LA-5455-MS

INFORMAL REPORT

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187.481

Use of Multiple 4π Radiation Sources for Quasi-Uniform Irradiation of Square Surfaces

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ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

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LA-5455-MS

INFORMAL REPORT

UC-34

ISSUED: November 1973

Use of Multiple 4π Radiation Sources for Quasi-Uniform Irradiation of Square Surfaces

by

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This work was supported in part by the Defense Nuclear Agency.

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USE OF MULTIPLE 4π RADIATION SOURCES FOR QUASI-UNIFORM IRRADIATION OF SQUARE SURFACES

by

R. W. Clark
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ABSTRACT

The question of distance and location of multiple 4π radiation sources from square planar target surfaces is addressed, with the constraint that the surface be irradiated with 80% uniformity. Results of computer calculations are presented, giving source location coordinates for optimum use of the sources under the uniformity constraint.

The results are presented of calculations of distance and location of 4π radiation sources with respect to a square target surface using N ($= 1, 4, 8, 9, 16, 24, 25$ and 256) equal strength sources, and requiring that the target be irradiated quasi-uniformly (80% uniformity).

The following assumptions were made for these computer (CDC 6600) calculations:

1. All sources for a given case emit with equal strength.
2. All sources are 4π sources. $\phi(r) = S_0/4\pi r^2$.
3. All sources emit with the same spectrum.
4. Sources have no dimensions (point sources).

Three of the cases are shown in Fig. 1, and source array end views for all cases are shown in Fig. 2. All sources for all cases were taken to be in a planar array, with the plane parallel to the target surface plane.

With L being the length of a side of the target square, and taking the center of the coordinate system to be in the center of the source array, then we may scale the source locations to the target dimension L by taking $x_j = \alpha_j L$, $y_j = \gamma_j L$, and $z = \beta L$. The sum of the vector magnitudes

Fig. 1. Source-Target Sample Geometries.

Fig. 2. Case Source Array End Views.

of the flux at a point x, y, z on the target is given by:

$$\Sigma |\Phi(x, y, z)|$$

$$= \frac{S_0}{4\pi L^2} \sum_j \frac{1}{\left(\frac{x}{L} - \alpha_j\right)^2 + \left(\frac{y}{L} - \gamma_j\right)^2 + \beta^2} \quad (1)$$

The sum of the normal components Φ_n of Φ is given by

$$\Phi_n(x, y, z)$$

$$= \frac{S_0}{4\pi L^2} \sum_j \frac{\beta/r}{\left[\left(\frac{x}{L} - \alpha_j\right)^2 + \left(\frac{y}{L} - \gamma_j\right)^2 + \beta^2\right]^{3/2}} \quad (2)$$

where (β/r) is the cosine of the angle that $\vec{r}$ makes with the normal to the surface and r

$$= \left[\left(\frac{x}{L} - \alpha_j\right)^2 + \left(\frac{y}{L} - \gamma_j\right)^2 + \beta^2\right]^{1/2}$$

Calculations were done for both $\Sigma |\Phi|$ and Φ_n .

For computational purposes, the normalization $(S_0/L^2) = 1$ was chosen. The computational technique used is to choose a β and find α_j and γ_j required for $(\Phi_{\max} - \Phi_{\min})/\Phi_{\max} \leq 0.2$, i.e. 80% uniformity, where the sources are moved symmetrically in x and y as if they were on an elastic sheet. Once a set of coordinates is found to satisfy quasi-uniformity, smaller β 's are chosen and the process is repeated until the maximum Φ_{ave} is found, i.e., maximum use of the sources is made while still satisfying the uniformity constraint.

Symmetry arguments dictated source arrays, and thus calculations only needed to be done for one octant of the target surface (see Fig. 1). Calculations were done using 351 grid points in the octant.

Computational results for $\Sigma |\Phi|$ and Φ_n are summarized in Tables I and II, respectively. The Φ 's in Column (2) of each table increase with N because of the normalization. Each number in Column (2) is the average of the 351 grid point values for the given case.

