Quality-Assurance Check of Collimator and Phantom-Scatter Factors

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ABSTRACT

The Radiological Physics Center (RPC), during the site visits of the institutions participating in NCI sponsored clinical trials, reviews dosimetry data. During the visit, many institutions provide phantom and collimator-scatter factors for various square-field sizes. Usually collimator-scatter factor, S_c, is measured and the phantom-scatter factor, S_p, is derived. The reported values, for a specific nominal beam energy, show a wide variation. Primarily, S_p for a given beam energy is expected to be independent of linac's make and model. The RPC has analyzed the accumulated data for output factors and S_c from ~ 90 institutions for ~ 140 beams. Values of S_p were then calculated from the reported values of S_c and output factors. For each nominal beam energy, the derived S_p values were plotted as a function of field size. Best hyperbolic fit to these data shows one standard deviation (σ) to be 1% for 4, 6, 10, 15 and ≥18 MV beams. The RPC then used the best-fit values of S_p to recalculate S_c from the reported output factors. The recalculated values, 'S_c', were plotted against field size for each of the nominal energy. Excepting for ≥18 MV, the hyperbolic fits show σ to be 1-1.5 % for all energies. For a

given nominal energy, spread in ‘S_c’ data is unable to distinguish linac’s make and model. The data for S_p and S_c provided in this work should prove useful as a secondary check.

INTRODUCTION

Photon beam treatment planning systems (TPS) typically split the total output factor, S_{cp}, into two components, namely the head scatter factor, S_c, and the phantom scatter factor, S_p. The standard method for determining S_p is to measure S_c and S_{cp} for symmetric fields and then divide the measured S_{cp} by S_c.

Split of S_{cp} into the two components S_c and S_p is important for dose and monitor unit calculations. Currently many TPS require entry of S_{cp}, S_c and S_p data at the depth of maximum dose (d_{max}). In addition, hand calculations and in-house developed computer programs also use these data at d_{max}. As such, the data presented in this work are the values at d_{max}. Values for S_p at depth 10 cm are available in literature[1].

Any error in S_c obviously, translates into an error in S_p. For unblocked symmetric fields, errors in S_c and S_p mutually compensate. However, dose calculations for blocked, asymmetric and IMRT fields may result in a significant error due to errors in S_c and S_p. Hand calculations or computer programs not splitting S_{cp} into its S_c and S_p components may result in errors up to 3% in dose calculations for highly blocked fields.

The measurement of S_c is non-trivial and may result in significant errors. An improper size and materials of mini-phantom, and improper geometry during the measurements can result in incorrect S_c values.

In order to help identify possible gross errors in S_c and S_p, we have analyzed a significant amount of data accumulated by the Radiological Physics Center (RPC) to present standard values for both S_c and S_p which can serve as a quality-assurance tool. In addition, this work addresses a few important and interesting questions.

1. What are the magnitudes of errors in Sp and Sc in current use in radiation therapy?
2. How much do the errors impact on dose calculations?
3. Is there an easy way to reduce in S_p and S_c values?

MATERIALS AND METHODS

The Radiological Physics Center (RPC) currently monitors 1328 radiation therapy facilities participating in cooperative clinical trials. During on-site dosimetry review visits, the RPC collects the institution's dosimetry data which in many cases, include S_c, S_p

and S_{cp} values. The data correspond to field sizes from 6 x 6 to 30 x 30 cm^2. This work includes data from:

- 91 institutions
- 170 different x-ray beams (^{60}Co to 25 MV)
- Varian, Siemens, Elekta/Philips accelerators

Analysis employed the following sequence.

1. S_p data were grouped separately for ^{60}Co, 4, 6, 10-15, $\geq$18 MV beams. (10 and 15 MV data overlapped).
2. Values of S_p were plotted against field size.
3. Obvious outliers were identified and excluded from further analysis.
4. Average S_p was determined for each field size.
5. Hyperbolic function (shifted origin) was fitted to average S_p values. ($<S_p>$ denotes the function-fit values and are referred to as "standard S_p" values)
6. The $<S_p>$ and S_{cp} values were then used to calculate revised S_c values, denoted by "S_{c2}".(institution's measured Sc values are denoted as "S_{c1}")
7. Obvious outliers were identified and excluded from further analysis.
8. Average "S_{c2}" for each field size was determined.
9. Hyperbolic function was applied to the average S_{c2} values. ($<S_{c2}>$ denotes the function-fit values and are referred to as "standard S_c" values)

