5. CONCLUSION – OUR WORK IS COMPLETE... OR IS IT?

As alluded earlier, subsequent to the completion of the first versions of SPARGE™ [7], I *personally* traveled across our country making presentations to industry professionals at trade shows, private company functions and Universities, among others. We were invited to and even taught full-day seminars on the Engineering and Physics underlying the SPARGE™ program at numerous locations. Our technical lectures were even given (and were extremely well received) at JFK Airport for the Port Authority of NY and NJ, the EPA, as well as several East Coast State Environmental Regulator offices. SPARGE™ indeed was utilized at JFK Airport (and hundreds of other contaminated sites) with resounding success, assisting in the remediation of the estimated 2 million gallons of free phase JP fuel, some feet thick, located underneath the tarmac and beneath several jetways. Its use was also employed to remediate a wide array of client sites and contaminant species, including large hydrocarbon and mixed waste plumes beneath refineries, bulk storage facilities, under malls, highways and city streets, farms, residential neighborhoods and airports. Each of these remediation systems were operated without *any* above-ground indication to the casual observer or site guest, as the below ground bioremediation cells continued to reduce the quantity of free phase and adsorbed contaminants to non-detect levels in just a few short months or years at remarkably low cost.

As more and more clients clamored to employ SPARGE™ for their own sites, we began to tally up the length of each successful remediation system we had designed and installed. After racking up a total of 100 miles of remediation well screen length we stopped the tally – we decided that we had made our point and mark in the industry, namely 100 miles of remediation systems with a 100% success rate – not bad!

But success, as we very soon discovered, has its responsibilities and limitations. To our surprise, quite a number of clients had difficulties executing SPARGE™-designed systems as their technical staff failed to understand, and had no prior experience in, how to select and install the motive equipment that each remediation system required. Every HAS well/system requires its own dedicated positive displacement high-pressure blower, among other equipment, but which *specific* blower does one select that *exactly matches* the needs of the remediation system? Physics *demands* that this precision be met, namely what the well requires in delivery pressure and total mass flow has to be exactly that which the blower produces, no more no less. Once again, we soon discovered that unless one was a Mechanical Engineer with some years of experience designing such equipment, or were specifically taught and mentored in the art, it was nearly impossible for the layperson to properly select and specify the necessary features required of the 'right blower' such that the system just designed would work as it was intended. Figures 6 & 7 and the following explanation should give the reader a more encompassing example of this issue.

[7] Since that time there have been at least 14 upgrades and additions to the SPARGE™ program that essentially have doubled the program's size.

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Fig 6 A compilation of but a *few* of the positive displacement blowers available to the remediation practitioner from the three major suppliers of this equipment in the United States.

Photos courtesy Dresser Industries/Roots, MD Pneumatics & Gardner Denver

As Figure 6 illustrates, the quantity of available blower *models*, even when limited to the three vendors shown, is <u>sizable</u>. When one further considers that there may be 20 or more *variations* to each blower model [8], and that the blower's output is directly related to these variations and its rotational speed (which is essentially unlimited), the blower selection process is 'somewhat involved' at best. To further exemplify this point, consider Figure 7, which is a vendor-created multiple variable performance compilation graph that is reduced to a single page for a single blower. The remediation practitioner *must* use *each* blower's graphical specification & performance document correctly and accurately when evaluating it to establish if it *can* be *correctly* employed in the practitioner's application. Without occupying several pages of instructional text to describe *how* one uses a typical performance graph, suffice it to say that if one finds that the blower being evaluated does *not* meet the needs of the remediation system, the practitioner must select another blower and repeat the graph/performance characteristics evaluation process again and again until the correct blower and its characteristics and rotational speed are *correctly* chosen.

[8] Such variations include the number of rotors (either two or three), the lengths of these rotors, and more.

