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SHIELDING ASSESSMENT OF THE ET-RR-1 REACTOR UNDER POWER UPGRADING.

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ABSTRACT

The assessment of present shielding of the Egyptian first research reactor (ET-RR-1) in case of power upgrading from 2MW to 10 MW is presented and discussed in this investigation. It was carried out for the present EK-10 type fuel elements with 10% enrichment. The shielding requirements for the ET-RR-1 (which is the Egyptian WWR-C reactor) when its power is upgraded to different power levels are also discussed. The optimization curves between the upgraded reactor power and the shield thickness for the seven neutron energy groups are presented and analyzed. The calculations have been made using the ANISN code with the DLC-75 data library. The results showed that the present shield necessitates an additional layer of steel with thickness of 10, 20 and 25 cm. when its power is upgraded to 3, 6 and 10 MWt in order to cut-off all neutron energy groups to be adequately safe under normal operating conditions. It should be noted that for paper size limitation,this work is confined only to the assessment of ET-RR-1 shielding against neutrons while such assessment against gamma radiation will be published in another work.

KEY WORDS

Reactor safety, shielding assessment, WWR-C reactors, power upgrading, shield design.

INTRODUCTION

As far as the shield design is concerned, only neutrons and gamma-rays are needed to be considered since these are - by far - the most penetrating radiations. Neutrons, because of their high relative biological effectiveness, constitute a significant source of undue radiations. Furthermore, the calculation of the neutron attenuation is expentionally difficult. Neutrons attenuation is affected by degrading the energy of neutrons primarily by inelastic scattering but

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also by elastic ones until they are be absorbed. Therefore, the neutron shielding accuracy depends on the accuracy of nuclear data as well as the rigorousness of the analysis method. The present work presents an accurate assessment for the ET-RR-1 reactor shield when its present power level is upgraded from 2 MWt to different levels; 3, 4, 5, 6, 8 and 10 MWt respectively. The neutron attenuation profiles for the different energy groups through the present shield are analyzed. Moreover, the shielding requirements for the ET-RR-1 reactor when its power is upgraded to different power levels are also discussed. The optimization curves between the upgraded reactor power and the shield thickness are discussed to obtain the optimum shield radius with such that safe accessibility and ALARA requirements [1] could be achieved. optimum shield material that is required to cut off the different neutron energy groups

THEORY AND NUMERICAL SOLUTION

The present investigation utilizes the transport theory which provides the basic theory for analyzing the nuclear reactors [2] .The Boltzmann transport equation for the energy - dependent steady - state condition can be written for the directional flux density $\phi(r,\Omega,E)$ in the form [3,4] :

$$\Omega\,.\,\nabla\phi\,(r,\Omega,E)+\Sigma_t(r,E)\,\phi\,(r,\Omega,E)\;=\;\int_0^\infty dE'\int_1^1 d\Omega'(\phi\,(E)\,\nu\Sigma_f(r,E')\;+$$

$$\Sigma_s(r,\Omega\rightarrow\Omega',E\text{--}E')).\;\phi\,(r,\Omega',E')+S(r,\Omega,E) \qquad (1)$$

with the notations of the equation are those the well known ones. This equation is solved numerically using the discrete ordinates Sn method [5]. The energy-dependence is discretized in the usual multigroup approximation to get [6]:

$$\Omega\,.\,\nabla\phi_g\,(r,\Omega)+\Sigma_{t,g}(r)\,\phi_g\,(r,\Omega)=\sum_{g'=1}^{IGM}\int_1^{+1} d\Omega'\,(\,\phi_g\,\nu\,\Sigma_{f.\,g'}(r)\;+$$

$$\Sigma_{s,\,g'\rightarrow g}(r,\Omega'\rightarrow\Omega,)\,).\;\phi_{g'}\,(r,\Omega')+S_g(r,\Omega)\quad\ldots g,\,g'=1,2\ldots\ldots,IGM \qquad (2)$$