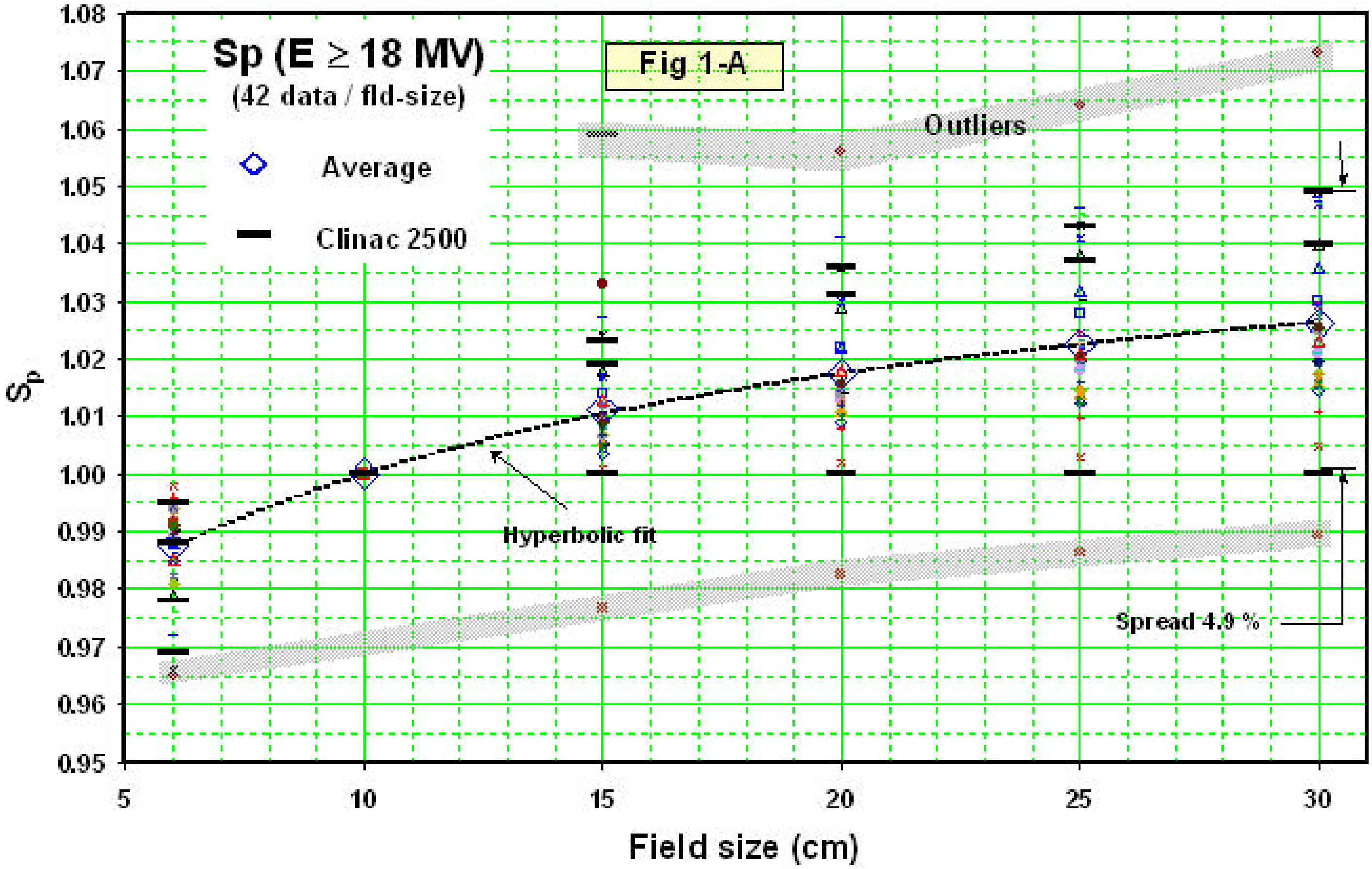
RESULTS

Some general notations apply to all the figures 1A - E, 2 and 3A - E. Shaded areas represent the data as obvious outliers, which constitute <5% of the total data. These outliers are excluded in averaging and curve fitting processes. The large open diamond for each field size (6 x 6, 10 x 10, 15 x 15, 20 x 20 and 30 x 30 cm^2) represents the average value of S_p or S_c for that field size. The other assorted shapes/sizes of symbols correspond to various makes/models of linacs including more than 1 set of data for the same make/model of linac. As discussed below, noise of the data is unable to distinguish makes/model of linacs. The dashed curve is a hyperbolic fit to the average values (large open diamonds) in each figure.

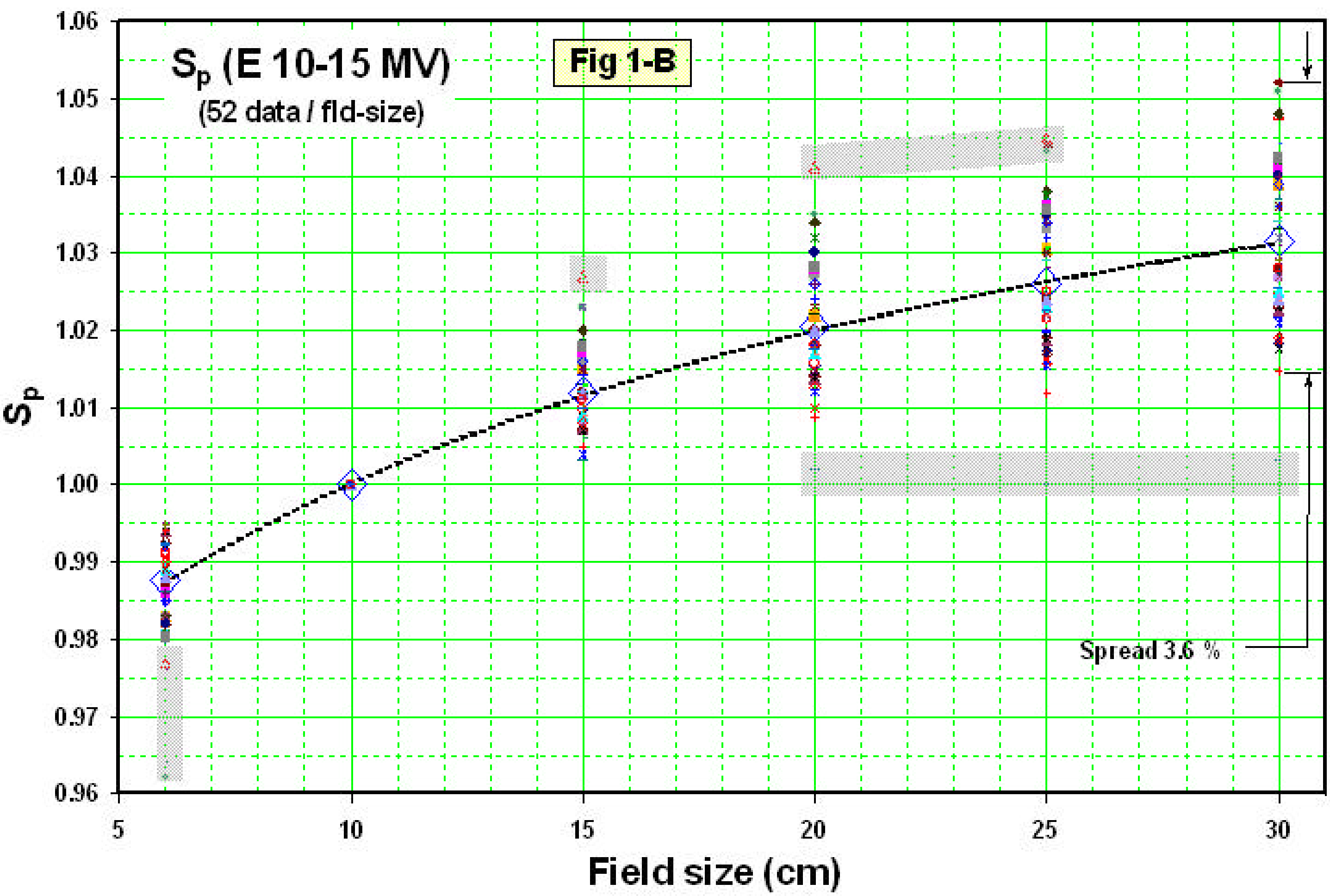
It is reminded that S_p data presented here correspond to d_{max}. These values change significantly with depth. The convolution-based treatment planning systems (ADAC, HELAX, etc.) require entry of S_{cp}, S_c and S_p data at a depth of 10 cm, for which one may use the published data[1] as a Quality Assurance tool.

Figures 1A - E are the Sp data for 4, 6, 10-15, ≥18 MV and ^{60}Co beams. For a given nominal beam energy, one expects S_p to change insignificantly with linac's make or model. The bold horizontal bars in figure 1A are 18 MV data for Clinac 2500's from different institutions emphasize the large spread (up to 4%) in data even for the same make/model of linac. As a result of large spread in the data, we are unable to distinguish between linac makes/models. In fact, this is true in general for all S_c and S_p data for all energies. As is obvious from figure 1A, the largest spread (maximum to minimum) in the S_p data for 18 MV is 5% for a 30 x 30 cm^2 field (two standard deviations of $\pm$2.5%). Therefore, the Sp values based on the hyperbolic fit to these data are assigned a precision of 1.2% at the level of one standard deviation (σ). The same logic of precision has been applied to rest of the data presented in the remaining figures.

