E.1189 Very Early Magnetron Prototype, July 1940

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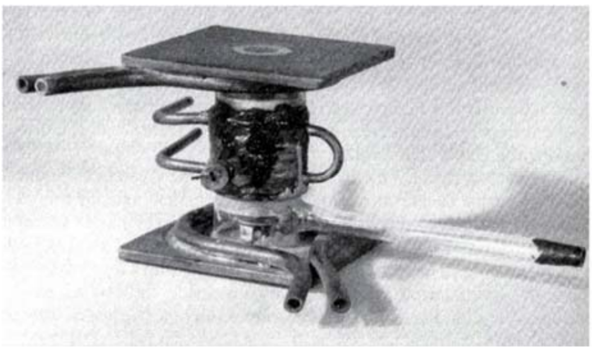
The collection already included other demo units of multi-cavity magnetrons, with end caps removed to show the internal design of the anode block. Just the copper tube on the top of this newly arrived magnetron caught my attention. I had already seen similar appendices in the photos of some prototypes. While taking a few photos for the catalog, I noticed some small characters punched on the copper cylinder, 1189 C 528. Not known the meaning of the last four characters, but no doubt that the first four digits could stay for the design code E.1189. This was the GEC internal code for the first 10 cm multi-cavity magnetron, appeared in the mid 1940 and originating the countless types made in England and in America during the war and later. Eventually the design E.1189 was standardized as Admiralty Pattern W2510 or NT98 or as 3D by Canadian REL. What puzzled me was the absence of the finned radiator, eight or four fins depending upon the revision, always visible in the photos of this magnetron. Also the copper tube brazed in the middle of the outer wall of the copper cylinder was unusual.

Basing on what I found on the subject and on the opinion of the leading experts contacted on this topic, I believe at the best of my knowledge that this sample is the first prototype to be assembled and operated out of the very early four units of eight-cavity E.1189 listed by Megaw in his secret report. It was likely operated from the late July 1940 for preliminary internal tests at GEC Wembley, while manufacturing the eight-cavity sample brought to America by the Tizard Mission. Shortly later this sample was used for an endurance test, until the heater opened after 210 hours. In the following pages we will see a reconstruction of the basic milestones in the development in Great Britain of the first operational multicavity magnetron and the reasons that led me to that conclusion.



- The experimental sample of Randall and Boot was sealed by wax between two water-cooled end plates. It worked on the bench at Birmingham in February 1940. Right, a close-up view of the copper anode cylinder of the E.1189 sample.

Two views of the cathode surface. The oxide layer is uniform and in good shape for about four-fifths of the cathode cylinder. Near one of the ends the layer is quite thin somewhere, leaving exposed the underlying metal. Oxide also looks swollen and detached in the small area evidenced in the image at right. One side of the cylinder ends in a flange, spot welded to the one end baffle. Not sure, but metal looks to be nickel. Click to enlarge.

- Detailed view of the internal hole corresponding to the side copper tube. It is round and exactly in the middle of the resonator. By the way, looking from outside through the copper tube, the visible cathode surface appears in a good shape. Unfortunately in the second image the oxide surface is out of focus and just its uniform whitish look can be appreciated. On the right, the hole hosting the output coupling loop looks to have the same diameter.

- Left, the barely visible handwriting on the anode block, containing the characters '/HR210'. Not sure but the first part of the writing might contain '75', indicating that the tube was operated for 75 hours before the endurance test. Right, the heater wire is broken at the welding to the floating end baffle, opposite to the one welded to the cathode cylinder. Click on each image to enlarge.

Description of the sample.

The copper anode block does not have radiating fins. It is a cylinder measuring 50 mm diameter by 32 mm overall height. The code '1189 C 528' is punched on the outer wall. A partially erased hand inscription containing characters '??75/HR210' is still visible on the copper body, near to the heater spacers. The block has eight hole-and-slot resonating cavities all around its axis. Other measures are similar to those given for the E.1189 eight-cavity type: 20 mm anode useful length, 16 mm anode internal diameter, 1.6 mm slot width, 3.3 mm slot aperture. Inside one of the two end spaces, the wall around the cathode rod still shows traces of a clear and sticky substance, likely sealing grease.