Then the angular-dependence is discretized in the discrete ordinates approximation to get [6]:

$$\Omega_m.\,\nabla\phi_{g,m}(r)+\Sigma_{t,g}(r)\,\phi_{g,m}(r)\;=\;\sum_{g'=1}^{IGM}\,(\,\phi_g\,\nu\,\Sigma_{f.g'}(r)\,\phi_{g'}^{\,l=0}(r))\quad+$$

$$\sum_{g'=1}^{IGM}\sum_{l=1}^{L}\,((2l+1)\,P_l\,(\mu_m)\,\Sigma_{s,\,g'\rightarrow g}(r)\;\phi_{g'}^{\,l})\;+\;S_{g,m}(r)\qquad\ldots.m=1,2\ldots\ldots,MM \qquad (3)$$

where $\phi_{g'}^{\,l}$ is the zeroth, first, ..., lth moments of the group directional flux density

$$=\sum_{m=1}^{MM}\;\omega_m\,P_l\,(\mu_m)\,\phi_{g,m}^{\,l}(r)\quad,$$

ω_m = a set of non-negative angular weights assigned to the scattering angle cosine" μ" (i.e. an area fraction on a unit sphere where $\sum_m \omega_m = 1.0$).

MM = total number of discrete angular directions,
L = highest scattering order represented in the scattering cross section, and
$P_l(\mu_m)$ = the L^{th} Lagendre Polynomial evaluated at angular direction cosine (μ_m).

The spatial- dependence is discretized in the finite - difference approximation, adopted by the ANISN code [6,7] which is given - in its general form - by [7]:

$$\mu (A_{i+1}\, \phi_{g.i+1} - A_i\, \phi_{g.i}) + ((\alpha_{m-1/2})/\omega)(\phi_{g.m+1/2} - \phi_{g.m-1/2}) + \Sigma_{tr} V \phi_g = SV \tag{4}$$

where μ is the cosine of Sn quadrature solid angles, A and V are the area and volume elements ($A = 2\pi r_i$, $V = \pi (r^2_{i+1} - r_i^2)$) for cylindrical geometry, and i , m are the mesh interval and direction indices. The neutron flux is defined across a mesh interval r_i ,r_{i+1}. α is a coefficient associated with ray-to-ray transfer in curved mesh intervals, given by:

$$\alpha_{m+1/2} = \alpha_{m-1/2} - (1/2\,\omega)\,\mu\,(A_{i+1} - A_i) \tag{5}$$

S is the source term (all terms in the R.H.S. of Eq. (3) are allowed to be lumped into a fixed source term S). The resulting transport equation - after its discretizations to Eqs. (3), (4) and (5) - is then solved iteratively by inner and outer iterations [7,8]. The outer iteration is for spatially energy group summed fission source along all total energy groups (g,g'=1-- IGM) and all mesh intervals (I=1-- IM). The inner iteration is for individual group fluxes resulted from a given source.

ANISN TECHNICAL DESCRIPTION AND EXECUTION

To execute the ANISN code for the present investigated problem , some technical description are used . These are: order of angular quadrature = 16, left and right boundary conditions are reflection and no reflection respectively, no. of zones = 6 and 5, no. of fine mesh interval in the problem geometry = 30 and 40, type of calculation is the Eigen- value calculation, with first guess of Eigen- value =1, length of C.S. table = 10, position of Σ_{tot} , Σ_{gg} (within group scattering), Σ_a and Σ_f in the C.S. table = 3,4,1 and 2 respectively, max. number of inner and outer iterations = 20 and 100 respectively, relative convergence criterion for source, scatter and up-scatter ratios = 1.0E-04, convergence relaxation factor for up-scatter and scatter ratio = 0.5, and point flux convergence criterion = 2.0 E-04. Moreover some modular function routines - of a package named FE-CM1 [9] - were also constructed and coupled to ANISN code through the option I of its mixing table options.

THE PHYSICAL MODEL CONFIGURATION

The ET-RR-1 reactor multilayer shield is composed of light water, iron and ordinary concrete as well as the first barrier of cladding material. Figure (1) shows a vertical cross-section of the ET-

RR-1 multilayer shield representing the sections adopted to be employed in the model configuration. It is taken at the horizontal center- line level passing through the thermal column. Based on this section, the reactor cylindrical geometry is modeled in two different region-wise configurations (I&II). Configuration I: from core center-line to the right hand side passing through six regions; core ,central and shield tanks with reflector , first layer of thermal shield, second layer of thermal shield , biological shield and a steel enclosure shield layer. Configuration II: from core center-line to the left hand side passing through five regions; core ,central tank with reflector , thermal column, thermal column envelope and thermal column shield (iron or graphite depending on whether the thermal column is opened or closed).