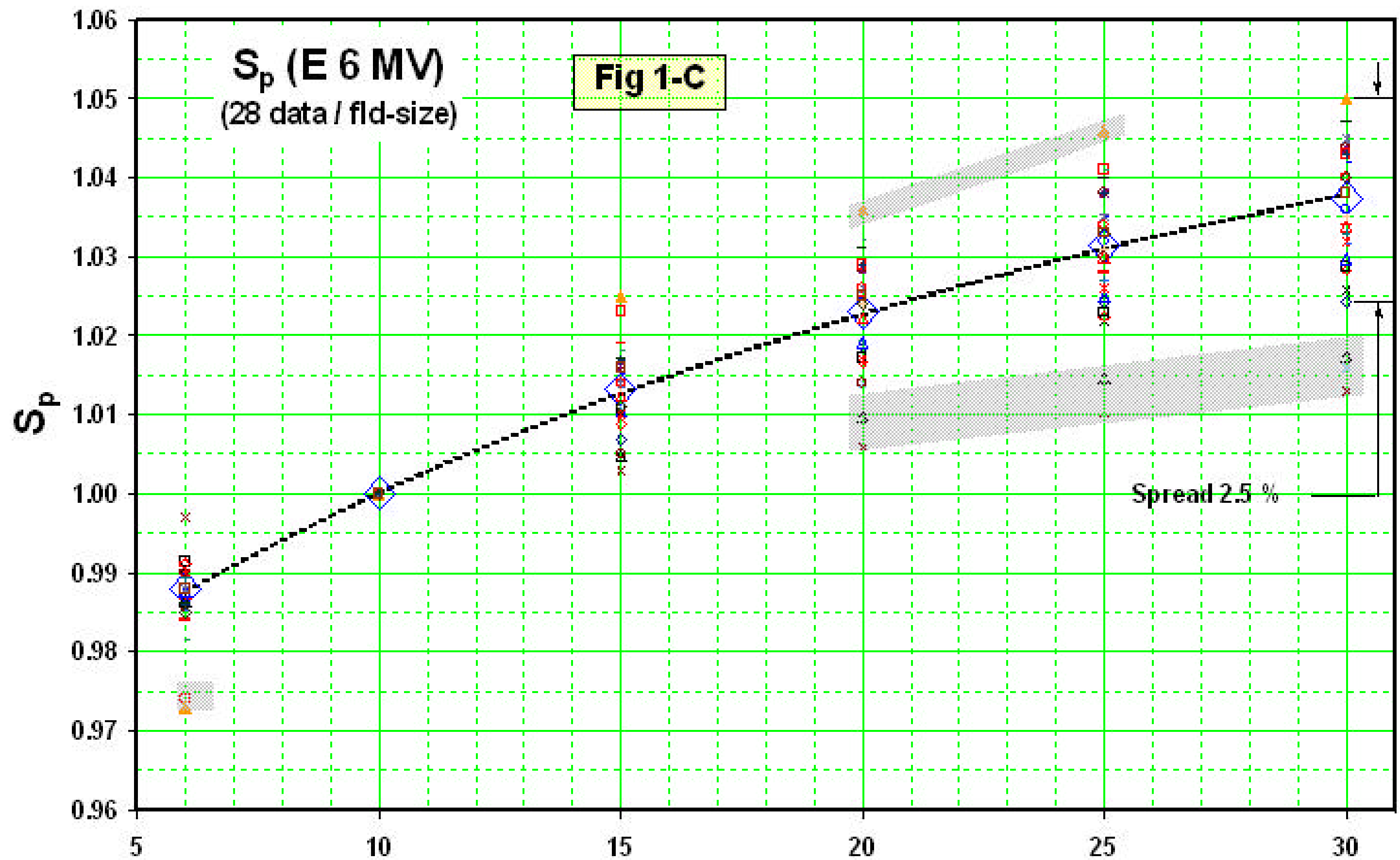
Based on the spreads in data, the hyperbolic-fit values of S_p at other energies 10-15, 6 and 4 MV are assigned an uncertainty of $\pm$0.9%, $\pm$0.7%, and $\pm$0.3%, respectively at one σ level. Since the Co-60 data is sparse, precision is not assigned.



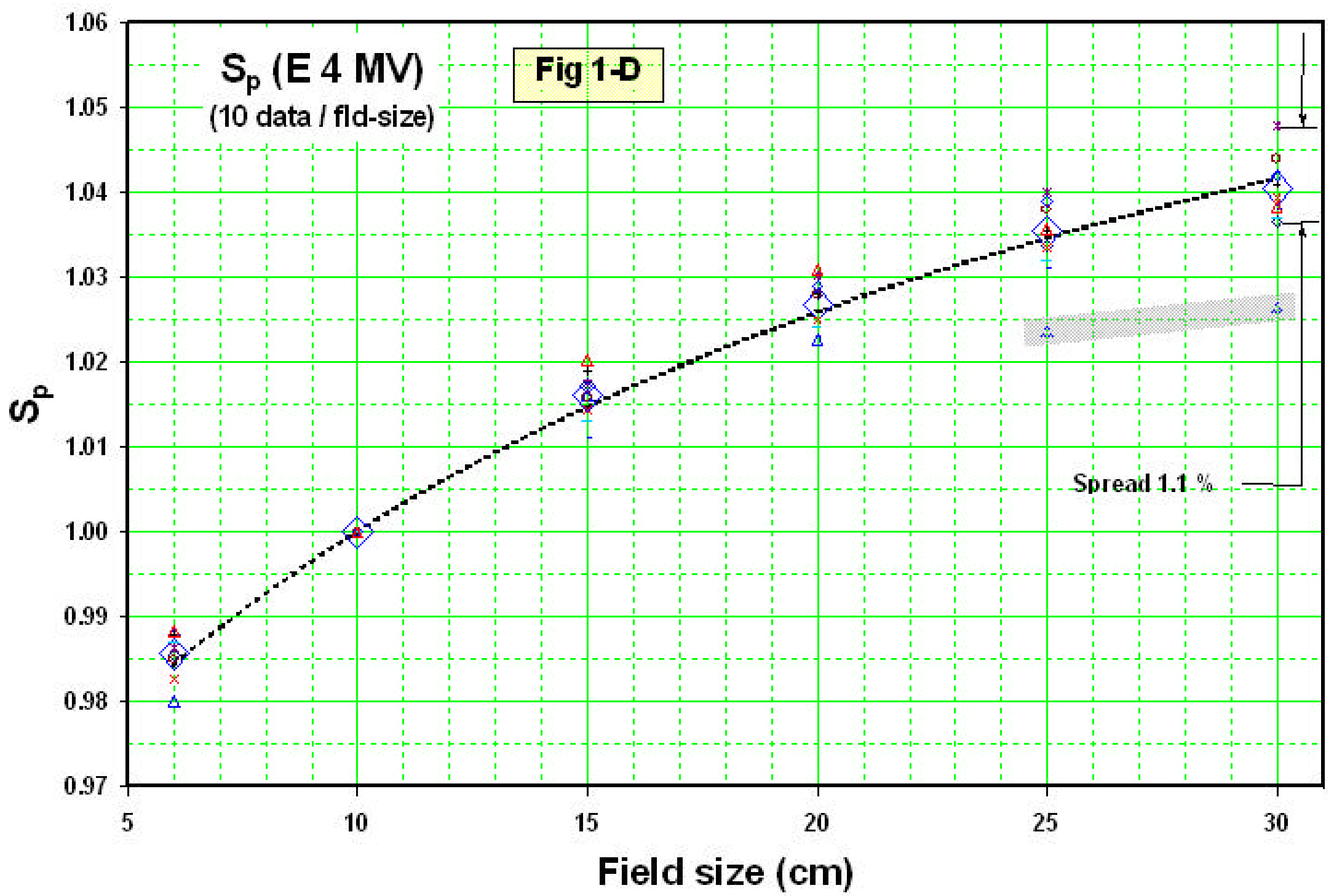
Sp (E ≥ 18 MV)
(42 data / fld-size)
Average
Clinac 2500
Fig 1-A
Outliers
Hyperbolic fit
Spread 4.9 %
S_p
Field size (cm)



