quad, 8-node brick) provide for linear temperature variation but constant mechanical strain. In regions of nonzero temperature gradient, it will be necessary to average stresses within the element to avoid errors. This averaging was done for the results presented here.

The calculations described here used 4-node planar elements. Later project calculations used 8-node planar elements (parabolic) and it is strongly recommended that the high-order elements be used exclusively for all future thermal and thermal-stress calculations.

RESULTS

The model of Fig. 1 has been analyzed for various spacings using constant heat flux. The plots of temperature and horizontal thermal stress changes (σ_y , σ_z , σ_{max}) are assembled in Appendixes A, B, C, and D, respectively, for canister spacings of 10 ft. The calculations began at day 1 and proceeded forward in increments of 1 day for 70 days. However, only results for certain days through day 25 are shown since the transverse tensile stress changes peak within this period (see Fig. 4). Note that the unheated residual compressive stress field in this region will be on the order of twice the original horizontal compressive stress or approximately 20 times the indicated maximum (tensile) thermal stress increments. Consequently, a net compressive stress can be expected to exist at all times.

The temperature contours of Appendix A are essentially parallel to the row of canisters (horizontal in the plots) for distances of one-half to one times the canister spacing from the row center line. Consequently, the row of canisters may be approximately represented by a distributed heat source for all points of interest outside this region. The temperature contours for 5- and 15-ft canisters (not shown) indicate the same pattern at similar distances.

FIG. 4. Calculated maximum (most tensile) thermal stress changes for 25 days after placement.

CONCLUSIONS

In conclusion, we can state that while canister spacing affects temperature and thermal stress distribution around the canisters, the effect is not large and a row of canisters may be approximated by a distributed source without introducing significant error. Further, the resultant tensile stress increments are very small compared with the compressive stresses already in the rock and no net tension will occur in the vicinity of the canisters.

ACKNOWLEDGMENTS

The work described was performed during the latter part of 1978 and early 1979 both by the author, who was then an employee of the Mechanical Engineering Department of Lawrence Livermore National Laboratory, and by M. A. Gerhard, who is currently in that department. The graphic output displayed in this report was produced in late 1979 and early 1980 after development of some improved contour plotting programs. We wish to thank B. Brown and J. Hallquist for making available the GRAPE and THCR for the temperature and thermal stress contours, respectively.

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APPENDIX A

Temperature contours for a canister spacing of 10 ft for periods of 1, 2, 6, 10, 20, and 25 days after emplacement of spent fuel as shown in Figs. A-1 to A-7. The C contour represents 5°C above ambient temperature, the D contour represents 10°C , the E contour represents 15°C , F represents 20°C , G represents 25°C , H represents 30°C , and I represents 35°C .

MAX PLANEWAVE HOLE SPACING TEST TRIAL 2 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

FIG. A-1.

 

FIG. A-2.

14

CLIMATE CHANGE AND THE IMPACT OF CLIMATE CHANGE ON THE
 TIME OF THE

FIG. A-4.

CLIMAX PLANNAR HOLE DRILLING IN THE CRYSTAL MOUNTAIN AREA, TEXAS
 TIME 150

FIG. A-5.

CLIMAX PLANTAR HOLE SPACING TEST SERIAL 2
TIME 10:00

FIG. A-6.

CLIMAX PLANAR HOLE SPACING TEST FROM
TIME 250

FIG. A -7.

APPENDIX B

Thermal stress change contours in the tunnel longitudinal (Y) direction
for periods of 1, 2, 6, 10, 15 and 25 days after emplacement of spent fuel.

1. The first part of the document is a list of the names of the persons who were present at the meeting. The names are listed in alphabetical order.

2. The second part of the document is a list of the topics that were discussed at the meeting. The topics are listed in alphabetical order.

3. The third part of the document is a list of the actions that were taken at the meeting. The actions are listed in alphabetical order.

4. The fourth part of the document is a list of the persons who were responsible for the actions that were taken at the meeting. The persons are listed in alphabetical order.

FIG. 8-2.