Note in the tables that 4 sources are superior to 5, 8 are superior to 9, and 24 are superior to 25. This arises because for $N = 5, 9$, or 25 , the on-axis source results in a "hot spot" in the center of the target surface which can only be eliminated with higher β 's, or α 's and γ 's than for $N = 4, 8$, and 24 .

If pointwise doses are of interest, regardless of angle of incidence, then Table I is appropriate. If normal fluences (energy per unit area) through a mathematical surface (zero thickness) are of interest, then Table II is appropriate.

For Case VI, a smaller β and higher $(\Phi_{\text{code}})_{\text{ave}}$ solution than that shown in Tables I and II exists. However, we present the $\beta = 0.12$ solution since $\beta = 0.1$ may be a practical lower limit on β for any real radiation scheme.

Once a real L and Φ_{ave} are specified, the required strength S per source for each case may be found using,

$$S_0 = L^2 \frac{\Phi_{\text{ave}}}{(\Phi_{\text{code}})_{\text{ave}}}$$

and $z = \beta L$, $x_j = \alpha_j L$, and $y_j = \gamma_j L$ are used to find x, y, z of the sources.

TABLE I: $\Sigma|\frac{1}{f}|$

Case	(1) # Sources [†]	(2) ($\frac{1}{f}$ code)ave	(3) $\frac{\frac{1}{f}_{\max} - \frac{1}{f}_{\min}}{\frac{1}{f}_{\min}}$	(4) α_j, γ_j (Outer Sources)	(5) β	(6)** $\frac{\frac{1}{f}_{\text{code}}: \text{Case I}}{\frac{1}{f}_{\text{code}}: \text{Case X}}$
I*	1	0.0368	20.0%	0,0	1.414	1.0000
II.A*	4	0.70	19.97%	0.41,0.41	0.39	0.0526
II.B	5	0.585	19.7%	0.53,0.53	0.53	0.0629
III.A	9	1.50	19.9%	0.59,0.59	0.35	0.0245
III.B*	8	2.04	19.3%	0.45,0.45	0.27	0.0180
IV.A	16	3.01	19.9%	0.675,0.675	0.29	0.0122
IV.B	8	1.75	19.95%	($r = 0.57$)	0.30	0.0210
IV.C	8	1.80	19.76%	0.55,0.55	0.27	0.0204
V.A	25	5.465	19.9%	0.8,0.8	0.19	0.0067
V.B*	24	6.35	19.7%	0.66,0.66	0.19	0.0058
V.C*	16	3.07	19.3%	0.84,0.84	0.25	0.0120
V.D	9	1.06	19.9%	0.82,0.82	0.45	0.0347
V.E	8	1.43	19.96%	0.6,0.6	0.35	0.0257
VI [†]	256	98.20	19.5%	0.731,0.731	0.12	0.00037

TABLE II: $\frac{1}{f}_n$

Case*	(1) # Sources*	(2) ($\frac{1}{f}$ code)ave	(3) $\frac{\frac{1}{f}_{\max} - \frac{1}{f}_{\min}}{\frac{1}{f}_{\max}}$	(4) α_j, γ_j (Outer Sources)	(5) β	(6)** $\frac{\frac{1}{f}_{\text{code}}: \text{Case I}}{\frac{1}{f}_{\text{code}}: \text{Case X}}$
I*	1	0.0235	19.92%	0, 0	1.770	1.0000
II.A*	4	0.3807	19.84%	0.41,0.41	0.51	0.0617
II.B	5	0.3105	19.94%	0.57,0.57	0.69	0.0756
III.A	9	0.7134	19.97%	0.63,0.63	0.47	0.0329
III.B*	8	0.9787	19.99%	0.46,0.46	0.38	0.0240
IV.A	16	1.4445	19.78%	0.705,0.705	0.37	0.0163
IV.B	8	0.8428	19.33%	($r = 0.58$)	0.43	0.0279
IV.C	8	1.0193	19.66%	0.51,0.51	0.35	0.0231
V.A	25	2.5412	19.44%	0.76,0.76	0.27	0.00925
V.B*	24	3.4099	19.99%	0.59,0.59	0.26	0.00672
V.C*	16	1.4066	19.93%	0.82,0.84	0.36	0.0167
V.D	9	0.5374	19.89%	0.84,0.84	0.62	0.0437
V.E	8	0.6932	19.86%	0.64,0.64	0.47	0.0339
VI [†]	256	52.416	18.9%	0.656,0.656	0.12	0.00045

*Most favorable for given N range.