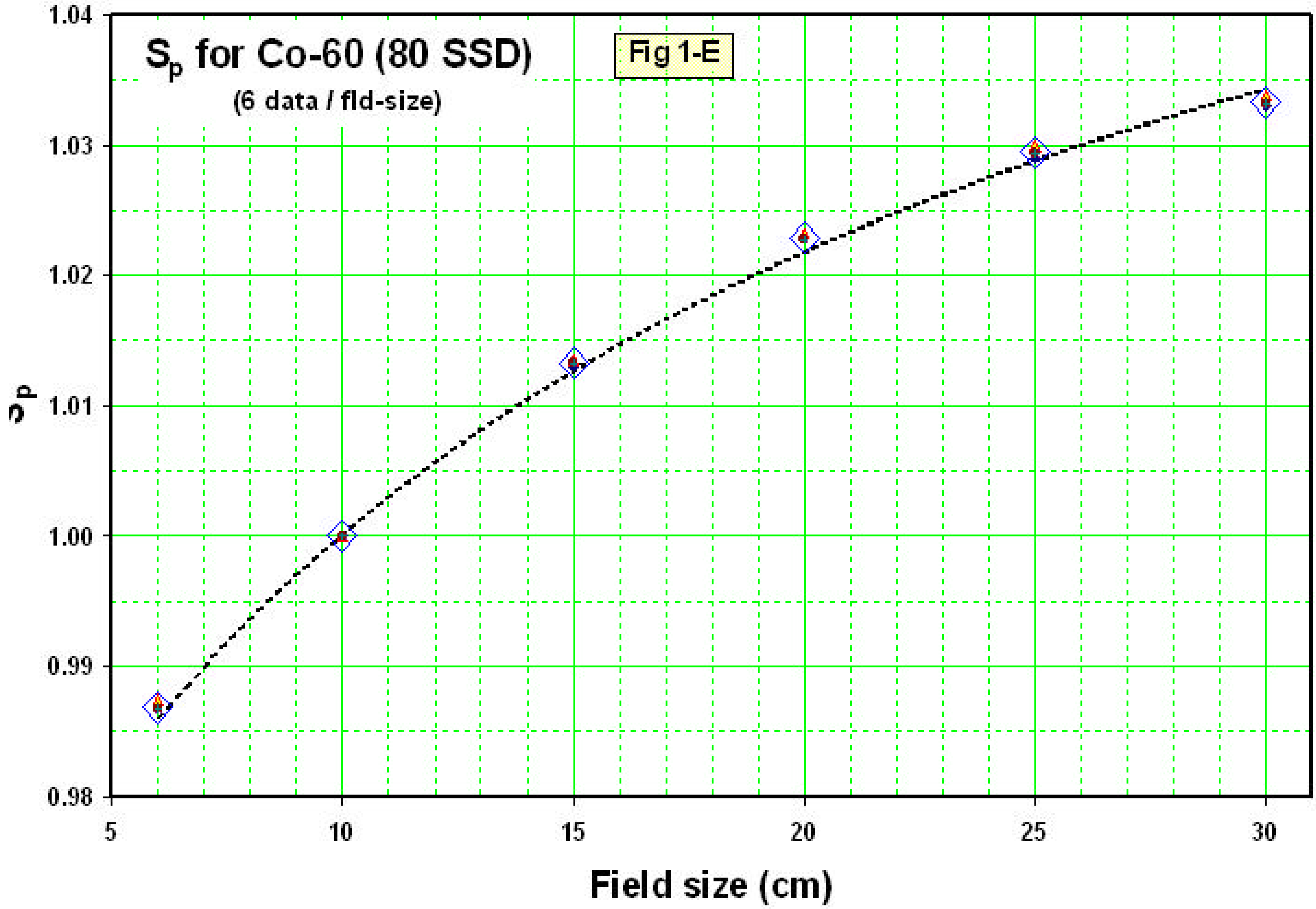
S_p (E 10-15 MV)
(52 data / fld-size)
Fig 1-B
Spread 3.6 %
S_p
Field size (cm)



Sp (E 6 MV)
(28 data / fld-size)
Fig 1-C
Sp
Spread 2.5 %
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
5
10
15
20
25
30

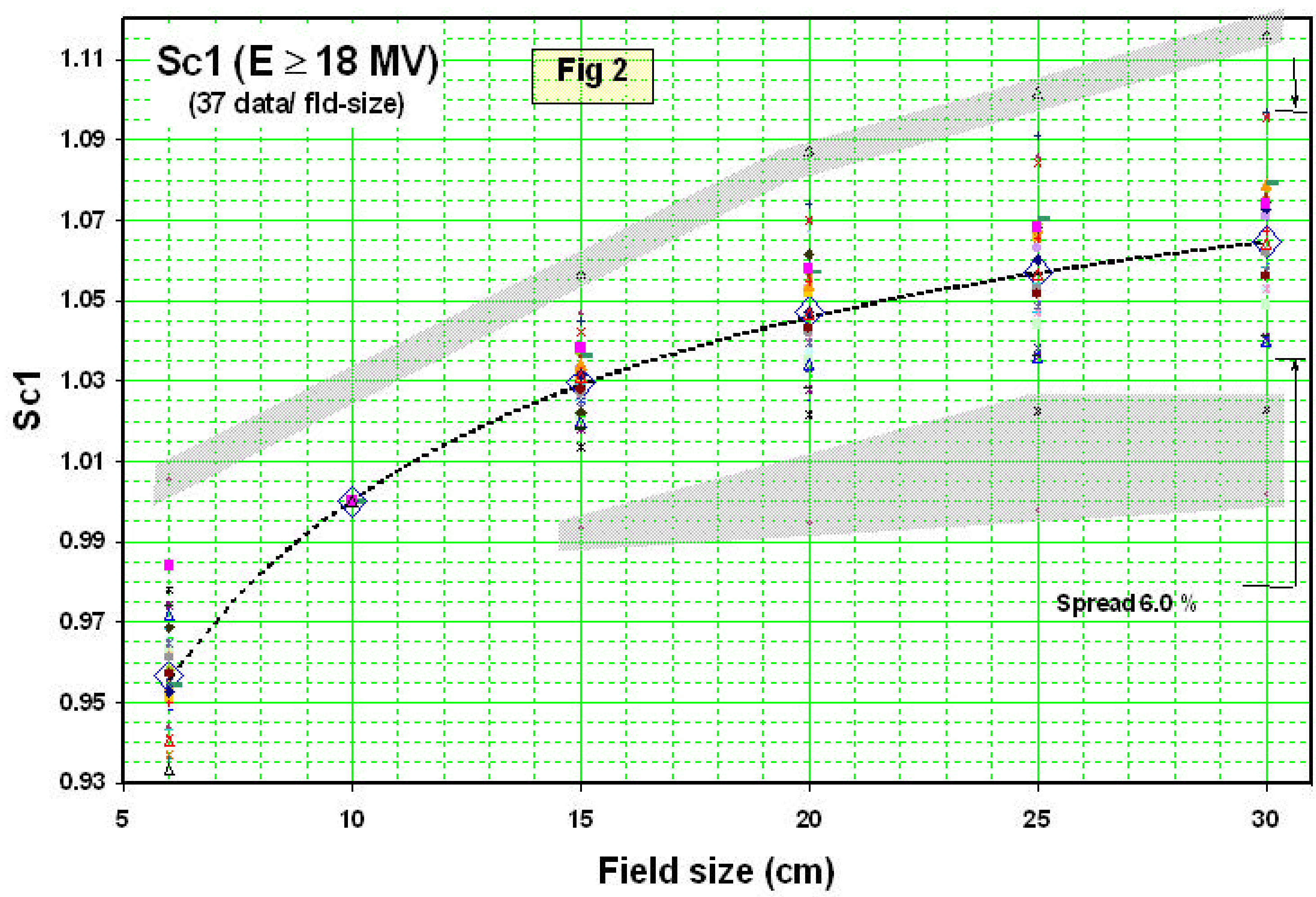


Sp (E 4 MV)
(10 data / fld-size)
Fig 1-D
Sp
Spread 1.1 %
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
5
10
15
20
25
30
Field size (cm)