A large center hole accommodates the 10 mm diameter oxide-coated cathode assembly, held by two rods going to outside, through the glass stems, to the flexible heater-cathode leads. Two end baffles are welded to the heater rods, to shield both ends of the cathode, also connecting the ends of the heater helix to the rods. On the side corresponding to the common heater/cathode connection, the baffle is spot welded to the flanged cathode cylinder. The oxide layer appears uniform over about two-third of the surface. A relevant thinning of the oxide can be observed near the two ends of the cathode cylinder, leaving the nickel exposed in a couple of zones. Near to the cathode assembly floating end, the oxide layer is swollen and even detached in a small zone.

A small copper tube, about 20 mm long and flared to the external edge, is brazed on the outside of anode block, halfway between its ends and orthogonally to the cathode/heater supporting rods. The tube shape recalls that of the heater and cathode spacers. Almost certainly used to evacuate the anode chamber, maybe terminated by a glass tube, like the ones used for heater.

By no way this sample can be confused with the quite common display units obtained removing the end caps from standard magnetrons, to show their internal construction. None of the known magnetrons looks like this one. The code punched on the copper block, the absence of both the end covers and of any radiator and especially the presence of the side copper tube suggest that this sample was a very early developmental prototype of the GEC eight-cavity E.1189 magnetron design. The cathode/heater subassembly is complete and the oxide layer shows clear signs of rough operations, even beyond safe limits. The bubble in the oxide might indicate local arcing. Traces of clear sealing wax reinforce the possibility that it was used in a test rig while continuously pumped, almost certainly closed by movable end plates, into the pole pieces of a permanent magnet.

For sure this prototype was built to be powered and actually it was, to the point of damaging the oxide cathode layer somewhere. No need for the complete cathode subassembly, including oxide, heater and end baffles, if it was intended as a nice paperweight. Its manufacture looks too accurate to believe that it could be built in handicraft laboratory, such as that of the Birmingham University could be. Everything leads us to assume that it was built at GEC for internal test purpose.

Reasoned dating of the sample

Trying to know more about this device and even to date it, I started digging into all the available books, papers and magazines for information on the GEC E.1189 magnetron or even its successors, NT98 or 3D. Some of the sources are listed in the references at the end of this card. Results were quite disappointing. Not one of the units shown in the articles looked like this sample. Also available data on the eight-cavity development were quite confusing. The E.1189 No.12 is universally believed to be the first eight cavity magnetron manufactured at GEC. In his book Bowen, who picked up his sample on 12 August 1940, leads readers to believe that it was nothing more than a lucky, yet accidental result of Megaw's experiments. According to the chronology given by Callick, we learn that the development of the six-cavity magnetron went on at GEC for about four months, from April 1940 to at least 17 July. On the contrary the whole development of the eight-cavity variant was compressed more or less in one week, beginning in August and ending on 7 August, when Bowen was allowed to selected the sample he brought to America.

All sources take only into account remarkable milestones, as the official unveiling of new devices, the E.1188 or the low-profile air-cooled variant E.1189 designed by Megaw. On the contrary, the eight-slot E.1189 appears only in October, when the No.12 sample was X-rayed at Bell. We know that Bowen was briefed on the six-slot magnetron construction details on 7 August, few days before leaving Wembley with his precious luggage. Megaw himself does not talk of the development of the eight-cavity variant. Yet he lists four units of the eight-cavity type on which some kind of tests were run in his secret report(*7) on magnetron development program at Wembley. Megaw also talks on the E.1189 No.13, for which he gives operating plots in his 1946 paper (*8).

To know more on this prototype, the approach had to be different, trying to reconstruct an accurate history of the eight-cavity magnetron from the available articles on the events preceding its appearance, and then placing this sample in its right time window. Here is what I found.

The development of cavity magnetron was much less casual and by far more planned of what is commonly deemed. From Lazarus(*10) we learn that the Birmingham group headed by Oliphant was investigating on microwave power generators. In 1939 it was almost entirely focused on the development of a power klystron tube on information coming from the Stanford University, when Randall and Boot were asked to investigate on the possible fitting of resonators inside a microwave tube. Their studies moved from the resonators described by Hertz in the nineteenth century, leading to define a six-cavity cluster all around a filamentary cathode. It was successfully tested on 21 February 1940. Another key figure in our story is E.C.S. Megaw, who was working with a small group at GEC on ultra-high-frequency tubes since the early thirties. Megaw had a top structure behind him and the proper experience and competence to industrialize the prototype assembled at Birmingham. His experience on magnetrons dated back to the early thirties and he was well aware of secondary phenomena in microwave tubes, as the back bombardment. He knew Randall, who had worked at GEC a few years before. The liaison established at the beginning of April between Randall and Boot from one side and Megaw and his group from the other side was then not casual.