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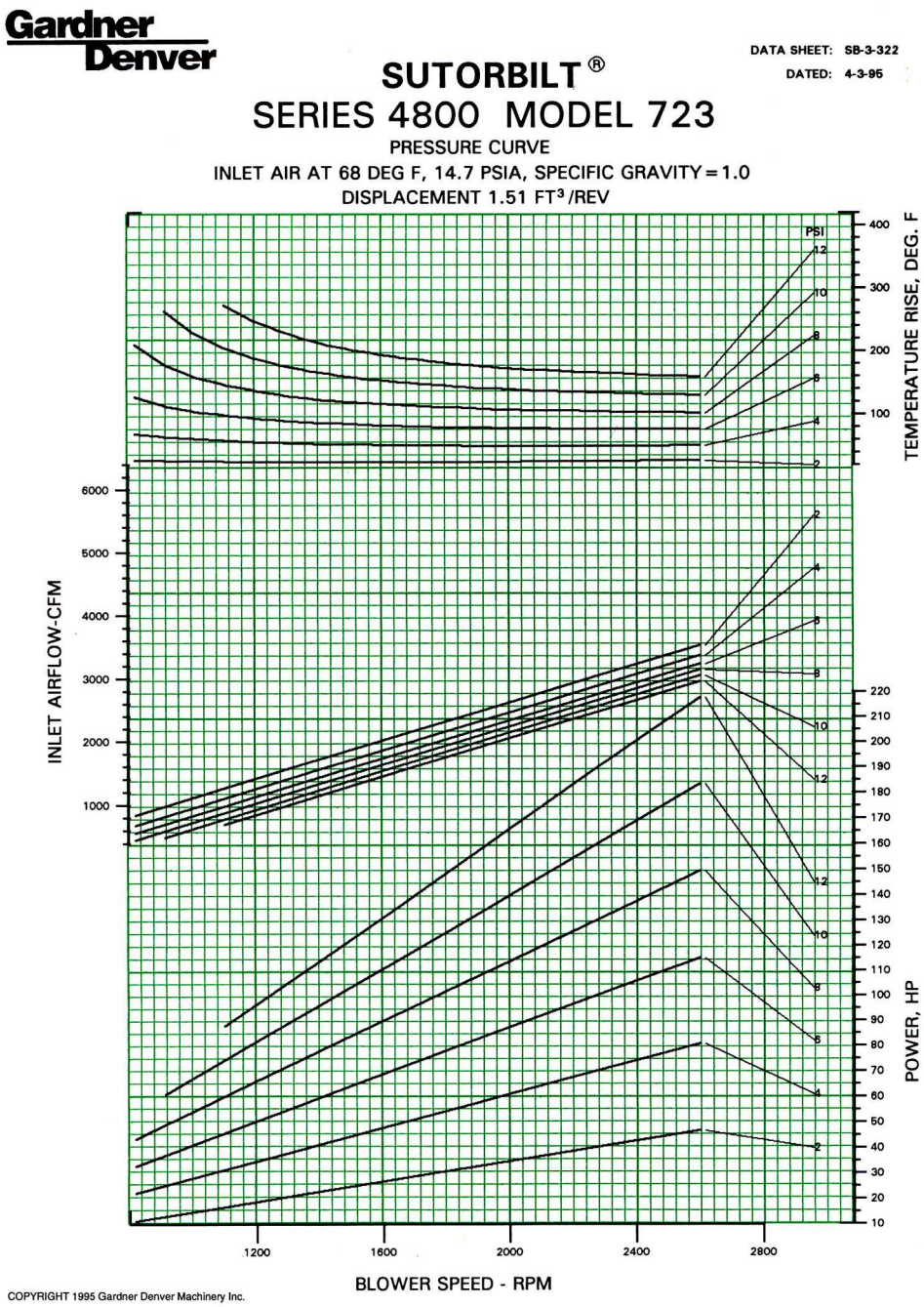

Fig. 7 A typical positive displacement (PD) blower performance compilation. Such graphs are typical in the industry. Note that for the make and model shown, its rotational speed can be specified from 0 – 2600 RPM, while its compressed gas output ranges between 200 to 3500 ICFM, and power input requirements range between 10 to 215 HP.

