


Outcomes and Features of the Inspection of Receiver Tubes (ITR) System for Improved O&M in Parabolic Trough Plants

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- CSP (PT) plants after several years since their commissioning demand new operation and maintenance (O&M) developments.

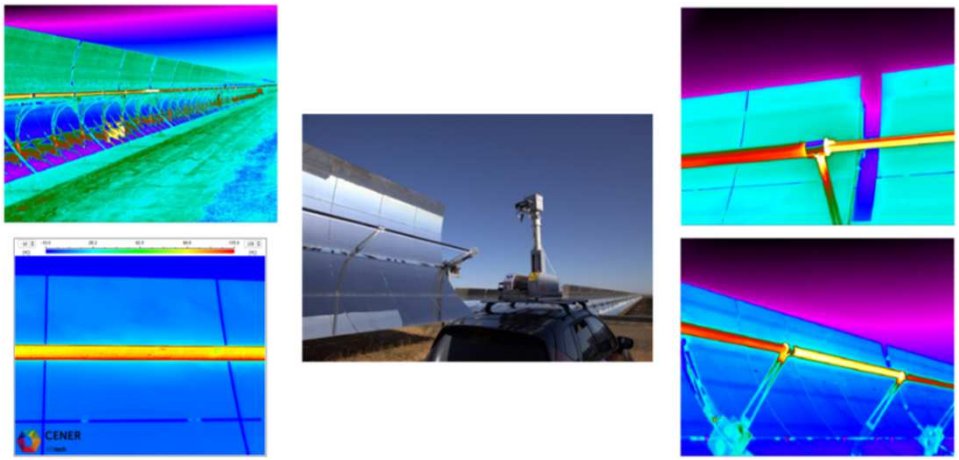
- Particularly, the receiver tube´s potential degradation over time is a truly challenge.

VACUUM LOSS

DEGRADATION

BREAKAGE

- Current version of the ITR System's last developments, advanced features and the main outcomes for a real, complete solar field inspection in a commercial PT power plant.



- Plant operators can more easily develop and adopt improved O&M strategies, such as corrective and preventive actions in the solar field, and even predictive actions in case of periodic inspections.

ITR SYSTEM MAIN FEATURES:

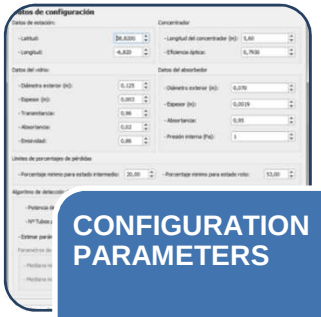
- Terrestrial Inspection Device (up to 15 km/h, 96 receivers per min)

ITR SYSTEM MAIN FEATURES:

- Terrestrial Inspection Device

ITR SYSTEM MAIN FEATURES:

- Integral Processing Software

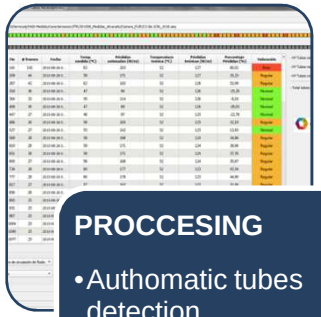


CONFIGURATION PARAMETERS

- Plant / Solar Field / Tube
- Detection

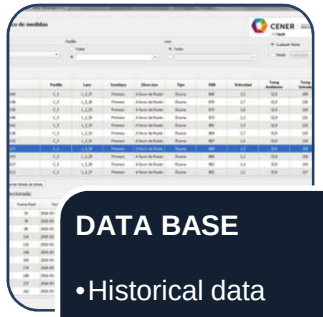
INPUTS

- IR video
- Operation Parameters
- Meteorological Paramenters



PROCCESING

- Authomatic tubes detection.
- Receiver glass temperatura meas.
- Theoretical simulation (Model)



DATA BASE

- Historical data
- Tubes codification
- Results -exploitation
- Alerts
- O&M Strategy

