



The Printer Working Group

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Working Draft

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PWG Safe G-Code Subset for 3D Printing v1.0

Status: Stable

Abstract: This Best Practice document defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190117.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190117.pdf>

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25 Title: *PWG Safe G-Code Subset for 3D Printing v1.0*

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78 **1. Introduction**

79 G-Code [ISO6893-1] [RS274D] [RS274NGC] [REPRAP] is a commonly-used format for 3D
80 printing with so-called Fused Deposition Modeling (FDM) printers. Besides the commands
81 used to move the print head and/or platform and to extrude material, G-Code includes a
82 variety of device control (e.g., set extruder temperature) and hardware access (e.g., write
83 file to SD card) commands that pose serious safety and security concerns. To make matters
84 worse, such commands are often printer-specific or have printer-specific variations in syntax,
85 requiring the equivalent of printer driver software to produce G-Code suitable for a particular
86 model or firmware version. Finally, differences in filament and extruder nozzle diameters
87 mean that G-Code created for one print job may not work on the same printer due to changes
88 to the material or extruder.

89 The IPP 3D Printing Extensions v1.0 [PWG5100.21] define the model and semantics for
90 networked 3D printing, along with a required high-level 3D file format. However, the
91 processing requirements of such a format require either improved printer controllers with
92 greater memory, storage, and CPU capacity or the use of Cloud services to offload that
93 processing.

94 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and
95 semantics for Cloud printing, however it does not specify an intermediate format suitable for
96 3D printing.

97 This document defines a "safe" subset of G-Code that can be used for direct and Cloud
98 printing configurations, along with a description of the capabilities and parameters that will
99 be needed to generate suitable layers for printing to the target printer.

100 The goal of this document is to enable the use of IPP with existing entry-level FDM printers
101 that are not able to perform their own slicing and to enable generic Cloud and local
102 infrastructure services to provide slicing services to existing FDM printers. Support for other
103 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension
104 [3MF-SLICE].

105

106 **2. Terminology**

107 **2.1 Terms Used in This Document**

108 *Cloud*: the environment supporting services such as Cloud Computing.

109 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network
110 access to a shared pool of configurable computing resources (e.g., networks, servers,
111 storage, applications, and services) that can be rapidly provisioned and released with
112 minimal management effort or service provider interaction." The NIST Definition of Cloud
113 Computing [NISTSP800-145].

114 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw
115 layers, sometimes also called material extrusion.

116 **2.2 Acronyms and Organizations**

117 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

118 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

119 *ISO*: International Organization for Standardization, <https://www.iso.org/>

120 *PWG*: Printer Working Group, <https://www.pwg.org/>

121

122 **3. PWG Safe G-Code Subset**

123 This document defines a safe G-Code subset with the MIME Media Type
124 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following
125 commands which represent the common subset of commands supported by most FDM
126 printers:

127 G0: Rapid Linear Move

128 G1: Controlled Linear Move

129 G4: Dwell

130 G21: Set Units to Millimeters

131 G28: Move to Origin (Home)

132 G90: Set Absolute Positioning

133 G91: Set Relative Positioning

134 G92: Set Position

135 M82: Set Absolute Extrusion

136 M83: Set Relative Extrusion

137 Tnnn: Set Tool

138 Most machine ("M") commands are not allowed since they directly control or access the
139 machine hardware. Temperature control and other machine settings are the responsibility
140 of the IPP Printer, which will likely use the IPP Job Template attribute values to send the
141 corresponding printer-specific G-code commands to a lower-level controller.

142 The line number command ("N") and checksum ("*") are similarly not allowed because they
143 are used for direct communications with the controller - IPP provides the necessary
144 infrastructure for reliable communication of the G-Code file to the IPP Printer.

145 Comments starting with the ";" character are allowed and continue to the end of the current
146 line.

147 For simplicity, safe G-Code always uses millimeters for the units (the default).

148 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

149 These commands move the current tool (extruder) and/or extrude material for printing.
150 Parameters for this command are:

151 Xnnn: Set X position in millimeters

152 Ynnn: Set Y position in millimeters

153 Znnn: Set Z position in millimeters

154 Ennn: Extrude the specified number of millimeters of material

155 Fnnn: Set the feed rate in millimeters/minute

156 Note: The "S" parameter is not allowed in safe G-Code.

157 **3.2 G4: Dwell**

158 This command pauses printing for a specifies amount of time. The "Pnnn" parameter
159 specifies the time interval in milliseconds.