Performance data graph compilation courtesy Gardner Denver

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Further, merely due to the physical process of compressing ambient air to the delivery pressure required of the HAS system (including the inlet friction and ancillary equipment and system leader pressure losses), the actual compressed air delivery temperature *at the blower's outlet* is typically very hot. So hot indeed that this poses a *significant* safety hazard to both site workers and the equipment itself. As an example, consider the blower performance compilation graph of Figure 7. At a *total* pressure of 12 psig, if the blower's inlet ambient air temperature were 70° F, its discharge pressure could be as much as 340° F, a 270° F rise! Human flesh begins to sear at 120° F, while HDPE well material begins to lose its structural strength at 140° F. It remains as obvious that some sort of in-line air-to-air heat exchanger is absolutely necessary within the system between the blower and the HAS well header entrance. The additional question now presents itself, *exactly* which heat exchanger does one select? And, when one specifies this selection, *exactly* what heat removal capacity, in BTU/hr, must this heat exchanger possess. Further, when this selection is made, *exactly* how much air pressure is 'lost' due to friction in the heat exchanger, this pressure drop must be accounted for in order to have the completed system deliver the SPARGE™ specified quantity of compressed air at the SPARGE™ specified entrance pressure or the remediation system will not function as designed or desired. So, what does one do?

These were the exact same questions that were repeatedly asked of us time after time subsequent to our delivering our SPARGE™ designs to our clients. We soon realized that each client, though well intentioned, did not have the technical expertise, that we were previously informed that they possessed, to specify all of the motive equipment and install each component of their horizontal air sparge injection systems correctly and safely. Something had to be done, and this is where our work continued, with the development of our SYSTEM DESIGN'R™ complete air sparge system Process Flow Diagram program, which was soon afterward expanded to include horizontal vapor extraction (HVE) systems.

The top portion of Figure 8 provides an illustrative example of our SYSTEM DESIGN'R™ program. The illustration includes the entirety of the heat exchange thermodynamic computation, the selection of required piping sizes, determination of system temperatures and pressure losses and all the data necessary to correctly specify the entirety of the HAS system to each equipment supplying vendor. In addition, the program also designs the blower's entrance air filter and outlet silencer (definitely required in every HAS/HVE system) and determines the pressure losses in each of these components. When coupled with vendor supplied blower performance data, selection of the *right* blower, and several alternates, becomes an easy and automatic exercise.

What makes SYSTEM DESIGN'R™ somewhat industry-unique is that it accepts the necessary SPARGE™ computed system performance data *automatically* in order to complete its work. This feature was incorporated in all of our remediation system design and evaluation programs, that they would function in part

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similar to that which Microsoft employs in their Office™ [9] program series. Where possible and practical, each of our design and evaluation programs that can 'dovetail' with or have further system performance evaluations done with another program based upon its own calculated results will *automatically* create an output database that is readily accepted into the next program, and if necessary the ensuing design program after that.

In total, from our 'humble beginnings' of creating our initial SPARGE™ HAS system design and analysis Computational Fluid Dynamics program, we have developed a total of 13 Environmental Remediation System Design and Analysis computer programs and forensic tools! With minor exception, each automatically dovetails into its ensuing complementary analysis program through the creation of a digital database that is automatically accepted as the input data of that subsequent design or analysis program.

One again referring to Figure 8, in addition to SYSTEM DESIGN'R™, the figure's compilation also includes small illustrative examples of two more of our analysis programs, DISPERSION™ and *IN SITU* STRIPPER™. These programs and their value to the Industry will be discussed in future papers, however they have been highlighted in this publication for a specific reason.

IN SITU STRIPPER™ was developed to calculate the effects of in-situ air stripping of <u>each</u> of a plume's contaminant specie as bioremediation and/or co-metabolic biodegradation of that plume <u>concurrently</u> progresses. In-situ air stripping is typically <u>completely</u> ignored or quickly dismissed as an effective and viable remediation technology, and this is a great mistake. In a future paper, the remediation of a specific site in which we were involved, it heavily contaminated with mixed wastes including chlorinated and non-chlorinated solvents, will be discussed at some length. The reason for this more encompassing discussion is that in this example one of the more 'difficult' site contaminants that a previous contractor tried to remediate *unsuccessfully* for 13 years(!) using an <u>extensive</u> pump-and-treat system, was in fact <u>completely</u> removed by *in-situ stripping* in <u>less than</u> 90 days employing HAS wells!