From April, GEC began to work side by side with Birmingham at the development of the cavity magnetron just devised. We know from the paper ‘The Cavity Magnetron’ by Boot and Randall(*13) that several steps of development were already planned at the date. Likely GEC did most of the job in the steps listed below.

a) *The completion of a sealed-off version of the valve*
b) *The testing of other designs-e.g. different numbers and sizes of resonators*
c) *The introduction of large cathodes to provide high anode current...*

We know that all the three steps were completed before the end of September 1940(*13). The list of developmental samples built at GEC with different resonator systems is given in the Megaw’s secret report. Now let us summarize some of the relevant dates on which available sources agree.

April 1940	• The group of Megaw at GEC is asked to build operative samples of the prototype magnetron assembled by Randall and Boot at Birmingham and operated from February on the bench. The task will originate the E.1188 water-cooled CW magnetron. The design will be completed on May 16. • GEC also starts to collaborate with Birmingham to a developmental plan which includes different number of resonators and enhanced cathodes. • Megaw starts designing the E.1189, a low-profile air-cooled variant with six cavities, intended to be operated in the 38 mm gap of a standard magnet. The design, with a thoriated-tungsten helix filament, will be completed before May 9
9 May 1940	Dr. Ponte of CSF brings to GEC samples of M16 magnetron with oxide-coated cathode. Megaw launches a variant of his E.1189 early design, incorporating an indirect-heated oxide-coated cathode. CW and pulse tests run on M16 allow to characterize the behavior of this type of cathode, while assembling the two different E.1189 samples.(*8)
29 June 1940	E.1189 No. 1 starts operating on the test bench. Shortly later, on July 1, also E.1189 No. 2 starts operating. 1 kW pulses are obtained at 1000 oersteds. To reach 10 kW, 1400 oersteds are required(*8), too much for a standard 6 lbs permanent magnet.
8 July 1940	Lord Lothian, British ambassador in Washington, submits a direct appeal to Roosevelt: '*The British Government have informed me ... that they would greatly appreciate an immediate and general interchange of secret technical information with the United States, **particularly in the ultra short wave radio field**. ...*'. London was ready to send a small group of British military officers and civilian scientists to the United States '*to give you the full details of any equipment or devices in which you are interested without in any way pressing you beforehand to give specific undertakings on your side*". The appeal concluded '*for our part, **we are probably more anxious to be permitted to employ the full resources of the radio industry in this country** [the United States] **with a view to obtaining the greatest power possible for the emission of ultra short waves than anything else**.*' [Note: a study had shown that if all the British valve industries were called to build magnetrons, the nation could barely produce ten thousands units per year, enough to keep few hundreds or so radar sets in service. Raytheon alone will shortly later build some 2600 magnetron units a day.] The Tizard Mission is ready on the start line, just waiting for the green light from Washington, and the cavity magnetron is the very central issue of the mission.
11 July 1940	In a cabinet meeting with the Secretary of War Stimson and the Secretary of the Navy Knox, Roosevelt decides to accept the British proposal.
17 July 1940	In a meeting with CVD discussion deals among the others of a new '**<u>Megaw's air-cooled low field magnetron</u>'** (*15)**.** It could only be the eight-cavity one with oxide-coated cathode, since the six-slot one required over than 1400 Oersted to operate efficiently. The discussion is followed by '**General demand for specimens**'.
6 August 1940	**A crowd of visitors at GEC, including Oliphant, Randall and Ellis. Paterson writes: 'The Megaw's improved 10 cm magnetron with eight chambers appears up to expectations'. [No doubts that the decision is taken in favor of eight-cavity type]**(*15)
7 August 1940	After a briefing on the construction details of the six-slot E.1189, Bowen is allowed to select the magnetron to bring to America from a lot previously tested by Megaw (*4). It is the best performing one, the E.1189 No. 12, but none except Megaw is aware that it is an eight-cavity sample, certainly not was Bowen nor the briefer or the guys in charge of preparing the blueprints and the production details for the mission.
11 August	The unit No.12 with the production blueprints of E.1189 are collected by Bowen at GEC
19 September	The magnetron is unveiled in US at the Wardman Park Hotel to the leadership of NDRC
6 October	The E.1198 No.12 is powered at the Bell Laboratory, generating about 15 kW at 9.8 cm, in a field of 1100 oersteds according to Fisk. It is on Sunday. The day after the sample is X-rayed and Bowen is made aware of its 8-cavity design.
October 1940	Few days later the E.1198 is examined by Percy Spencer of Raytheon(*14). Qualification lots of exact copies of the E.1198 No. 12 will be requested by British to both Western Electric and Raytheon. By November WE starts releasing copies of the No.12(*10).