160 **3.3 G21: Set Units to Millimeters**

161 This command explicitly specifies that coordinates are in millimeters (the default).

162 Note: This command is only provided for completeness - there is no support in safe G-Code
163 for any other units.

164 **3.4 G28: Move to Origin (Home)**

165 This command moves the current tool to the home position (end stops). The "X", "Y", and
166 "Z" parameters may optionally be specified to move the tool on the specified axes - if not
167 supplied the tool is moved on all axes.

168 **3.5 G90: Set Absolute Positioning**

169 This command specifies that all coordinates are relative to the origin of the machine.

170 **3.6 G91: Set Relative Positioning**

171 This command specifies that all coordinates are relative to the current position of the tool.

172 **3.7 G92: Set Position**

173 This command sets the current tool positions without moving or extruding material.
174 Parameters for this command are:

175 Xnnn: Set X position in millimeters

176 Ynnn: Set Y position in millimeters

177 Znnn: Set Z position in millimeters

178 Ennn: Set extrusion to the specified number of millimeters of material

179 All positions are set to 0 if no parameters are specified.

180 **3.8 M82: Set Absolute Extrusion**

181 This command specifies that the extrusion ("E") coordinates in move commands are
182 absolute.

183 **3.9 M83: Set Relative Extrusion**

184 This command specifies that the extrusion ("E") coordinates in move commands are relative.

185 **3.10 Tnnn: Set Tool**

186 This command sets the current tool (extruder) to use, starting at 0. Tool numbers correspond
187 to the index within the "materials-col" Job Template attribute.

188

189 4. Generating Safe G-Code

190 IPP Clients [STD92] and Infrastructure Printers [PWG5100.18] can generate safe G-Code
 191 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table
 192 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-
 193 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"
 194 Printer Description attributes which provide a list of all possible materials and those that are
 195 loaded in the Printer, respectively.

196 **Table 1 - Information Needed to Generate Safe G-Code**

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section Error! Reference source not found.
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section Error! Reference source not found.

197 4.1 Material Extrusion Parameters

198 IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size,
 199 nor does it define a way to specify whether retraction is used. These can be added to the
 200 "materials-col" collection as:

201 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder
 202 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than
 203 1 nanometer.

204 "material-retraction (boolean)": Specifies whether retraction should be used with the
 205 material.

206 A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) |
 207 rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle
 208 diameter values. The presence of 'material-retraction' in the "materials-col-supported"
 209 Printer Description attribute indicates that the Printer supports material retraction.

210 4.2 Support for Additional "Safe" G-Code Commands

211 In addition to the common subset of G-Code commands listed in the previous sections,
 212 newer FDM printers support additional "safe" commands such as mixing of extruded material
 213 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").
 214 In order for a generic slicer to support these commands, a printer needs to advertise its
 215 support for them. The usual method employed for IPP is a PDL-specific capability attribute,

216 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a
217 named command.

218 5. Printing Safe G-Code

219 Printers that support safe G-Code can largely pass the print file to the controller - typically
220 all that is required is to add printer-specific commands to initialize the printer to set
221 temperatures and other machine settings, send the print file, and then add printer-specific
222 commands to return the printer to an idle state.

223 Status information returned by the printer can be used to set the values of the various IPP
224 Printer Status attributes.

225 5.1 Adding Printer-Specific Machine Commands

226 IPP Job Template attributes provide the values for extruder and build platform temperatures,
227 as well as the list of materials used in the print job. Table 2 lists the standard attributes a
228 FDM printer can use to configure the machine prior to printing.

229 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

230 When an IPP Client does not specify one or more of these attributes, the corresponding
231 default attribute values are used - "materials-col-default", "platform-temperature-default",
232 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and
233 "printer-volume-temperature-default" for the attributes in Table 2.

234 **5.2 Printer-Specific Attributes and Values**

235 IPP allows implementors to add printer-specific attributes and values as defined in section 7
236 of [STD92]. However, printers cannot depend on IPP Clients or Infrastructure Printers to
237 support such attributes or values, particularly for generation of safe G-Code. Default values
238 should be used as a backup when necessary.