DISPERSION™ is also highlighted in Figure 8 for the fact that it is the <u>first</u> analytical evaluation program in the Environmental Industry that *precisely* establishes the fate of <u>every</u> air sparge bubble once it exits <u>any</u> horizontal or vertical well. In clearly understood, remarkably precise fashion, the program permits the remediation practitioner to know *beforehand* <u>exactly</u> where <u>all</u> of the injected air goes in a simple to understand 3-D graphic. As Figure 8 illustrates, for the four-zone system identified to its right, this straightforward evaluation is <u>extremely</u> complex, but this complexity is understated, as illustrated by a single value entitled *Number of Equations Solved to Complete the Analysis*. For the system analyzed, that value is 54.4 <u>million</u> equations! The entirety of effort to complete this extraordinary quantity of analytical work took just over 1 minute to complete. Such an example of sheer Engineering effort gives one pause to consider how long it would take

[9] Office™ is a registered trademark of the Microsoft Corporation

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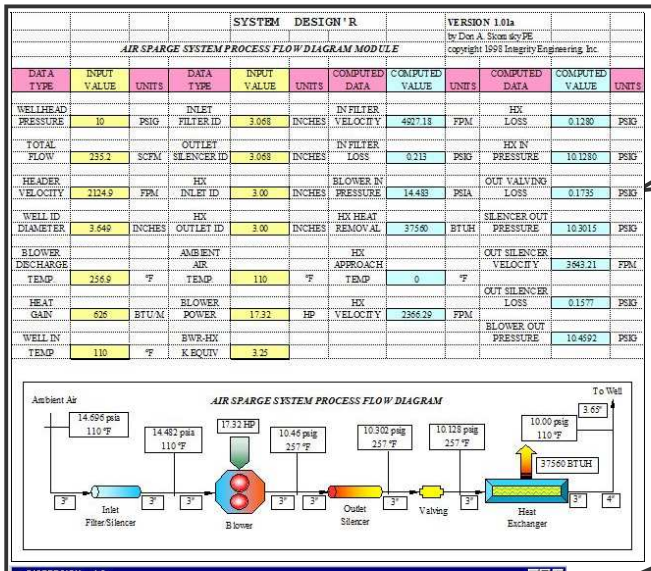


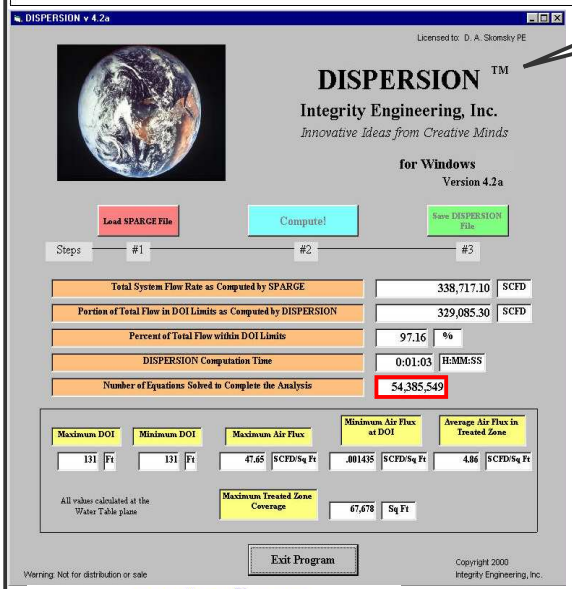
SYSTEM DESIGN'R — VERSION 1.01a — by Don A. Skomsky PE — copyright 1998 Integrity Engineering, Inc.