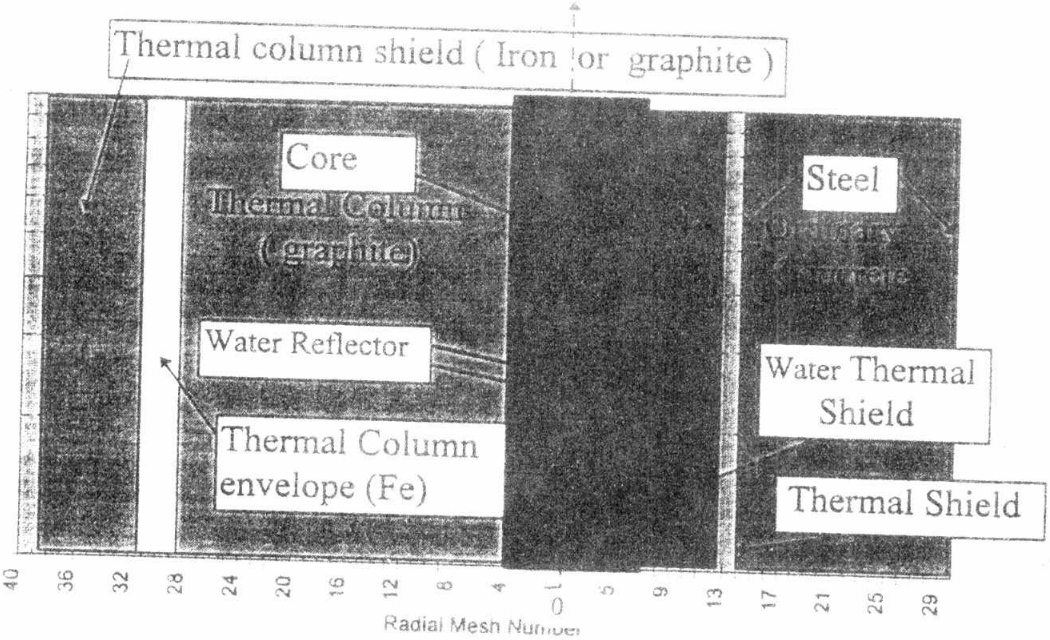
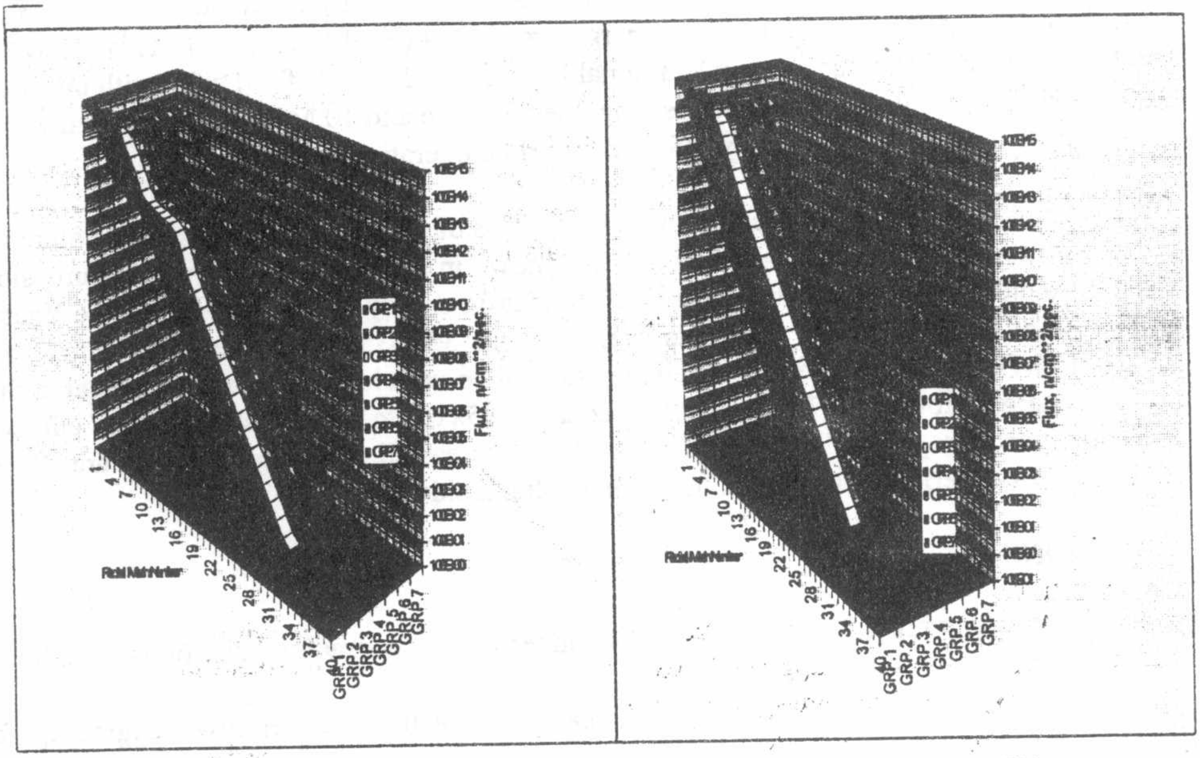