From what seen before, the magnetron was not just the most relevant secret that the Tizard Mission could bring to the USA but, in many respects, it was the very purpose of the mission. At the time the entry of America into the war was far from being obvious. The immediate target was to find companies capable of manufacturing large quantities of the new tube (and we know that Raytheon alone would soon build 2600 units a day). No doubts that the sample brought by Bowen had to be, as it really was, the best one available at the date. Until the morning of August 6, it was one of the six-slot E.1189 samples. Upon the approval of eight-slot design by Megaw, Oliphant, Randall and Ellis on 6 August, because of its satisfactory operation at 1000 Oersted, it became the No.12. The acceptable level of confidence in that design could only have derived by sufficiently extended test sessions on samples built to the new geometry. Megaw had performed that tests on four samples.

E.1189. (a) 6 - segment type, now replaced by (b).(opt.H = 1400 g.)

(d_a = 12.0, d_c = 12.0, l_a = 20, s.w. = 2.0, s.d. = 2.0, d_k = 4.5; λ = 9.8 cm.) *

15 valves made including experimental variants (see below).
Life data: 1 emission failure 225 hours (poor emitter initially). 3 between 50 and 100 hours. (2 had poor contacts in heaters initially, were repaired as soon as replacements became available and are now in service again; the third was accidentally broken; none showed any deterioration in performance). The remainder have been run for periods between 5 and 30 hours; all OK except 1 heater failure at 30 hours.

(b) 8 - segment type.(opt.H = 1050 g.)

(d_a = 16.0, d_c = 10.0, l_a = 20, s.w. = 1.6, s.d. = 3.3, d_k = 6.0; λ = 10.0 cm.)

4 valves made: 3 O.K. at 20, 30 and 60 hours respectively, 1 heater open-circuited at 210 hours.

Likely our sample is the fourth E.1189 type b, listed by Megaw, the one totalizing 210 hours until heater opened. Built while still assembling the sample to be given to Bowen, it was first used to perform functional tests and only after August 7 the endurance test was performed on it. Due to the presence of the magnet pole pieces at both the ends of the magnetron, the obvious reason for the side copper tube is for connecting to the vacuum pump during operation. We must remember from the above chronological table that the decision of authorizing the Tizard Mission was taken by Winston Churchill himself approximately in the first week of July: more or less in the same days the six-cavity E.1189 samples designed by Megaw had proven to work. It was evident that they could operate efficiently only at 1400 oersteds in the pole pieces of a bulky electromagnet, nevertheless they were the most powerful sources of microwaves anyone could expect at the date. In his notes Megaw writes of the semi-empirical rules he had defined during the developmental work to calculate relationships between geometry and operating parameters. When the issue of the magnetic field emerged, Megaw soon realized that the design had to be recalculated for eight-cavity. He does not say when the decision was taken but we can determine that date.

On 8 July the British ambassador in Washington had submitted to Roosevelt the appeal, accepted three days later: it was the start of the Tizard Mission. According to Paterson, on 17 July during the meeting with CVD the discussion dealt, among the others, on the ‘Megaw’s 10-cm low-field magnetron’ and there was a general request for samples. The low-field magnetron was obviously the eight-slot, since the already tested six-slot E.1189 required over than 1400 Oersted to operate efficiently, more or less the same field required to operate the Birmingham prototype and the GEC E.1188. In that meeting the decision of the design review was taken. The most plausible scenario is that two parallel roads were followed: urgent samples had to be built to the already existing and tested six-cavity design, while launching a rush program to build a small batch modified to eight-cavity. Indeed all sources agree to say that, on 7 August, Bowen was allowed to select the best performing one among a batch of six-cavity E.1189 magnetrons, just tested by Megaw himself. The selection was preceded by another relevant event reported by Paterson in his diary: '**6 August - A crowd of visitors at GEC, including Oliphant, Randall and Ellis. The Megaw's improved 10 cm magnetron with eight chambers appears up to expectations'.** Certainly that crowd of people met in Wembley to approve the eight-slot E.1189, so replacing the six-slot design.