OUTPUTS
Receiver Tubes Status Classification
Receiver Tube Power Indicator

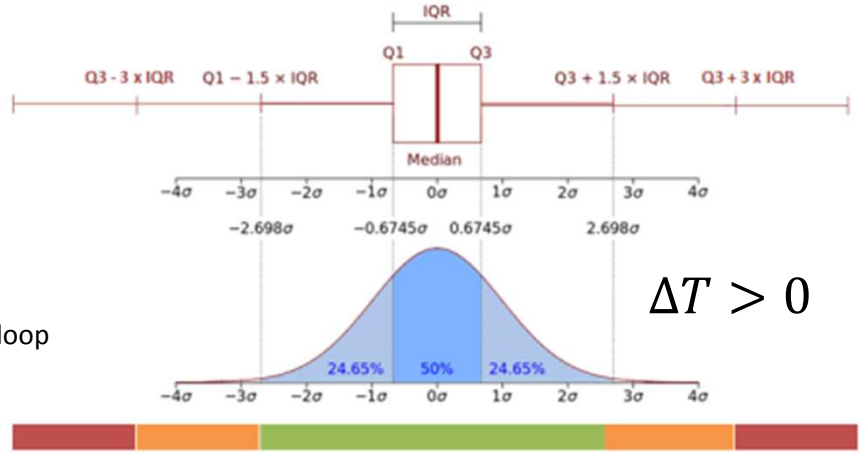
ITR SYSTEM OUTPUTS:

➢ **Receiver Tubes Status Classification**

- Non-seasonal data

$$\Delta T = \left(T_{glass\ meas} - T_{adjust*}\right)\ [^{o}C]$$

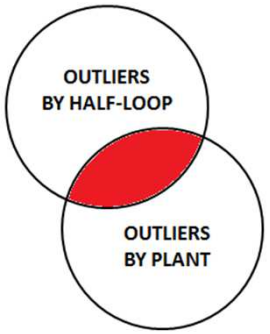
* relative to the linear distribution of $T_{glass\ meas}$ for each whole half-loop



- Box-and-whisker plot statistical analysis

Outliers or untypical values (by half-loop and by plant)

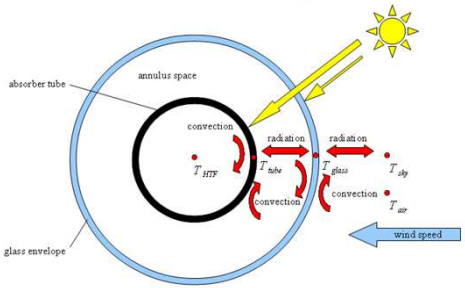
Category	Interval Limit
Green (Ok)	ΔT < Q3 + 1.5 x IQR
Orange (Regular)	Q3 + 1.5 x IQR < ΔT < Q3 + 3 x IQR
Red (No Ok)	Q3 + 3 x IQR < ΔT

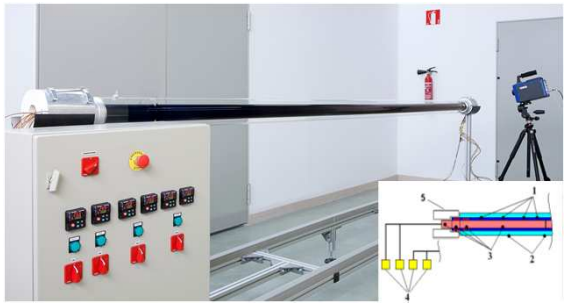


➡ **Outliers identification and localization (Outliers Map)**

ITR SYSTEM OUTPUTS :

- **Theoretical simulation (Model)**
  - A detailed one-dimensional object oriented heat transfer model was developed for the receiver tube. It is possible to determine Heat losses and power in nominal conditions.
  - Validation comparing model simulations with experimental measurements on the testing bench of CENER using different tube manufacturers in nominal conditions.
  - Absorber emissivity values resulting from heat losses tests and from specific measurements of the reflectivity at far IR wavelengths of absorber samples are assumed for modelization.