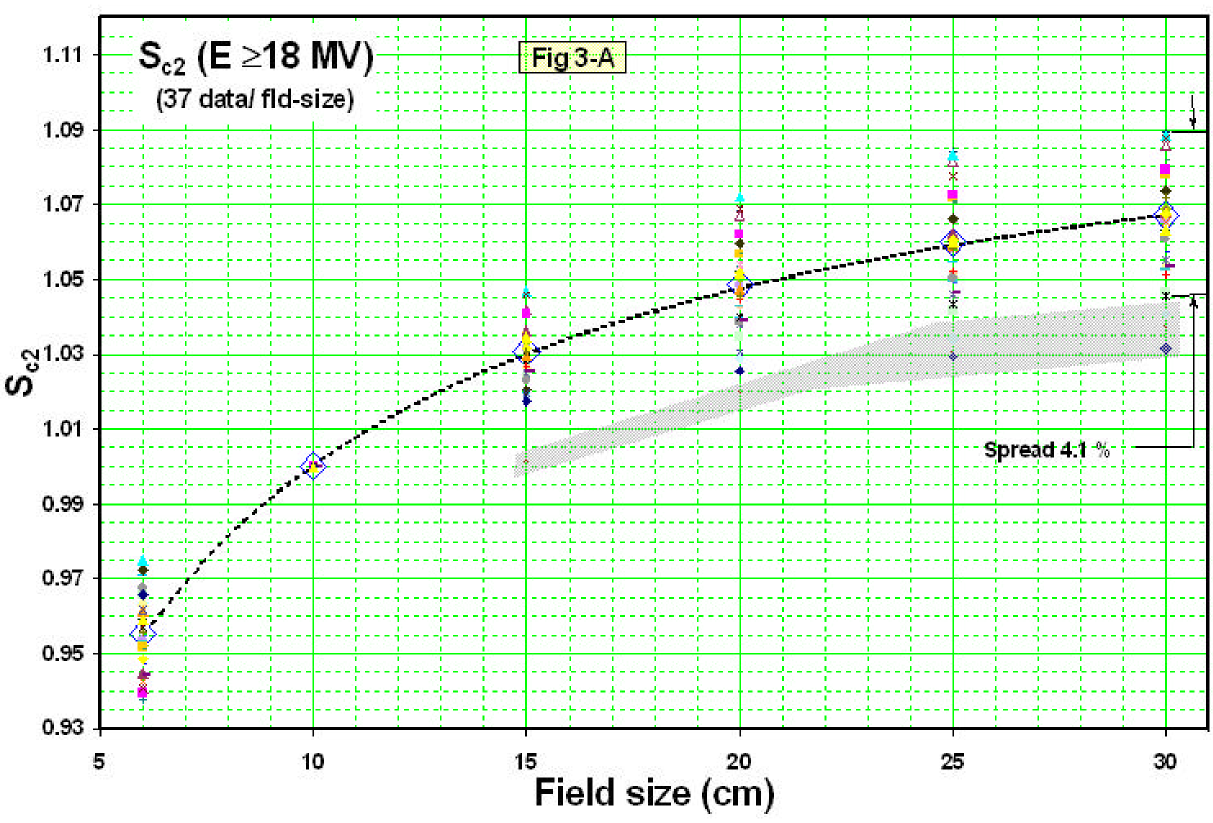
S_p for Co-60 (80 SSD)
(6 data / fld-size)
Fig 1-E
S_p
1.04
1.03
1.02
1.01
1.00
0.99
0.98
5
10
15
20
25
30
Field size (cm)

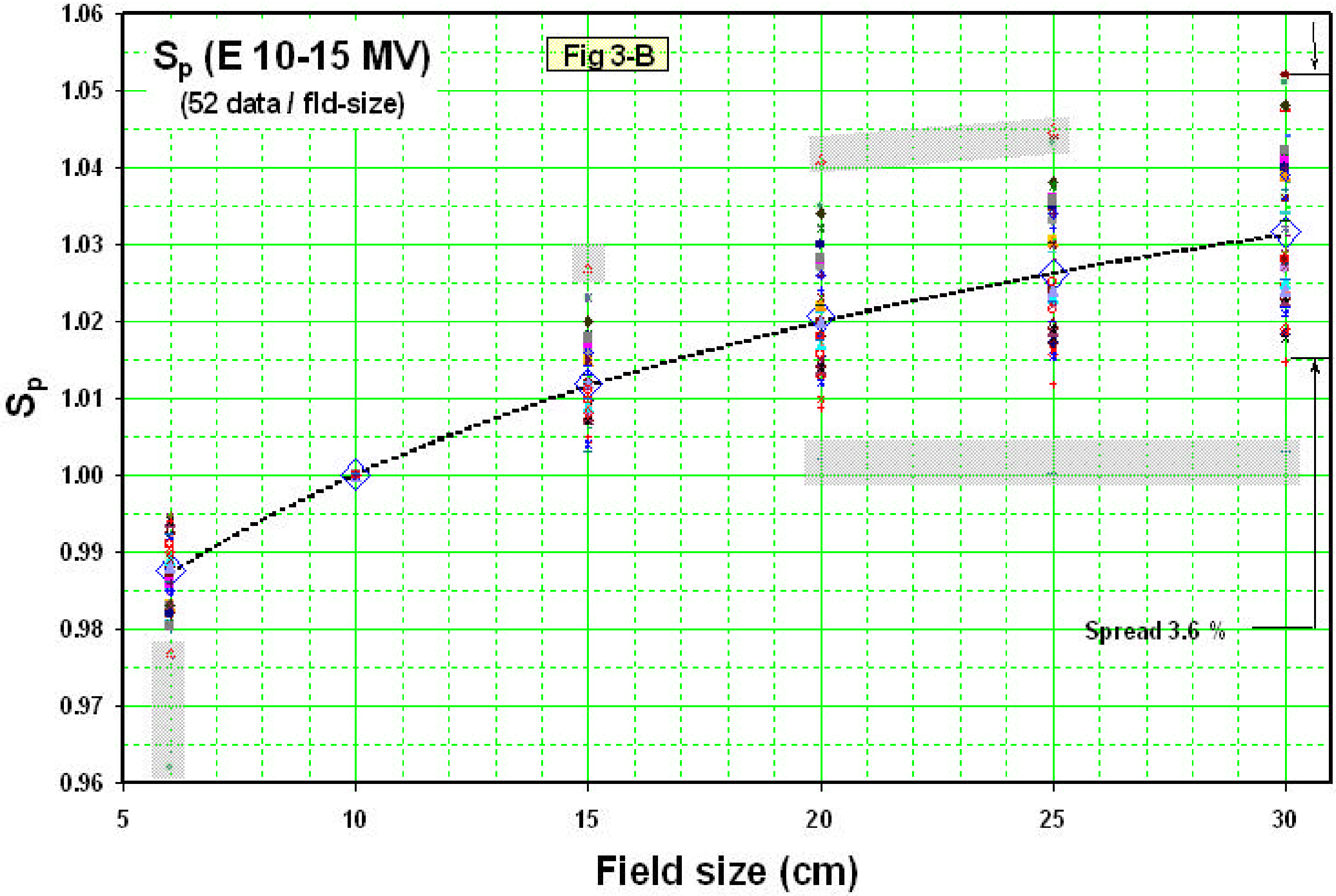
Figure 2 shows institution-provided head-scatter data "S_{c1}" for $\geq$ 18 MV beams. Scatter of this data is significant (6% at 30 x 30 cm^2) due to the likely reasons discussed in the Introduction. With an anticipation of reducing spread in the head-scatter data, modified values "S_{c2}" were calculated in an iterative fashion by dividing the institution-reported S_{cp} by the hyperbolic-fit S_p value.