Since no information can be found on the developmental steps of the eight-cavity variant, let us try to make plausible assumptions. Our time window is easily determined from the key dates given by Sir Paterson in his diary: certainly activities started just after the CVD meeting of July 17. All the developmental steps were carried out in a couple of weeks or so, within the other key date of August 6, when the most prominent figures in the development of the British multi-cavity magnetron were at GEC and approved the new eight-chamber Megaw's design. The whole cycle had been completed and the E.1198 No.12 was selected by Bowen just on the following day. Megaw left us two important clues. We know that four units of E.1198 eight-slot magnetrons were made and operated before October. We also know that apparently only two of them were sealed and serialized, becoming E.1189 No. 12 and 13. Megaw, in his 1946 paper on the magnetron development, talks of the E.1189 No.12 and gives the performance curves for the second sample. The most likely scenario is that he launched the production of four anode blocks, machined and drilled to the eight-slot design, and four 10 mm cathode subassemblies. Then, while two complete and sealed units were in progress to be fully assembled to become the samples No. 12 and 13, he carried out extensive performance tests on the other two units. At least the first experimental unit was operated on the test bench just partially assembled, without radiator, its end caps hastily sealed by vacuum grease and connected to the vacuum pump. Almost certainly the second unit too was only partially assembled and operated while continuously pumped, since very likely the four samples were built at the same time.

This scenario is indirectly confirmed by the Megaw's secret report. Referring to three out of four eight-cavity samples, option H=1050 g, he reports that tests ended respectively at 20, 30 and 60 hours, when samples were still properly working. The only plausible reason to end tests at different hours, while each of them was still running, is that the tests were no longer necessary at a given time, that is when the eight-cavity design revision was eventually approved on 6 August. Then we can assume that tests were all ended towards the end of 6 August, at the presence of Oliphant, Randall and Ellis. Now if we move back from that point, we can approximately date the completion and the start of tests for each of these three samples. Assuming that they were run some 10 hours per day, we can say that the first one was ready and operating on the test jig by August 1, the second sample, or the E1189 No.12, was running from August 4 and the third sample, the No.13, started running the day after. Should the above assumptions be true, on 6 August Megaw and his visitors had enough test data, coming from properly running magnetrons, to approve the eight-slot design. As consequence from that evening it superseded the old six-slot design and an eight-cavity sample, the best performing one, would be pre-arranged for Bowen and the Tizard Mission.

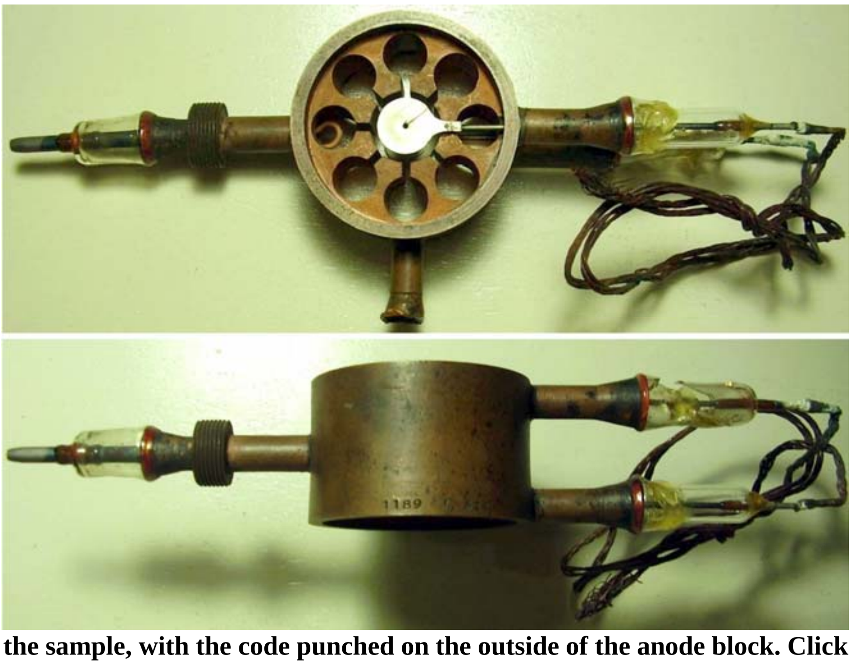
Almost certainly, because of the very short time available, durability test was decided after the design approval, using the fourth sample in the list. But for this test, terminated when heater opened, Megaw certainly selected the first sample put into operation, that was the one which had totalized the largest number of hours before. Therefore on 6 August, at the end of the above said performance test, this sample had certainly worked for more than 60 hours. This means that it began to oscillate by the end of July and anyway before the sample that had totalized 60 hours. Likely, assuming that a '75' appears in the hand writing on our sample before '210HR', we can date its first operation on July 30, 1940.