ITR SYSTEM OUTPUTS :

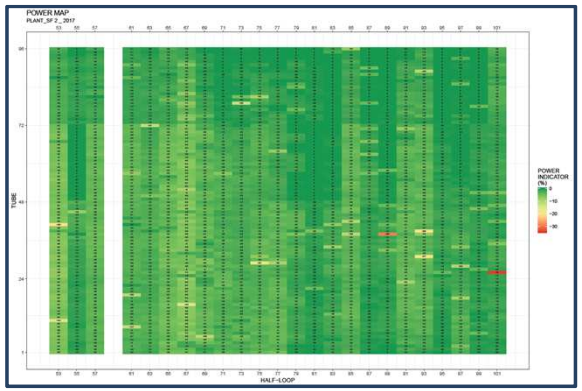
- **Receiver Tubes Power Indicator (PI)**

$$PI = \frac{P_{estim} - P_{theo}}{P_{theo}} \quad [\%]$$

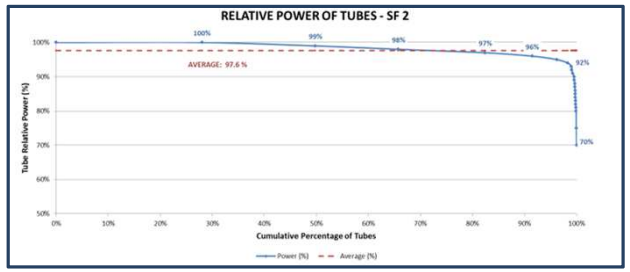
P_{estim} – *estimated power of the tube [W]*

P_{theo} – *theoretical power at nominal conditions [W] (vacuum nominal pressure condition)*

➡ **Tubes Power Indicator (Power Map)**



➡ **Relative Power of Tubes Plot**
(Relative power of tubes Vs
the cumulative percentage of tubes)



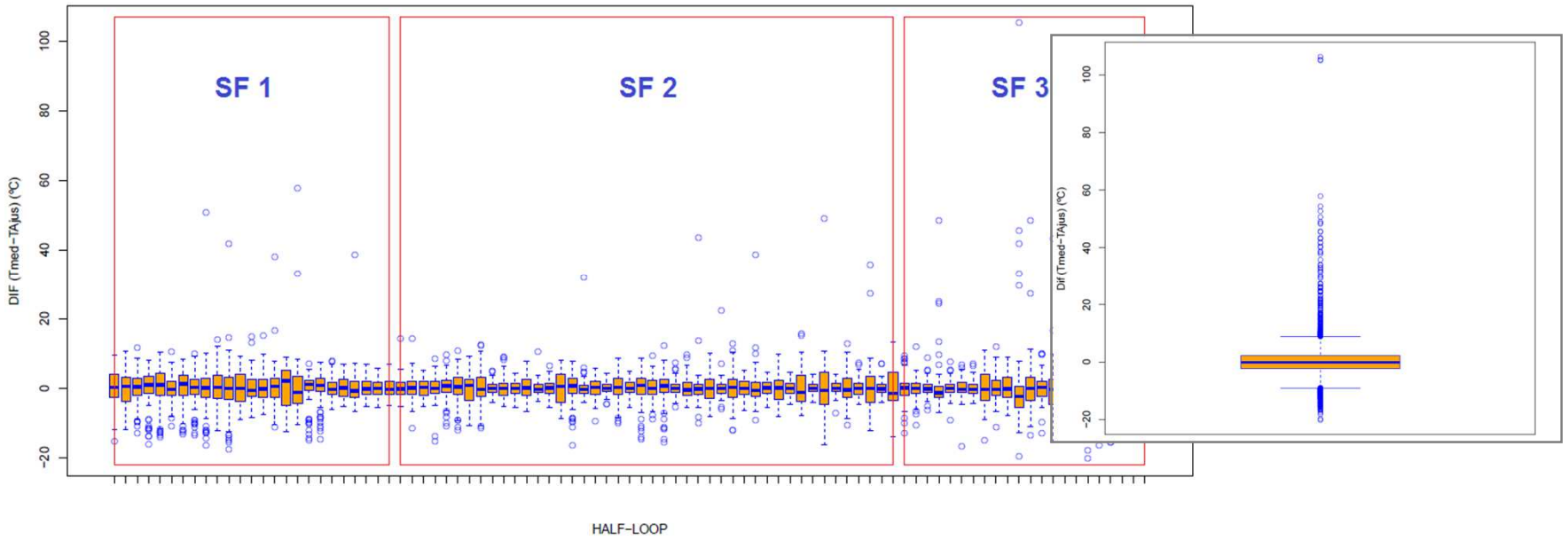
INSPECTION DATA:

- First commercial service performed in 2017 (3 solar fields; 8,736 tubes*)

  * the scope included all of the high temperature half-loops and some low temperature half-loops (SF2).

RECEIVER TUBES STATUS CLASSIFICATION:

- Box-and-whisker plot for half-loops inspected in each solar field.



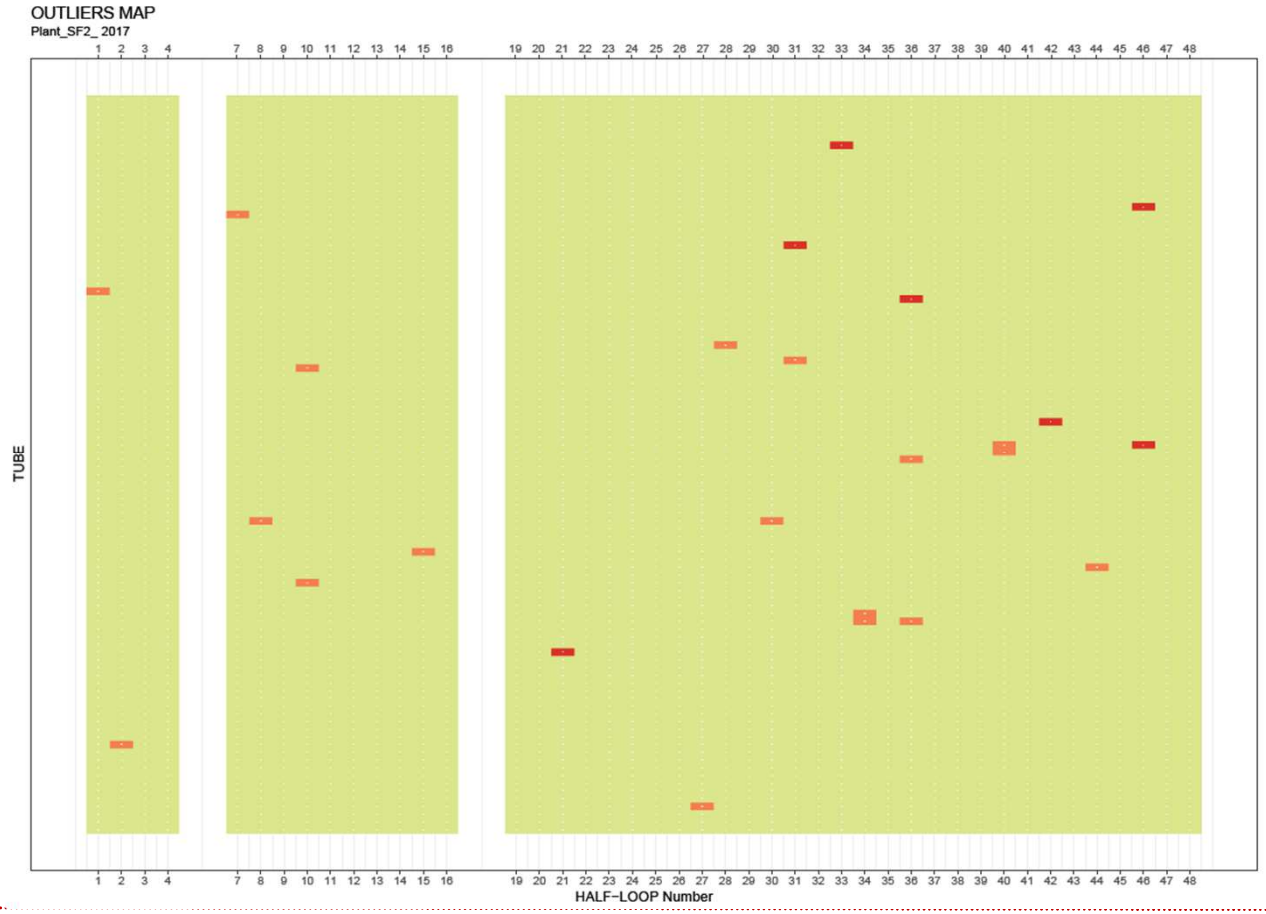
RECEIVER TUBES STATUS CLASSIFICATION:

- Inspection Data and Classification Results.

Classification Results	SF 1	SF 2	SF 3	Total
Total of ORANGE outliers	8	18	19	**45**
% of the total of tubes inspected	0,3%	0,4%	0,9%	**0,5%**
Total of RED outliers (Broken glass)	0	3	3	**6**
Total of RED outliers (Correct glass)	7	4	11	**22**
Total of RED outliers	7	7	14	**28**
% of the total of tubes inspected.	0,3%	0,2%	0,7%	**0,3%**
Total number of outliers	15	25	33	**73**
Total % of the total of tubes insp.	0,6%	0,6%	1,6%	**0,8%**

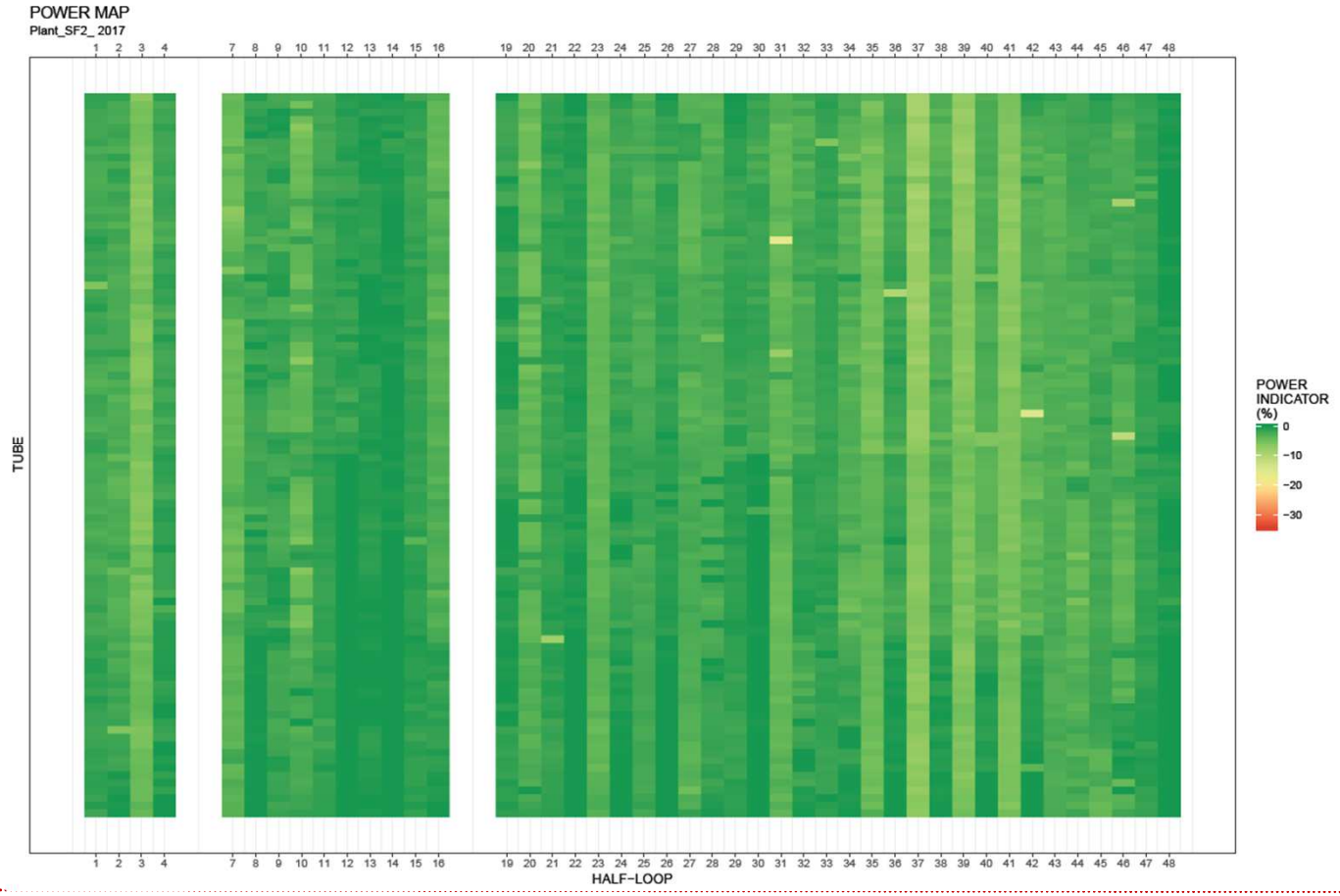
RECEIVER TUBES STATUS CLASSIFICATION:

- Outliers Map for the Solar Field 2 (SF2)



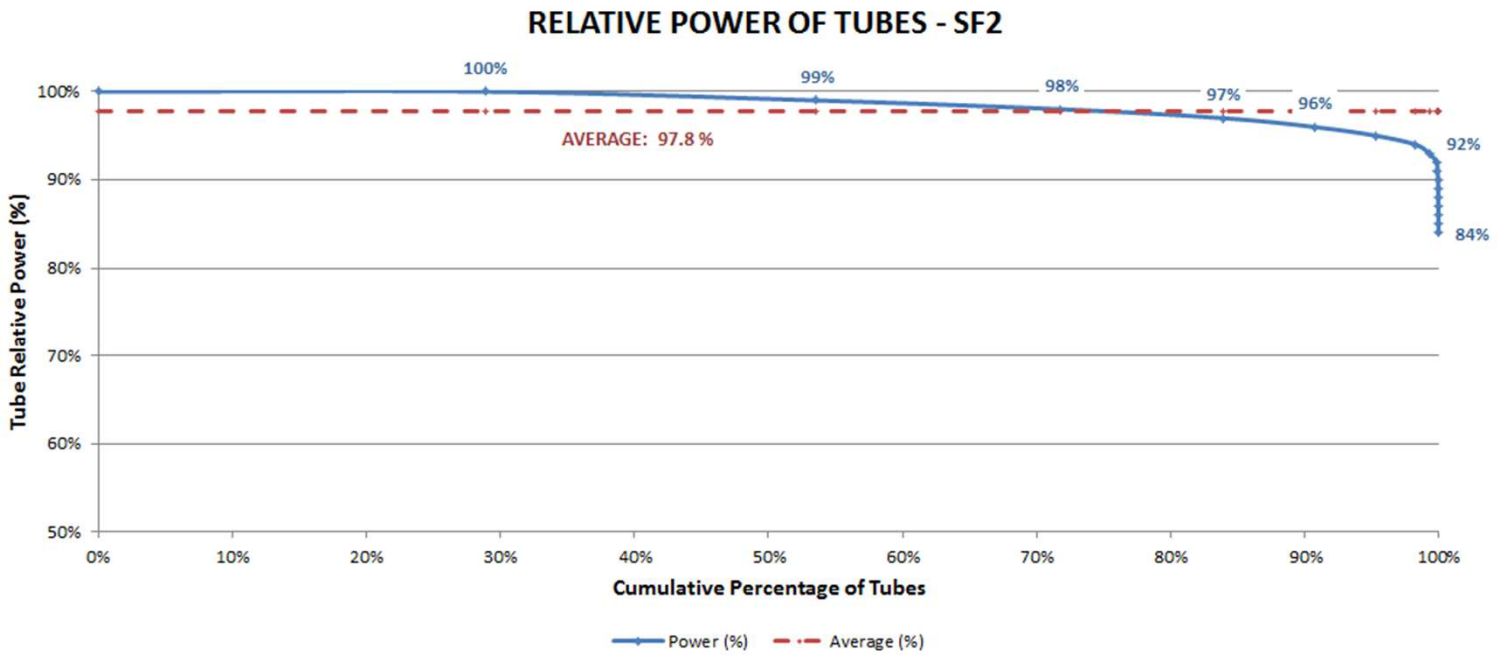
RECEIVER TUBES POWER INDICATOR:

- Tubes Power Indicator Map for the Solar Field 2 (SF2)



RECEIVER TUBES POWER INDICATOR:

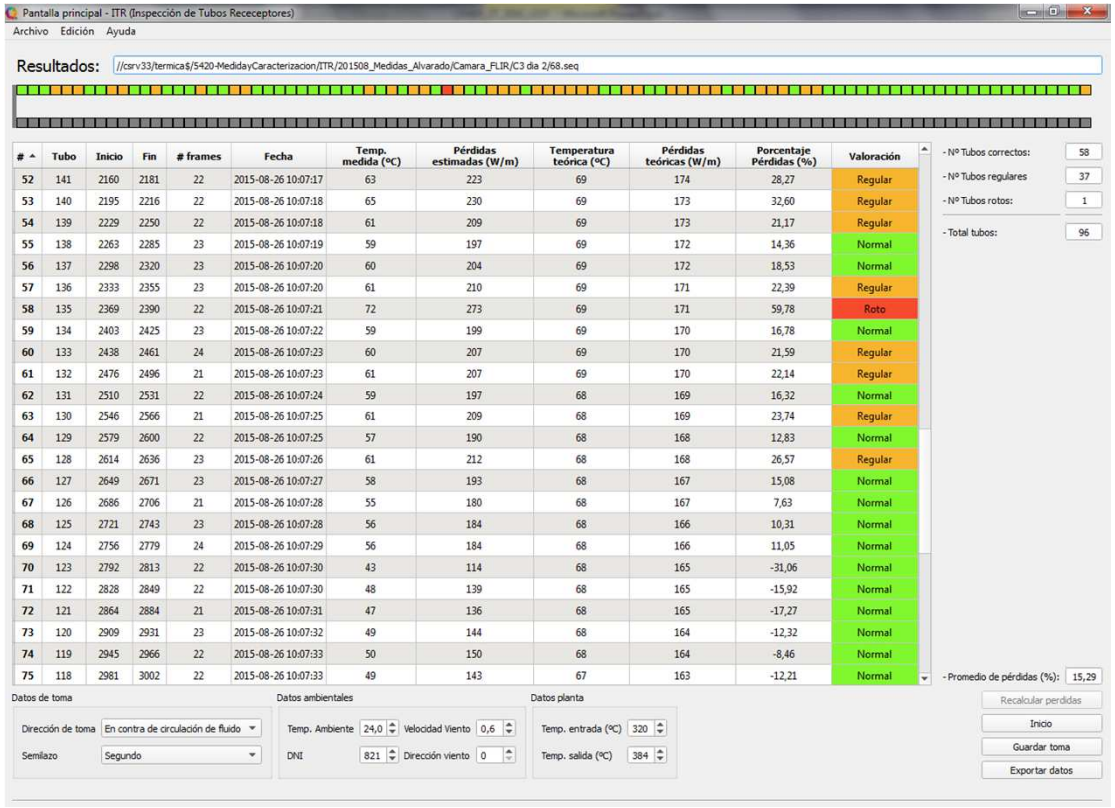
- Relative Power of tubes of the Solar Field 2 (SF2)