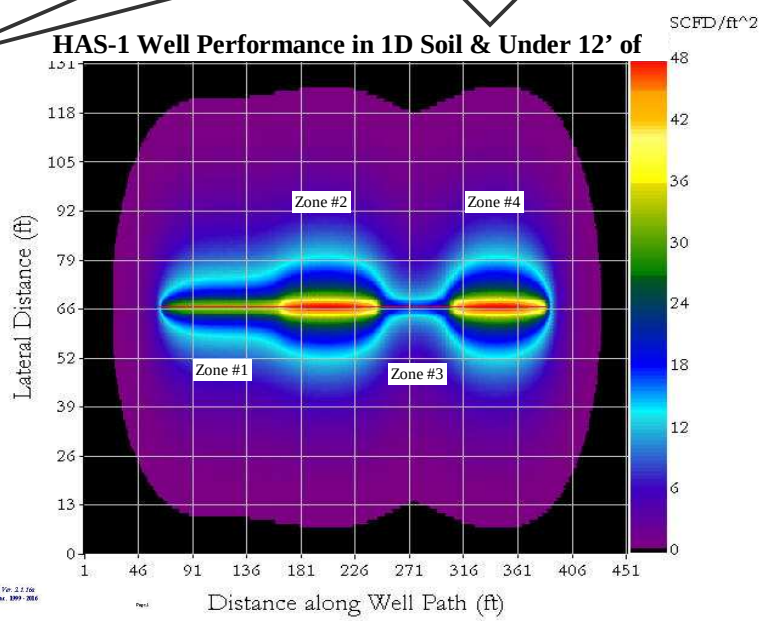
AIR SPARGE SYSTEM PROCESS FLOW DIAGRAM MODULE

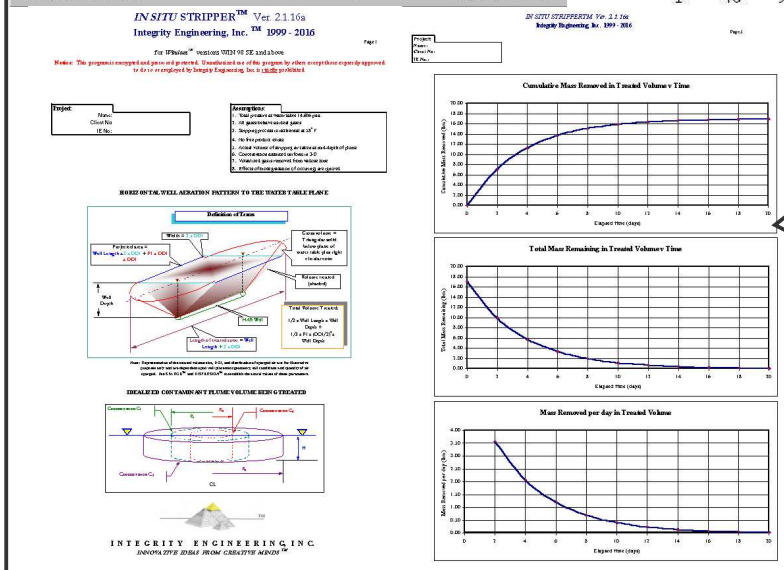
DATA TYPE	INPUT VALUE	UNITS	DATA TYPE	INPUT VALUE	UNITS	COMPUTED DATA	COMPUTED VALUE	UNITS	COMPUTED DATA	COMPUTED VALUE	UNITS
WELLHEAD PRESSURE	10	PSIG	INLET FILTER ID	3.068	INCHES	IN FILTER VELOCITY	4927.18	FPM	HX LOSS	0.1280	PSIG
TOTAL FLOW	235.2	SCFM	OUTLET SILENCER ID	3.068	INCHES	IN FILTER LOSS	0.213	PSIG	HX IN PRESSURE	10.1280	PSIG
HEADER VELOCITY	2124.9	FPM	HX INLET ID	3.00	INCHES	BLOWER IN PRESSURE	14.483	PSIA	OUT VALVING LOSS	0.1735	PSIG
WELL ID DIAMETER	3.649	INCHES	HX OUTLET ID	3.00	INCHES	HX HEAT REMOVAL	37560	BTUH	SILENCER OUT PRESSURE	10.3015	PSIG
BLOWER DISCHARGE TEMP	256.9	°F	AMBIENT AIR TEMP	110	°F	HX APPROACH TEMP	0	°F	OUT SILENCER VELOCITY	3643.21	FPM
HEAT GAIN	626	BTU/M	BLOWER POWER	17.32	HP	HX VELOCITY	2366.29	FPM	OUT SILENCER LOSS	0.1577	PSIG
WELL IN TEMP	110	°F	BWR-HX K EQUIV	3.25					BLOWER OUT PRESSURE	10.4592	PSIG

System Design'r™ *automatically* calculates and displays a complete sparge system Process Flow Diagram (PFD), enabling the user to precisely specify and select all system equipment by mfgr., model no., speed, size, heat removal capacity, pipe size(s), and much much more.