(A) 10^{-10} A/cm² (B) 10^{-9} A/cm² (C) 10^{-8} A/cm² (D) 10^{-7} A/cm²
 (E) 10^{-6} A/cm² (F) 10^{-5} A/cm² (G) 10^{-4} A/cm² (H) 10^{-3} A/cm²

(I) 10^{-2} A/cm²
 (J) 10^{-1} A/cm²
 (K) 10^0 A/cm²

(L) 10^1 A/cm²
 (M) 10^2 A/cm²
 (N) 10^3 A/cm²
 (O) 10^4 A/cm²
 (P) 10^5 A/cm²
 (Q) 10^6 A/cm²
 (R) 10^7 A/cm²
 (S) 10^8 A/cm²
 (T) 10^9 A/cm²
 (U) 10^{10} A/cm²

FIG. B-3.

TABLE B-4. SUMMARY OF RESULTS OF THE ANALYSIS OF THE
COLLECTION OF 1971-72

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COLLECTION OF 1971-72

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COLLECTION OF 1971-72

FIG. B-4.

Q41. 5120 - HANDED TO THE...
CONTINUED ON P. 2

...
...
...
...

...

A = 1.0E+03
B = 9.53E+02
C = 8.48E+02
D = 7.44E+02
E = 6.34E+01
F = 5.32E+02
G = -4.27E+02
H = -3.21E+02
I = -2.16E+02
J = -1.11E+02

FIG. B-5.

DATA FOR CHARTING OF STRESS CONTOURS OF Y STRESS

TIME = 1.0E+05
 MIN. V. = 1.0E+03
 MAX. V. = 7.9E+01

COORDINATES

A = 1.3E+05
 B = 1.19E+03
 C = -1.06E+03
 D = 9.2E+02
 E = 7.4E+02
 F = -6.62E+02
 G = -5.31E+02
 H = -4.01E+02
 I = -2.70E+02
 J = -1.39E+02

FIG. B-6.

TRANSIENT ANALYSIS OF THE INTERIOR TEMPERATURES OF THE CONTAINERS OF THE JPL-2

TIME = 1.0E+02
 MIN = 1.0E+02
 MAX = 1.0E+02

TEMPERATURE

A = 1.0E+03
 B = 1.58E+03
 C = 1.23E+03
 D = 1.08E+03
 E = 9.73E+02
 F = 7.73E+02
 G = -6.21E+02
 H = -4.68E+02
 I = -3.16E+02
 J = -1.63E+02

FIG. B-7.

$\Delta H_{\text{f}}^{\circ}(\text{H}_2\text{O}) = -285.8 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{CO}_2) = -393.5 \text{ kJ/mol}$

The reaction is:
 $\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$

$\Delta H_{\text{f}}^{\circ}(\text{C}_2\text{H}_5\text{OH}) = -235.1 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{O}_2) = 0 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{CO}_2) = -393.5 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{H}_2\text{O}) = -285.8 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{C}_2\text{H}_5\text{OH}) = -235.1 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{O}_2) = 0 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{CO}_2) = -393.5 \text{ kJ/mol}$
 $\Delta H_{\text{f}}^{\circ}(\text{H}_2\text{O}) = -285.8 \text{ kJ/mol}$

FIG. B-8.

APPENDIX C

Thermal stress change contours in the tunnel transverse (Z) direction for periods of 1, 2, 6, 10, 15, and 25 days after emplacement of spent fuel.

CANISTER SPALLING TO FIVE FEET WITH A 1000 LBS. WEIGHT
 CONTOURS OF Z STRESS

UNIT: PSI
 MIN. X = -1.11E+02
 MAX. X = 3.74E+01

UNIT: INCHES

A = 1.11E+02
 B = -1.85E+02
 C = 1.64E+02
 D = -1.59E+02
 E = 1.11E+01
 F = 8.70E+01
 G = -6.21E+01
 H = -3.73E+01
 I = 1.24E+01
 J = 0.

FIG. C-1.

CANISTER SPACING TO THE RIGHT OF THE CANISTER
CONTOURS OF Z-SHAPED

TIME = 1.0E+01
MAY = 1.0E+01
MAX = 1.0E+01

TIME = 1.0E+01
A = 2.0E+01
B = -2.30E+02
C = -1.97E+02
D = -1.65E+02
E = 1.0E+01
F = 1.00E+02
G = -6.75E+01
H = -3.50E+01
I = 0.
J = 3.00E+01

FIG. C-2.