Fig. (1) Geometrical Model of the Radial Shield Layers of the ET-RR-1.

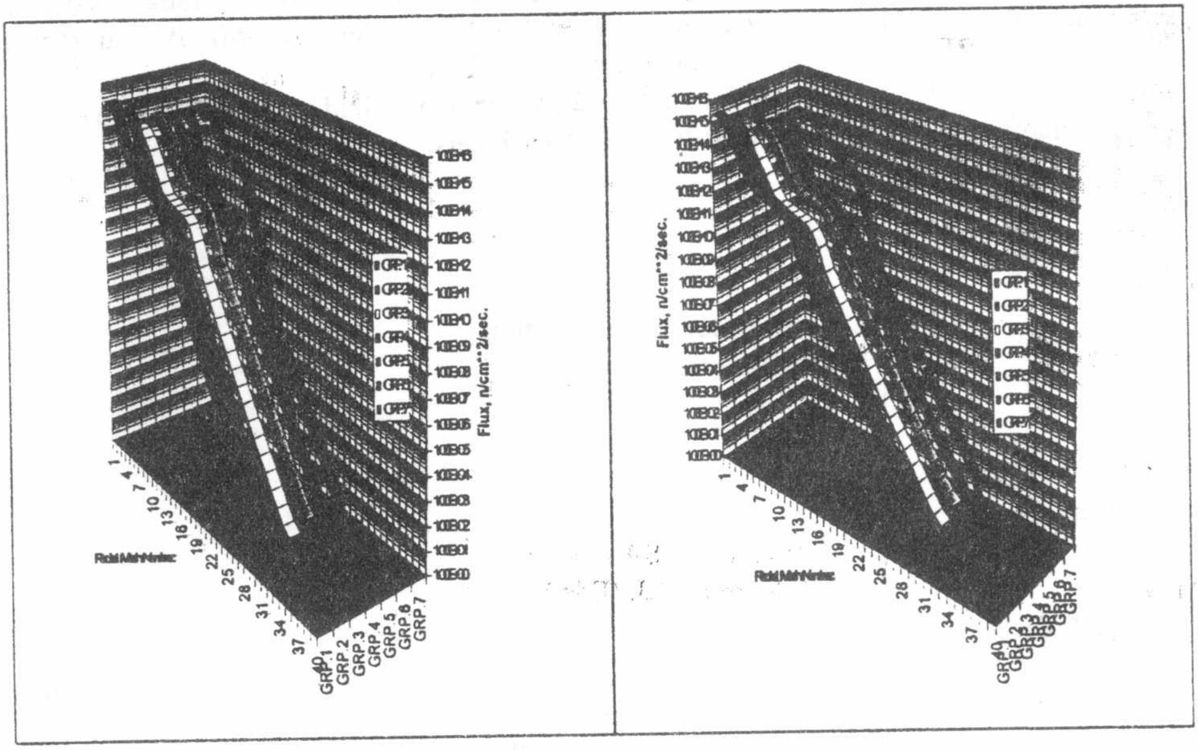
RESULTS AND DISCUSSIONS

The radial attenuations of the neutron fluxes steradiancy for both configurations I, II representing the ET-RR-1 model when its power is upgraded up to 10 MWt (calculated using the ANISN / FE-CM1 code system) are shown in Fig (2). It must be mentioned that the whole range of neutron energies (up to 17.3 Mev) is grouped into 7 energy group structure [9],and each radial mesh interval = 10 cm. A regular decrease for the neutron distributions in the high energy groups (no. 1 to 6) is noticed from figures. The neutron flux behaviour for the low energy range (< 0.1 Mev included in group no. 7) increases at first upon entering light water layers of Config.I as a result of its highly slowing down power, and then decreases due to neutron capture. The low energy range distribution of neutron flux in Config.II, however, showed a slight increase upon entering each of the graphite layers followed by a slight decrease. Such increase may be referred to the moderation of neutrons by carbon atoms while the decrease may be regarded to the neutron capture of carbon. It is also shown ,from Figs. 2(a,b), that all energy groups have been cut-off at the outer periphary of ET-RR-1 reactor reflecting a good shielding capability at 2 MWt power



(a) Config. I at 2 MW

(b) Config. II at 2 MW



(c) Config. I at 6 MW

(d) Config. I at 10 MW

Fig.(2) The Calculated 7 Energy Groups Neutron Flux Attenuation Through The ET-RR-1 Shield At Different Power Levels.