Perhaps our second most complex computer analysis program **DISPERSION™** *automatically* calculates the fate of every air bubble discharged from *any* HAS well and displays the 3-D maximum and minimum DOI's and flux of aeration at the water table. To illustrate the program's complexity, the reader may wish to view the number of equations solved for this system in the left-side image (the contents of the red box), this value is typically in excess of 20 million!







Even though the *preferred* (or *desired*) means of site remediation is bio-remediation (or co-metabolic bio-degradation), this does not mean that other remedial process(es) are not concurrently at play! In fact *in situ* air stripping exists every time a HAS well is operating. IE developed ***In Situ* Stripper™** for the specific purpose of computing contaminant removal due to *in situ* air stripping for *any* site, under *any* conditions and for *any* contaminant(s). As illustrated here, this site's contamination will be cleaned up in a matter of days by air stripping alone! HAS wells are *ideal* for this purpose.

Fig. 8 Additional system performance analyses available in the SPARGE™ suite of computer programs developed by IE.

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for one skilled in the art of Engineering to complete this number of calculations *by hand*. Certainly the effort would be daunting at best.

As stated earlier, Integrity Engineering has developed a total of 13 analytical tools intended to design and/or forensically analyze environmental remediation systems, specifically those deploying horizontal wells. Each analytical evaluation program has been expanded to include all vertical and slant wells. In closing this paper, it is appropriate to provide the reader with a tabulation of each of these programs, beginning with SPARGE™, so the totality of our work in advancing the industry's Engineering capabilities may be made known to all practitioners toward the goal of increasing their skills in the art of Environmental Engineering.

Engineering Design & Analysis Computer programs and forensic tools developed by Integrity Engineering include:

1. SPARGE™ - The industry's first FEA Computational Fluid Dynamics design and analysis program specifically written to design HAS remediation systems employing horizontal injection wells,
2. EXTRACT™ - This program performs the same functions as SPARGE™ but in 'reverse', by designing and analyzing Vapor Extraction remediation systems employing horizontal wells. Due to Physical laws and their constraints, EXTRACT™ is actually more complex than SPARGE™ in its robustness,
3. STEAM™ - Performs the same design and analysis functions as SPARGE™ for horizontal wells injecting saturated steam instead of air as its motive fluid,
4. INJECT™ - Performs the same design and analysis functions as SPARGE™ for horizontal wells injecting fresh water instead of air as its motive fluid,
5. WATER™ - Performs the same design and analysis functions as EXTRACT™ for horizontal wells withdrawing groundwater instead of contaminated vapor as its motive fluid,
6. DISPERSION™ - Determines and graphically displays the fate and the extent of aeration of the entirety of air injected by any horizontal or vertical air sparge well,
7. SYSTEM DESIGN'R™ - An automatic Process Flow Diagram analysis preparation program that analyzes and specifies all of the motive equipment for any HAS or HVE system,
8. *IN SITU* STRIPPER™ - Automatically calculates the time-based removal of any contaminant present in the saturated zone due to volatilization caused by the injection of air by any horizontal air sparge well,
9. SLOT CHECK'R™ - A forensic field evaluation tool and computer program that measures the geometry of any injection or extraction well's screen and precisely establishes its percent open area,
10. VAPOR™ - A forensic field analysis computer program that calculates the overall performance of any HAS or HVE system,
11. GasFlow SENSOR™ - A hand-held soil gas permeability measurement instrument,
12. pH Neutral™ - A process system acid-base neutralization analysis computer program that specifies the quantity and concentration of any base needed to neutralize any volume of acid, and the reverse,

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13. DISPERSION Z-AXIS™ - A computer program currently in beta form that calculates and graphically displays the quantity of soil aeration in section cuts from the well to the water table along the major axis of any HAS injection well.

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