 

[illegible]

 

1. *Chlorophyll a* (Chl *a*)

1. *Chlorophyll a* (Chl *a*)

$$G = 5.947 \cdot 10^4$$

H 2.156 +01

16

[illegible]

2025.10.16

FIG. C-3.

PARAMETER CHANGES IN THE FIRST TWO STEPS OF THE
CONTOURING OF Z-CONTENTS

PARAMETER CHANGES
MAX. X = 2.475×10^1
MAX. Y = 6.313×10^1

PARAMETER CHANGES

A = 4.041×10^1
B = 2.638×10^2
C = 2.245×10^2
D = -1.865×10^2
E = 1.055×10^1
F = 1.172×10^1
G = -7.075×10^1
H = -3.225×10^1
I = 0.
J = 4.465×10^1

FIG. C-4.

CANISTER SPACING IN FEET, SHOWING THE CONTOURS OF Z STRESS

$\sigma_{xx} = 1.00E+01$
 $\sigma_{yy} = 1.00E+01$
 $\sigma_{zz} = 1.00E+01$

$\sigma_{xy} = 1.00E+01$
 $\sigma_{yz} = 1.00E+01$
 $\sigma_{zx} = 1.00E+01$

$A = 1.00E+01$
 $B = 2.89E+01$
 $C = -2.49E+01$
 $D = 2.10E+01$
 $E = 1.77E+01$
 $F = 1.30E+01$
 $G = -9.07E+01$
 $H = -5.11E+01$
 $I = 0.$
 $J = 2.83E+01$

FIG. C-5.

CANISTER SHADING TO 100% OF THE AREA OF THE AREA
CONTOURS OF 7.5% (1.0)

MIN. V = 0.0E+00
MAX. V = 5.0E+01

MIN. H = 0.0E+00

A = 2.60E+02

B = -3.18E+02

C = 2.77E+02

D = 2.36E+02

E = 1.74E+02

F = 1.53E+02

G = -1.11E+02

H = -7.00E+01

I = -2.86E+01

J = 0.

FIG. C-6.

CANISTER SPACING TO EFFECT DRYING OF CANISTER BEDS
 CONTOURS OF Z-VALUES

MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE

MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE
 MAXIMUM Z-VALUE

FIG. C-7.

APPENDIX D

Thermal stress change contours in the maximum (most tensile) principal direction for periods of 1, 2, 6, 10, 15, and 25 days after event.

CANISTER SPACING 10 FEET, CENTRICAL, SYMMETRIC, 1000 PSI
 CONTOURS OF MAXIMUM PRINCIPAL STRESS

MIN. S = -5.78E+01
 MAX. S = 2.78E+01

MIN. S = -5.78E+01

A = -5.78E+01

B = -4.83E+01

C = -3.88E+01

D = -2.93E+01

E = -1.98E+01

F = -1.03E+01

G = 0.

H = 8.74E+00

I = 1.83E+01

J = 2.78E+01

FIG. D-1.

CANISTER SPACING 10 FEET, CENTROIDAL THERMAL STRESSES
 CONTOURS OF MAXIMUM PRINCIPAL STRESS

TIME = 1.13E+05
 MIN(X) = -1.02E+02
 MAX(X) = 6.24E+01

CONTOUR LEVELS

A = -8.69E+01
 B = -7.20E+01
 C = -5.71E+01
 D = -4.21E+01
 E = -2.72E+01
 F = -1.22E+01
 G = 0.
 H = 1.76E+01
 I = 3.26E+01
 J = 4.75E+01

FIG. D-2.

CANISTER SPACING 10 FEET, 1000 PSI, 1000 PSI, 1000 PSI, 1000 PSI
 CONTOURS OF MAXIMUM PRINCIPAL STRESS

MAX Y = 1.47E+02
 MIN Y = -1.24E+02
 MAX X = 9.04E+01

STRESS LEVELS

A = -1.47E+02
 B = -1.24E+02
 C = -9.97E+01
 D = -7.60E+01
 E = -5.02E+01
 F = -2.84E+01
 G = 0.
 H = 1.91E+01
 I = 4.29E+01
 J = 6.67E+01

FIG. D-3.