†Better solution exists (see text).

‡See Fig. 2 for array.

**Column (2) Case I (single source requirement) divided by Column (2) Case X.

Alternatively, S_0 for each case may be determined using the fractions in Column (6) of the tables as follows:

1) Given L and $\bar{\epsilon}_{ave}$ required, compute S_0 for Case I.

2) Multiply that S_0 by the number in Column (6) to obtain the required strength per source for the other cases.

3) If $\bar{\epsilon}_{min}$ is specified rather than $\bar{\epsilon}_{ave}$, the values of S_0 calculated should be multiplied by ~ 1.12 . This $\sim 12\%$ increase was determined from $\bar{\epsilon}(x, y, z)$ field plots (351 points) for the various cases.

Octant field plots for $\Sigma|\bar{\epsilon}|$ and $\bar{\epsilon}_n$ for selected cases are shown in Figs. 3-12 for 21 major grid points. The high and low values of $\bar{\epsilon}$ are also indicated. From these figures one may see how $\bar{\epsilon}$ varies over the octant for the cases indicated.

It is of interest to note that $(\bar{\epsilon}_{code})_{ave}$ increases faster than β^{-2} , due to more efficient use being made of each source for $N > 1$ (larger solid angles subtended by target). This is illustrated in Fig. 13 where $\Sigma|\bar{\epsilon}|_{ave}$ and $\bar{\epsilon}_n'_{ave}$ are plotted versus β . Conversely, as N increases, the requirement on S_0 decreases faster than β^2 .

For completeness, Fig. 14 shows $\Sigma|\bar{\epsilon}|_{ave}$ and $\bar{\epsilon}_n'_{ave}$ versus N , the number of sources. The dashed line illustrates that in going from $N = 1$ to $N = 4$, the $\bar{\epsilon}$'s increase as N^2 , but increase as $N^{1.275}$ thereafter.

Arrays of sources on non-planar surfaces may also be considered. However, such arrays may not greatly alter the results of Tables I and II for the following reasons:

1) If the source array is concave as viewed from the target surface, off-axis exterior sources may give large angles of incidence at certain points on the target. If $\bar{\epsilon}_n$ is important, large β may be needed to maintain uniformity.

2) If the source array is convex as viewed from the target surface, near and on-axis sources may give rise to a hot-spot in the center of the target unless β is sufficiently large.

In any event, for estimation purposes, the above calculations should be useful in determining N if S_0 is technology limited.

Fig. 3. Target Octant Fluence Field Grid Plot.

Fig. 4. Target Octant Fluence Field Grid Plot.

Fig. 5. Target Octant Fluence Field Grid Plot.

Fig. 7. Target Octant Fluence Field Grid Plot.

Fig. 6. Target Octant Fluence Field Grid Plot.

Fig. 8. Target Octant Fluence Field Grid Plot.

Fig. 9. Target Octant Fluence Field Grid Plot.

Fig. 11. Target Octant Fluence Field Grid Plot.

Fig. 10. Target Octant Fluence Field Grid Plot.

Fig. 12. Target Octant Fluence Field Grid Plot.

Fig. 13. Fluence vs β ; Various Cases Plotted.

Fig. 14. Fluence vs Number of Sources; Various Cases Plotted.

ACKNOWLEDGEMENTS

This work, done in Group P-7 under the direction of J. W. Mather, was supported in part by the Defense Nuclear Agency, and in part by the U. S. Atomic Energy Commission.

The discussions with J. Mather, J. Downing, K. Ware, and A. Williams were most helpful.