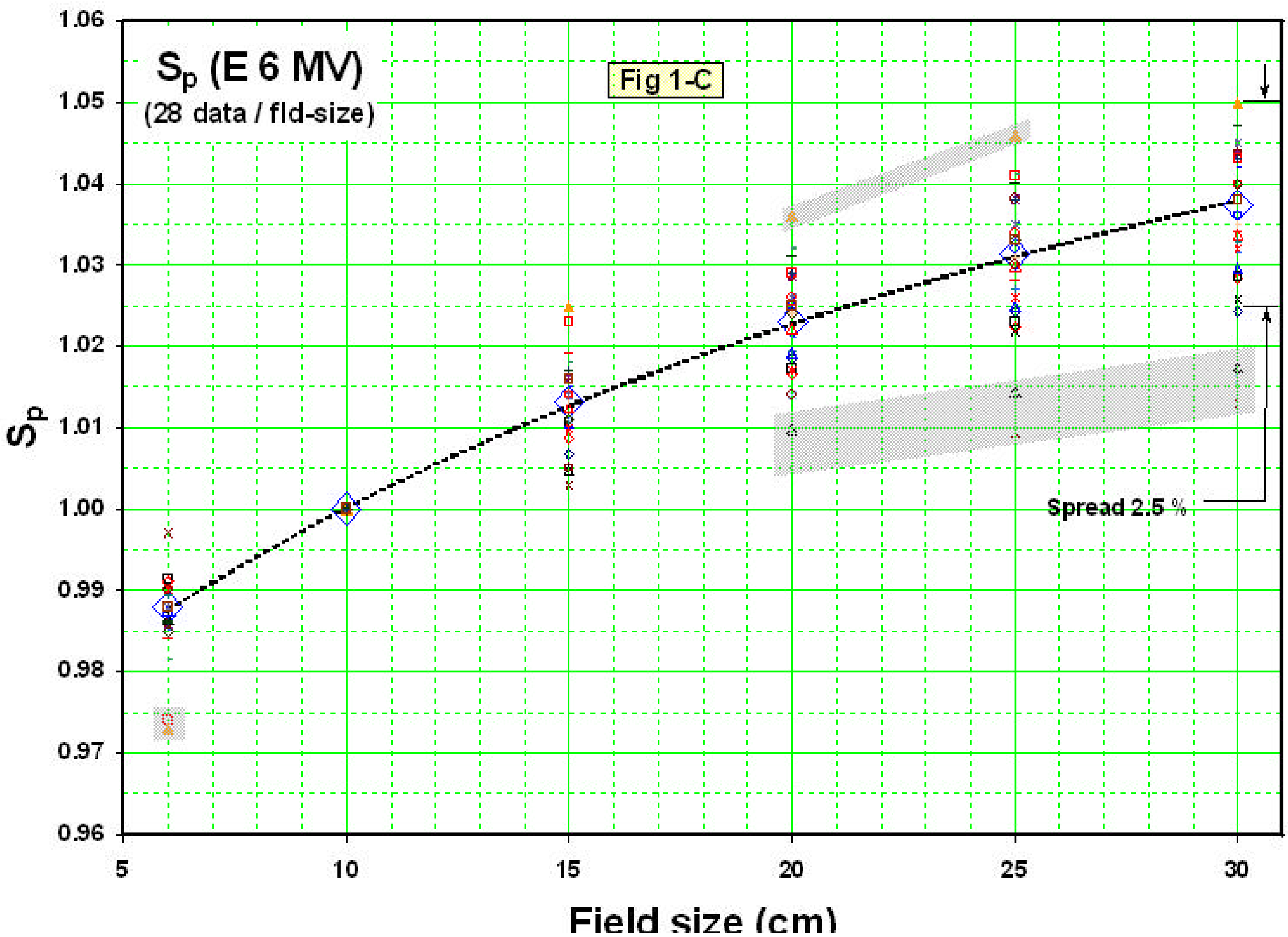
Figures 3A-E show the calculated headscatter data, S_{c2}, for 4, 6, 10-15, ≥18 MV and ^{60}Co beams. These calculated headscatter data, S_{c2}, for the energy group ≥18 MV are shown in Figure 3A. Notice that the data, S_{c1} and S_{c2}, in figures 2 and 3A, respectively, belong to the same set of institutions. The difference is that whereas S_{c1} are direct measurements, S_{c2} are derived from S_{cp} and S_{c1} using the iterative process outlined in the preceding section.

Comparison of figure 3A with figure 2 clearly shows that the iteration has indeed helped reduce the spread (1σ) of 1.5% in S_{c1} down to 1.0% in S_{c2}. As such, the heads-catter data at other energies (figures 3B - E) are presented only in terms of S_{c2}. These figures reflect the spreads in terms of 1σ to be ±0.8%, ±0.7%, and ±0.3% for energy groups 10-15, 6, and 4 MV, respectively.





Sp (E 10-15 MV)
(52 data / fld-size)
Fig 3-B
Spread 3.6 %
Sp
Field size (cm)
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
5
10
15
20
25
30