level which is not valid for higher power levels (Figs.2(c,d)). This is clearly illustrated from Fig.3 ,where the shielding outer radius exceeds the ET-RR-1 present shield periphery for Config. I (300 cm.) at power levels ranged from 3 to 10 MWt for energy group no. 1 (E= 17.33299 Mev) and at 10 MWt power level for energy group no.4 (E =1.9205 Mev). This means the present ET-RR-1 shield necessitates an additional layer of steel (in Config. I side) with thickness of 10, 20 and 25 cm. when its power is upgraded to 3, 6 and 10 MWt in order to cut-off all neutron energy groups in be adequately safe under normal operating conditions.

The effect of power upgrading on the limiting safety radius of Config. II(when thermal column is closed ,i.e. is not used) is illustrated in Fig.4. As shown in figures, in the thermal column side, the present shield is highly capable to cut-off all neutron energy groups for all the investigated power levels.The limiting safety radius is ranged from 355 -359 cm. corresponding to power levels 2 to 10 MWt, Fig.4(a). In case when the thermal column is under use, the calculated flux density the energy group (no.7, E < 0.4 Mev) equals 1.85×10^6 to 4.7×10^6 steradiant n / cm^2 sec. for the corresponding power levels of 3 to 10 MWt whereas all other higher groups are cut-off within the ET-RR-1 periphary (400 cm. in thermal column side).

CONCLUSIONS

From the results of ET-RR-1 shield validation under power upgrading conditions, it could be concluded that:

1. The present ET-RR-1 shield design review has been evaluated under power upgrading for normal operation coditions.
2. In Config.I side, the shield necessitates an additional layer of steel with thickness of 10, 20 and 25 cm. when its power is upgraded to 3, 6 and 10 MWt in order to cut-off all neutron energy groups in be adequately safe under normal operating conditions.
3. In the thermal column side , when it is not used , the present shield is highly capable to cut-off all neutron energy groups for all the investigated power levels.