Coming to our sample, here its main features:

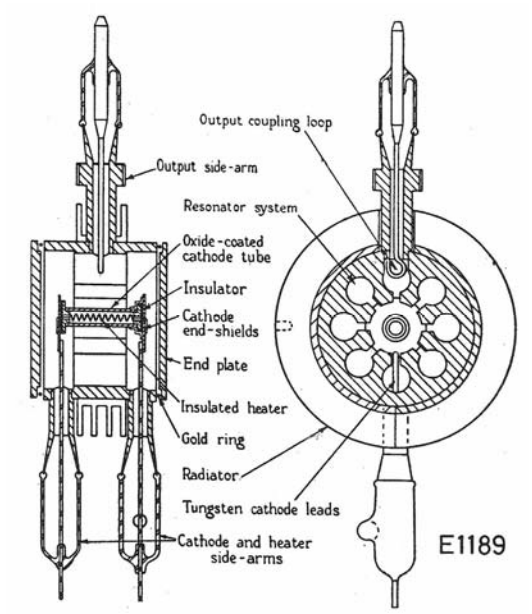
- **The design and the same dimensions of electrodes are identical to those of the final release of E.1189.**
- **It is complete with an oxide-coated cathode subassembly which shows clear traces of operation. The heater wire is broken at one end. Traces of vacuum grease are still visible inside the copper block, near to one of the edges.**
- **The absence of the external finned radiator, the presence of a copper short tube and the lack of end caps clearly indicate that it was an experimental unit, made for internal laboratory tests at GEC and operated while continuously pumped.**
- **On the copper anode block a punched code starts with the characters '1189', followed by C 528. 'C' could stay for the revision level of E.1189, after the six-slot filamentary cathode and the six-slot oxide-coated cathode designs.**
- **On the same block, handwritten with a marker, '??75/HR210' characters can be read, that could be the running hours at 6 August and the total life of the fourth sample listed by Megaw. 75 could stay for the hours worked until 6 August.**
- **The source of this sample was the same of several other historical tubes, related to the developments of British radar. Possibly coming from a British Marconi warehouse.**

No doubts then this sample is one of the four eight-cavity E.1189 developmental units listed by Megaw in his report. It is the fourth one of the list, left under endurance test for 210 hours, until opening of the heater. Likely operated, while still assembling the No. 12 brought to America by the Tizard Mission in August 1940.

This E.1189 prototype is the very early eight-cavity magnetron sample operated at GEC in performance tests, likely since the end of July and until the approval of the eight-cavity design review on 6 August. Later used to run an endurance test, until heater opened after 210 hours of operation.



Two more views of the sample, with the code punched on the outside of the anode block. Click to enlarge



Final draft of E.1189 magnetron approved as NT89 (A.P. W.2510) or REL 3D. The finned radiator is simpler than the one in the No.12 sample, with four fins instead of eight. Click to enlarge.

Acknowledgements

My thanks go to the many people which supplied information useful to reconstruct the development of multi-cavity magnetron at Birmingham and at G.E.C. Special thanks go to Mr. Yves Blanchard who sent this kind mail with his authoritative opinion, together with some rare documents, I added to the references below.

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Last edited on November 5, 2017 by Emilio Ciardiello