Sp (E 6 MV)
(28 data / fld-size)
Fig 1-C
Spread 2.5 %
Sp
Field size (cm)
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
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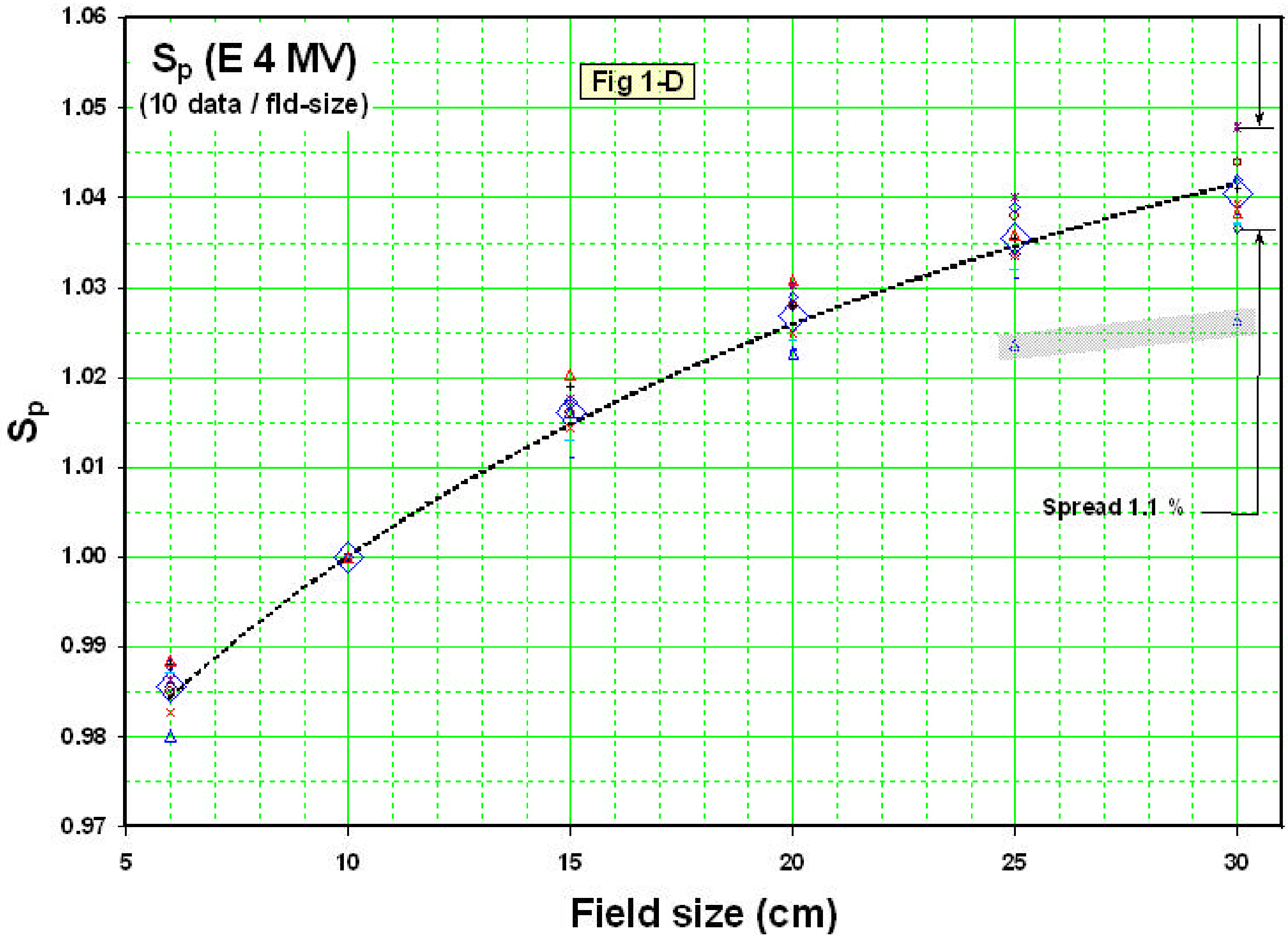
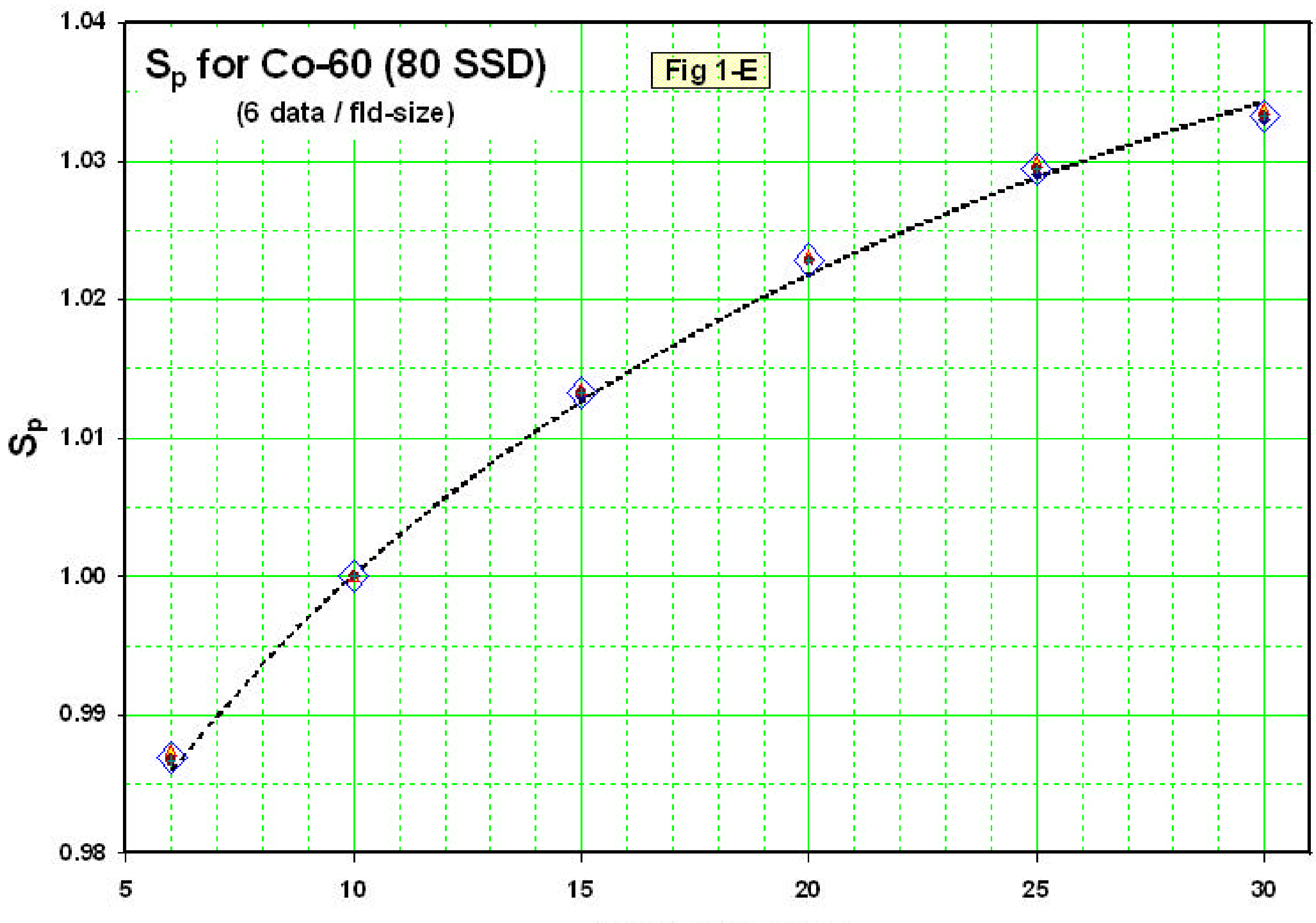


Sp (E 4 MV)
(10 data / fld-size)
Fig 1-D
Spread 1.1 %
Sp
Field size (cm)



Sp for Co-60 (80 SSD)
(6 data / fld-size)
Fig 1-E
Sp

Figure 4 presents the best hyperbolic fits to S_p data for 4, 6, 10-15, ≥18 MV and ^{60}Co beams. The BJR supplement 25 reports that the peak-scatter factor data submitted to the supplement were unable to resolve difference with respect to beam energies. However, despite large spread, our analysis enabled us to resolve differences in S_p with respect to beam energies.