NOMENCLATURE

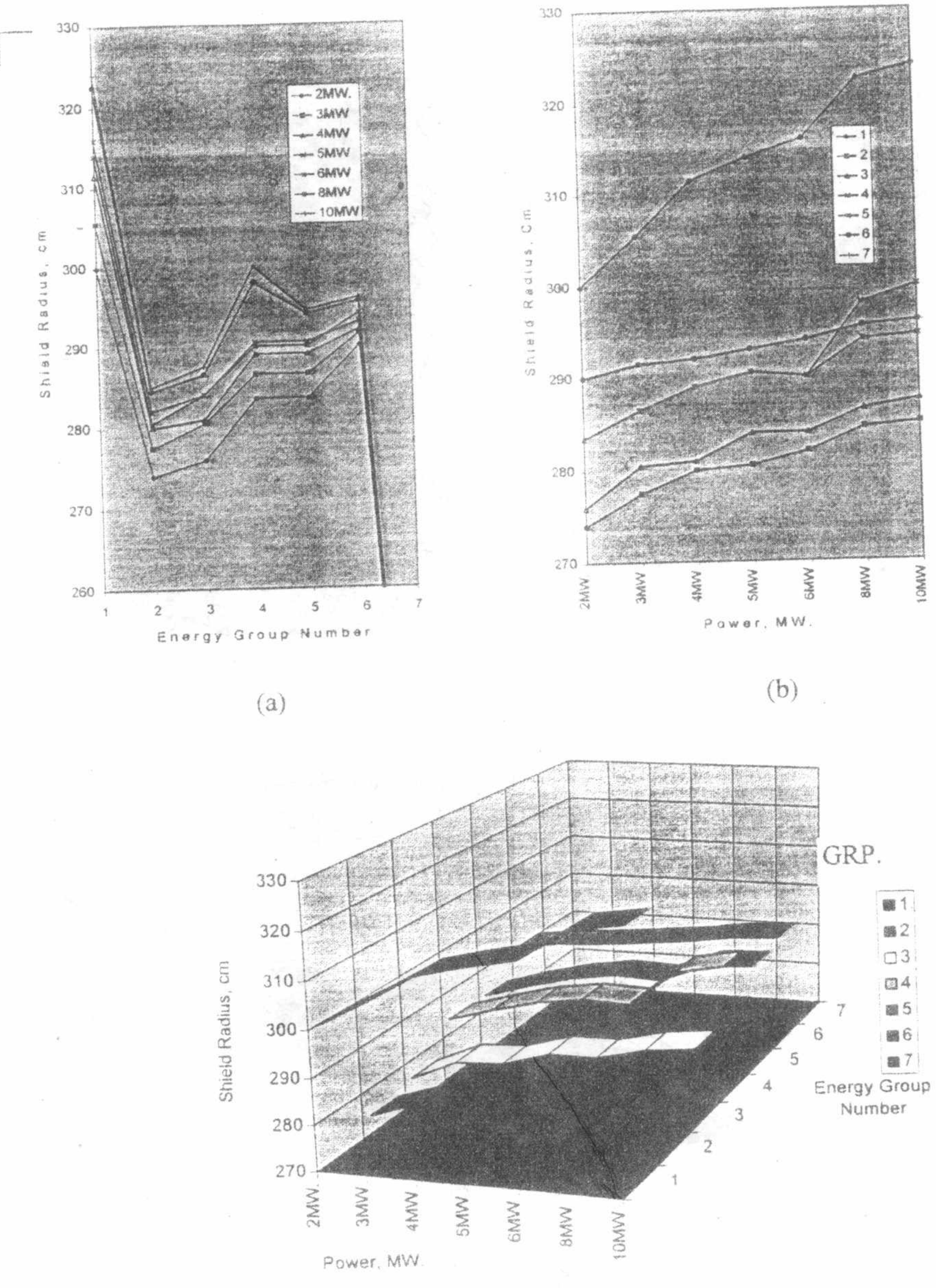
E	energy	ϕ	flux
r	space	Σ	macroscopic cross section
S	source term	Ω	angular direction

Subsripts:

f	fission
s	scattering
t	total

REFERENCES

[1] U.S. NRC, 10 CFR 50 , Appendix I , USA (1990).
[2] Gandini ,A. ,Ganesan,S. and Schmidt, J.J. (Eds.); “ Proc. ICTP and IAEA Workshop