Average Relative Power of Tubes Inspected per Solar Field

SF 1	SF 2	SF 3	Total
97%	98%	97%	97%

RECEIVER TUBES HISTORICAL PERFORMANCE DATABASE AVAILABLE :



#	Tubo	Inicio	Fin	# frames	Fecha	Temp. medida (ºC)	Pérdidas estimadas (W/m)	Temperatura teórica (ºC)	Pérdidas teóricas (W/m)	Porcentaje Pérdidas (%)	Valoración
52	141	2160	2181	22	2015-08-26 10:07:17	63	223	69	174	28,27	Regular
53	140	2195	2216	22	2015-08-26 10:07:18	65	230	69	173	32,60	Regular
54	139	2229	2250	22	2015-08-26 10:07:18	61	209	69	173	21,17	Regular
55	138	2263	2285	23	2015-08-26 10:07:19	59	197	69	172	14,36	Normal
56	137	2298	2320	23	2015-08-26 10:07:20	60	204	69	172	18,53	Normal
57	136	2333	2355	23	2015-08-26 10:07:20	61	210	69	171	22,39	Regular
58	135	2369	2390	22	2015-08-26 10:07:21	72	273	69	171	59,78	Roto
59	134	2403	2425	23	2015-08-26 10:07:22	59	199	69	170	16,78	Normal
60	133	2438	2461	24	2015-08-26 10:07:23	60	207	69	170	21,59	Regular
61	132	2476	2496	21	2015-08-26 10:07:23	61	207	69	170	22,14	Regular
62	131	2510	2531	22	2015-08-26 10:07:24	59	197	68	169	16,32	Normal
63	130	2546	2566	21	2015-08-26 10:07:25	61	209	68	169	23,74	Regular
64	129	2579	2600	22	2015-08-26 10:07:25	57	190	68	168	12,83	Normal
65	128	2614	2636	23	2015-08-26 10:07:26	61	212	68	168	26,57	Regular
66	127	2649	2671	23	2015-08-26 10:07:27	58	193	68	167	15,08	Normal
67	126	2686	2706	21	2015-08-26 10:07:28	55	180	68	167	7,63	Normal
68	125	2721	2743	23	2015-08-26 10:07:28	56	184	68	166	10,31	Normal
69	124	2756	2779	24	2015-08-26 10:07:29	56	184	68	166	11,05	Normal
70	123	2792	2813	22	2015-08-26 10:07:30	43	114	68	165	-31,06	Normal
71	122	2828	2849	22	2015-08-26 10:07:30	48	139	68	165	-15,92	Normal
72	121	2864	2884	21	2015-08-26 10:07:31	47	136	68	165	-17,27	Normal
73	120	2909	2931	23	2015-08-26 10:07:32	49	144	68	164	-12,32	Normal
74	119	2945	2966	22	2015-08-26 10:07:33	50	150	68	164	-8,46	Normal
75	118	2981	3002	22	2015-08-26 10:07:33	49	143	67	163	-12,21	Normal

- Robustness and reliavility of ITR methodology proven in Real Operating conditions
- Receiver performance & durability check along its operational live

- The assessment of the tubes status is based on **a robust procedure** of **glass cover measurement** from IR images.
- **Classification of outliers** based on contrasted statistical method allows to identify and locate the tubes with the worst behaviour in a detailed and traceable way.
- By the application of a validated model for the tubes heat losses characterization in nominal conditions, the **power indicator** is obtained for tubes at operation conditions at inspection time.
- Thanks to the ITR Inspection System, **improved O&M strategies**, such as corrective and preventive actions in the solar field, and even predictive actions in case of periodic inspections, can be adopted by plant operators.
- **Historical database available**, receiver performance & durability check along its operational live
- Nowadays supplied at **commercial scale**.

Thank you very much for your attention!!

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