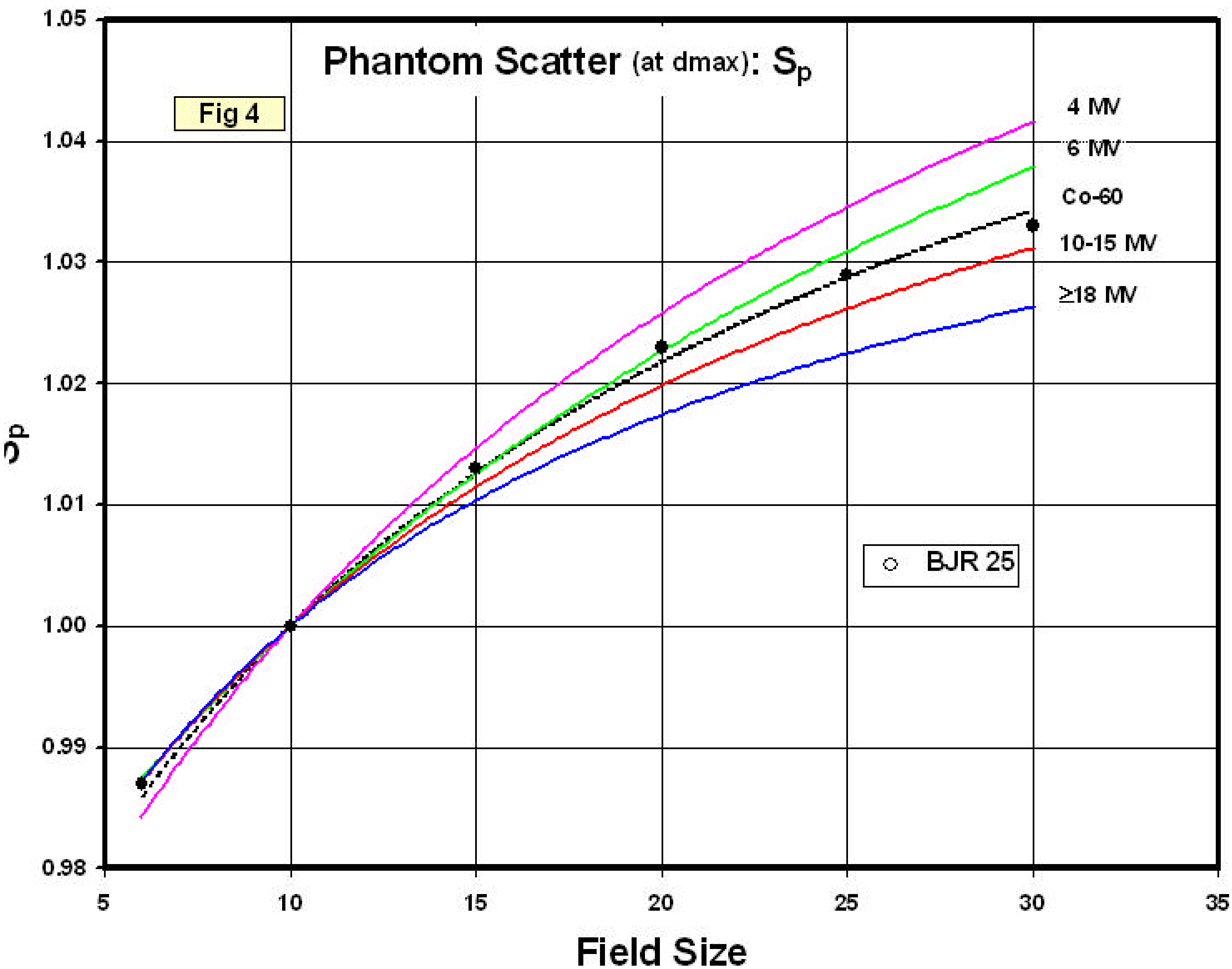
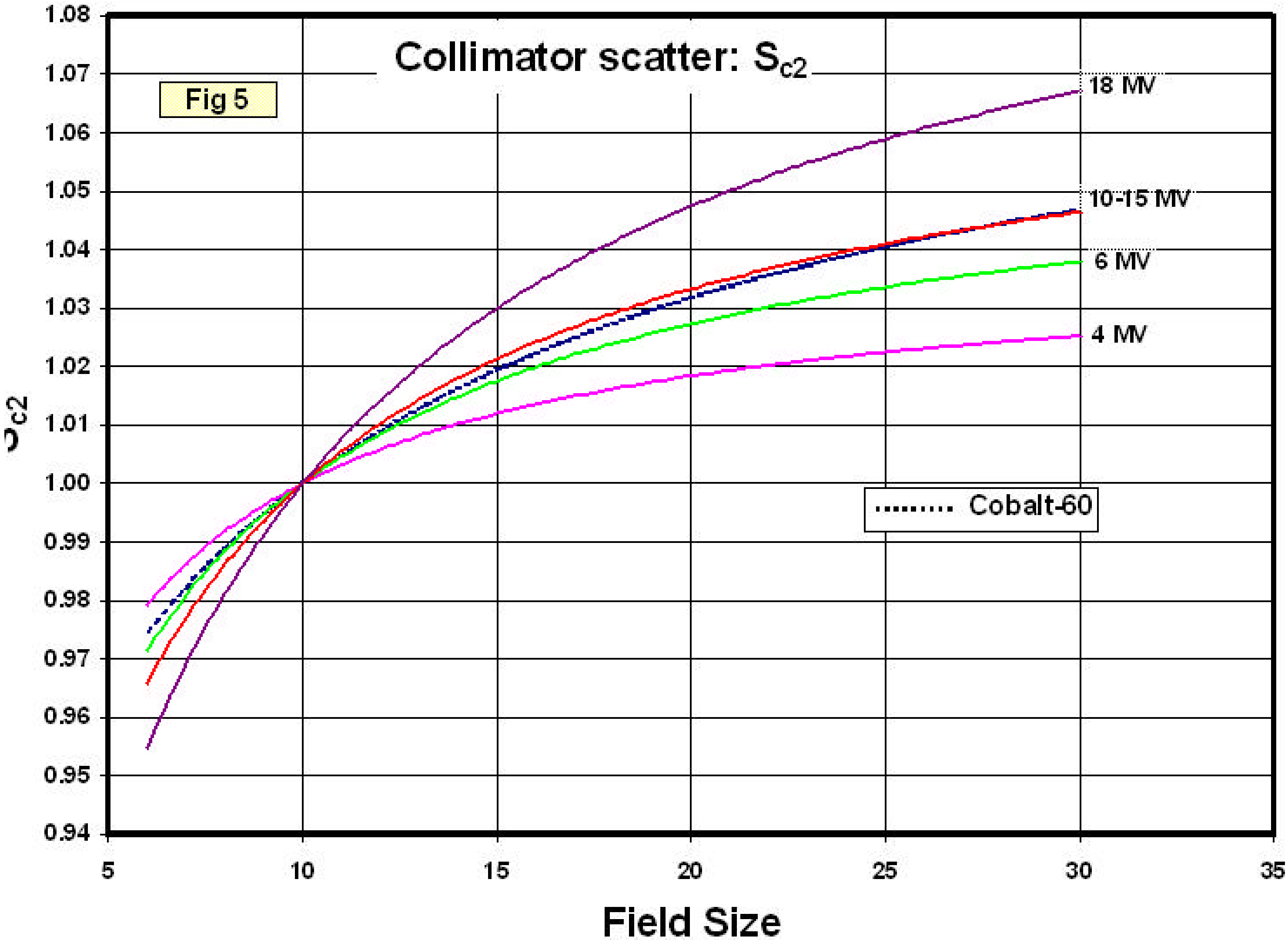


Figure 5 presents the best hyperbolic fits to S_{c2} data for 4, 6, 10-15, ≥18 MV and ^{60}Co beams. Values of S_p and S_c, based on these curves, are intended to be helpful as QA tools to identify possible large errors is measured or employed values.



CONCLUSIONS

Due to inappropriate size/material of mini-phantoms, the measured S_c values are prone to significant errors. These errors also propagate to S_p if they are derived from dividing the measured S_{cp} by S_c. As such,

1. There exists a large spread in S_c values used by institutions.

2. One may find our hyperbolic-curve based S_p values to be more precise than those derived from S_{cp}/S_c.

3. Our hyperbolic-based S_c values, calculated from our S_p values, have less uncertainty than those reported by institutions, however the uncertainty in our S_c values are unable to resolve any differences due to make/model of accelerator.

4. Our S_c and S_p curves should serve as useful quality-assurance tools to identify or reduce gross errors.

REFERENCE

1. P Storchi and J J M van Gasteren, "A table of phantom scatter factors of photon beam: function of the quality index and field size", Phys. Med. Biol. **41**, P 563-571 (1996).

ACKNOWLEDGEMENT

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