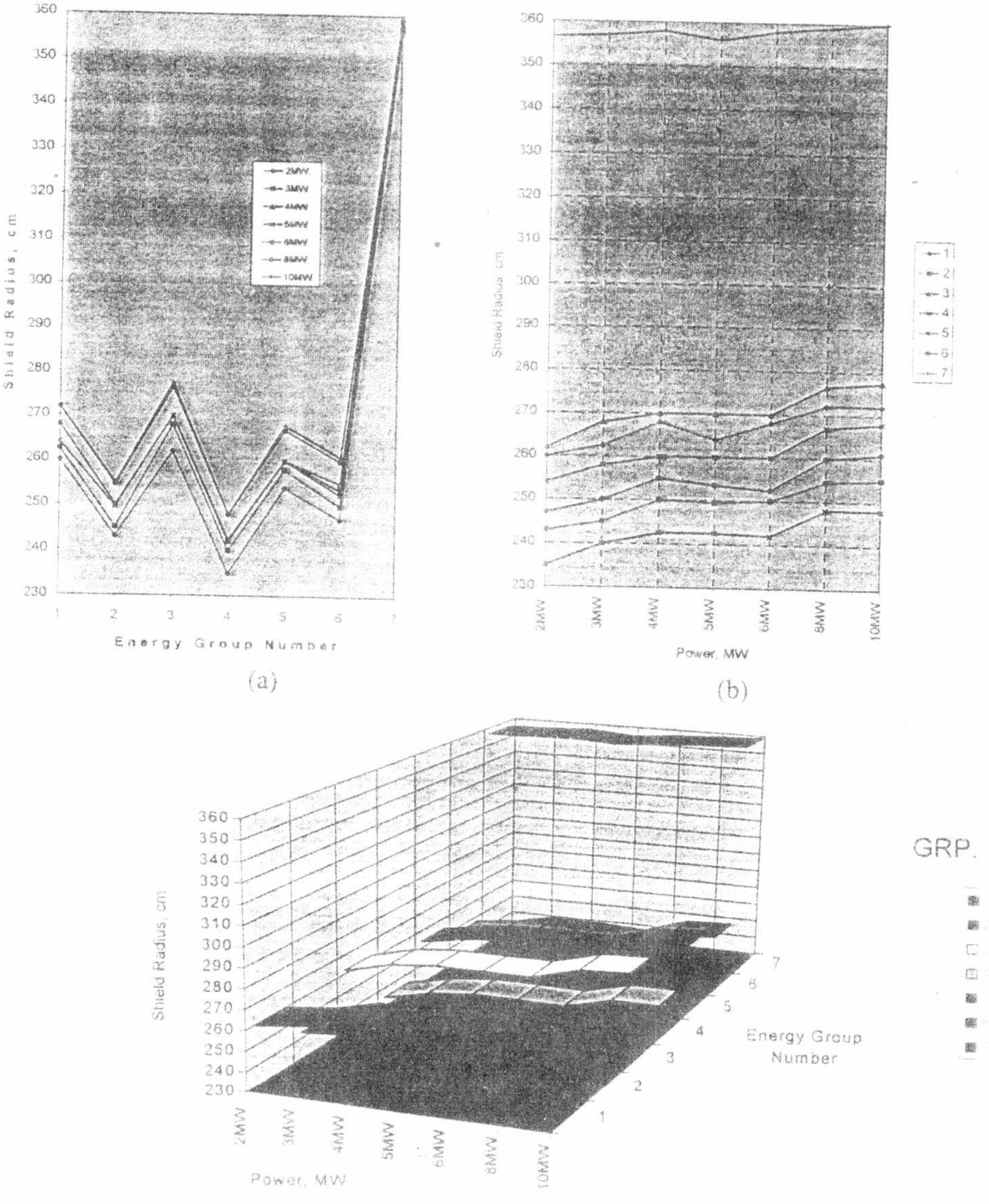


(a)

(b)

(c)

Fig.(3) Effect of ET-RR-1 Power Upgrading on the Limiting Safety Radius for Config. I



(a)

(b)

(c)

Fig.(4) Effect of ET-RR-1 Power Upgrading on the Limiting Safety Radius for Config. I (with thermal column closed)

on Nuc. Reactor Physics , Design and Safety " , W.S. Publ. Co. Ltd., N. J. (1995).
[3] Bell,G.I.& Glsstone,S.; Nuclear Reactor Theory , Van Nostrand Co., N. Y. (1990).
[4] Duderstadt, J.J.& Martine,W.R.; Transport Theory , Jhon Wiley & Sons,N.Y. (1979).
[5] Stevens,P.N. ; Weapons Radiation Shielding Handbook , DNA-1892, Rev.1, USA(1972).
[6] ORNL ; "RSIC Computer Collection ANISN " , CCC-514, ORNL , USA (1987).
[7] ORNL ; "RSIC Computer Collection ANISN " , CCC-254, ORNL , USA (1987).
[8] Rahman, Kh. A. ; " Determination of Multigroup Neutron Fluxes Distibutions in Some Subcritical Assemblies ", M.Sc. Thesis , Al-Azhar Univ. ,Cairo (1992).
[9] Ahmed, Ensherah E.M., et al ; " A Spherical Shield Configuration Model For Neutron Sources ", Proc. MSC'88 , p:521-525, Pitts., USA (1988).