CANISTER SPACING 10 FEET, CENTROIDAL THERMAL STRESSES
 CONTOURS OF MAXIMUM PRINCIPAL STRESS

MIN(X) = $-2.12E+02$
 MAX(X) = $8.31E+01$

CONTOUR LEVELS

A = $-1.85E+02$
 B = $-1.59E+02$
 C = $-1.32E+02$
 D = $-1.05E+02$
 E = $-7.80E+01$
 F = $-5.12E+01$
 G = $-2.43E+01$
 H = 0.
 I = $2.94E+01$
 J = $5.62E+01$

FIG. D-4.

CARISTER DRACING 10 FEET, CENTRICAL, THERMAL STRESS AND
CONTOURS OF MAXIMUM PRINCIPAL STRESS

TIME: 1.5E+06
MINIMUM: -2.54E+02
MAXIMUM: 3.87E+01

NODE VALUES

A = 2.04E+02
B = -1.95E+02
C = -1.66E+02
D = -1.37E+02
E = -1.07E+02
F = -7.82E+01
G = -4.90E+01
H = -1.97E+01
I = 0.
J = 3.87E+01

FIG. D-5.

CANISTER SPACING 10 FEET, CENTROIDAL STRESS CONTOURS
CONTOURS OF MAXIMUM PRINCIPAL STRESS

TIME 1.73E+06
MIN(X) = 2.89E+02
MAX(X) = 5.42E+01

CONTOR VALUES

A = 2.58E+02
B = -2.27E+02
C = -1.95E+02
D = -1.64E+02
E = -1.33E+02
F = -1.02E+02
G = -7.06E+01
H = -3.94E+01
I = 0.
J = 2.30E+01

FIG. D-6.

CANISTER SPACING 10 + 1 + 1. LIT. RUMTA. 1000000. 1000000.
 CONTOURS OF MAXIMUM PRINCIPAL STRESS

MIN. X = -1.00E+02
 MAX. X = 4.27E+01

MIN. Y = -1.00E+02

A = -1.00E+02

B = -2.55E+02

C = -2.22E+02

D = -1.88E+02

E = -1.54E+02

F = -1.22E+02

G = -8.94E+01

H = -5.64E+01

I = -2.34E+01

J = 0.

FIG. D-7.

APPENDIX E

Model mesh generator input listing.

```

1  PACKNAM,SLIC.
2  CALL,SLIC(R=INPUT,F=RTINF,F=SAMIDT.
3  END.
4  JER
5  BEGIN CLIMAX S.F.T. HORIZONTAL THERMAL DISTRIBUTION, REVISED.
6  LIMITS 15 39 1
7  RESTRAIN Y Z XX YY ZZ
8  POINT A 1 1 1 0. 3. 1.
9  POINT B 15 1 1 0. 1. 0.
10 POINT C 1 19 1 0. 0. 5.
11 POINT D 9 19 1 0. 5. 5.
12 POINT E 15 19 1 0. 5. 0.
13 POINT F 1 39 1 0. 0. 100.
14 POINT G 9 39 1 0. 5. 100.
15 REFPOINT CEN 0. 0. 0.
16 ARC A B CEN
17 LINE A C FST= 8.E-02
18 LINE C F FST= .625
19 LINE D G FST= .625
20 LINE B E FST= 8.E-02
21 LINE C D
22 LINE E D
23 LINE F G
24 SURFACE A E
25 SURFACE C G
26 ROTATE Y= -90.
27 ROTATE Z= -90.
28 RETURN VIEW WITH DIST=25. MODE=PL, TRANS Z=10
29 RELAX EQ A E ITER= 2 JSCAL= 1.0978
30 QUADS F B NUM= 8 THICK= 1. SHIFT
31 NUMBER F B
32 VIEW UXFILE BOX= "BOX R06 GREENLAW"
33 VIEW LABEL
34 VIEW NAMES REFPTS
35 OPTION SAMPP ADINA
36 RETURN

```

FIG. E-1.