239 **5.3 Canceling Jobs**

240 When a Job is canceled, Printers SHOULD stop sending G-Code commands as soon as
241 possible and then send printer-specific commands to the controller to return the printer to an
242 idle state.

243

244 6. IANA Considerations

245 6.1 Attribute Registrations

246 The attributes defined in this white paper will be published by IANA according to the
247 procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

248 <https://www.iana.org/assignments/ipp-registrations>

249 The registry entries will contain the following information:

250	Job Template attributes:	Reference
251	-----	-----
252	materials-col (1setOf collection)	[PWG5100.21]
253	material-extruder-diameter (integer(0:MAX))	[SAFEPCODE]
254	material-retraction (boolean)	[SAFEPCODE]
255		
256	Printer Description attributes:	Reference
257	-----	-----
258	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
259	rangeOfInteger(0:MAX))	[SAFEPCODE]
260	safe-gcode-supported (1setOf text(MAX))	[SAFEPCODE]

261 6.2 MIME Media Type Registration

262 The MIME media type defined in this white paper will be published by IANA according to the
263 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the
264 following file:

265 <https://www.iana.org/assignments/media-types>

266 The registry will contain the following information:

267 Type name: application
268
269 Subtype name: vnd.pwg-safe-gcode
270
271 Required parameters: N/A
272
273 Optional parameters: N/A
274
275 Encoding considerations: US ASCII
276
277 Security considerations: Safe G-code prohibits machine control commands,
278 however it is up to the consumer to verify that such commands are not part
279 of the print file.
280
281 Interoperability considerations: While the format is interoperable, the
282 contents of each file are still specific to the combination of material
283 parameters and printer capabilities used for the G-code.
284

285 Published specification: [this white paper]
286
287 Applications that use this media type: IPP 3D
288
289 Fragment identifier considerations: N/A
290
291 Additional information:
292
293 Deprecated alias names for this type: N/A
294 Magic number(s): N/A
295 File extension(s): pwggc
296 Macintosh file type code(s): N/A
297
298 Person & email address to contact for further information: Michael Sweet,
299 msweet@apple.com
300
301 Intended usage: COMMON
302
303 Restrictions on usage: N/A
304
305 Author/Change controller: The Printer Working Group, c/o The IEEE Industry
306 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ
307 08854, USA
308
309 Provisional registration? (standards tree only): No

310 7. References

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339 8011, January 2017, <https://tools.ietf.org/html/std92>
- 340

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350 white paper:

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352 **9. Change History**

353 **9.1 January 17, 2019**

- 354 • Added document version number to page headings.

355 **9.2 January 14, 2019**

- 356 • Updated status to stable
- 357 • Added version number to title
- 358 • Section 3.10: Tool number corresponds to the materials-col index.
- 359 • Section 5: Added subsection on canceling jobs.
- 360 • Section 7: Fixed reference link for STD92.

361 **9.3 July 4, 2018**

- 362 • Removed old comments.
- 363 • RFC 8011 is now STD 92.

364 **9.4 June 4, 2018**

- 365 • Status: Prototype
- 366 • Type: Best Practice
- 367 • Section 3: Reword M command prohibition.
- 368 • Changed registered extension to ".pwggc".
- 369 • Added RS274NGC reference.

370 **9.5 April 26, 2018**

- 371 • Made a PWG Best Practice working draft.
- 372 • Added reference to RepRapWiki for G-Code
- 373 • Added reference to ISO 6983-1 for current official G-Code specification
- 374 • Section 4: Mention materials-col-database and materials-col-ready
- 375 • Section 4.1: Retitle as "Material Extrusion Parameters"

376 **9.6 April 16, 2018**

- 377 • Status: Interim

- 378 • Introduction: Added discussion of nozzle and filament diameter influencing
- 379 portability of G-code, and why we want this.
- 380 • Added G21, M82, and M83 commands, and hooks for other printer-specific
- 381 commands (safe-gcode-supported)
- 382 • Updated T command (set tool) to use 0 as the first index.
- 383 • Added sections on generating and printing safe G-code
- 384 • Added IANA registration of new attributes and the MIME media type
- 385 • Added references to 3MF slicing and RFC 8011.

386 **9.7 April 12, 2018**

387 Initial revision.